KMGBF - Aligned Carbon Mitigation Methodologies

under the Satoyama Mace Initiative

Edited By

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SATOYAMA INITIATIVE

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Preface

Climate action has long been the main focus of global sustainability efforts. From a biodiversity point of view, frameworks to manage greenhouse gases need to do more than track emissions. They should, at least, avoid harming biodiversity and at best be proactive tools for sustaining the complex ecosystems that help us mitigate and adapt, by providing air purification, enriching and stabilizing soil, and regulating climate. This volume presents a compilation of practical and innovative methodologies designed to bridge the gap between carbon accounting and the multi-dimensional goals of the Kunming-Montreal Global Biodiversity Framework (GBF) —the global set of goals and targets adopted under the Convention on Biological Diversity to guide biodiversity action through 2030— and the Satoyama Initiative —a global initiative that promotes "societies in harmony with nature" by supporting socio-ecological production landscapes and seascapes where people and biodiversity can thrive together.

In reviewing these technical documents from a biodiversity angle, the primary objective was to evaluate how effectively they address ecological targets while pursuing greenhouse gas reductions. The methodologies demonstrate that carbon mitigation can be a supportive partner to biodiversity conservation, especially when implemented through a landscape or seascape approach that considers multiple users, multiple uses, and ecological connectivity.

Restoring Functional Landscapes and Seascapes

Much of this compilation focuses on nature-based solutions that restore degraded environments. The methodology for Wetland and Seagrass Restoration (Ya-Hui Chang and Shu-Mei Wang) is a prime example of this synergy. By re-establishing tidal flow and sediment supply, this approach directly contributes to achieving GBF Target 2 (restoring 30% of degraded ecosystems). It also considers sea-level rise and long-term site dynamics, helping to ensure that restoration areas remain resilient and have the "accommodation space" necessary to migrate landward over a 100-year horizon.

Similarly, the Biochar Utilization methodology (Shu-Mei Wang) promotes a circular economy by transforming agricultural residues into stable carbon sinks. From a biodiversity perspective, biochar serves as both a carbon reservoir and a soil amendment, improving the microbial environment. This methodology therefore supports GBF Target 10 (Enhance Biodiversity and Sustainability in Agriculture, Aquaculture, Fisheries, and Forestry) and Target 8 (Minimize the Impacts of Climate Change on Biodiversity and Build Resilience).

Enhancing Agricultural Sustainability

The methodology for the Avoidance of Methane Emissions through Resource Processing (Chiu-

Chung Young) outlines how diverting organic waste from anaerobic landfills to aerobic processing can create high-quality organic fertilizers. This supports GBF Target 7 (Reduce Pollution to Levels That Are Not Harmful to Biodiversity) by reducing the need for chemical inputs that can harm aquatic and terrestrial biodiversity through nutrient leaching, while also reducing methane emissions.

Complementing this is the methodology for Crop Rotation in Integrated Agricultural Land-use Systems (Amit Sharma and Chen-Piao Yen), which leverages satellite-based monitoring and artificial intelligence to optimize land management. By emphasizing diversified cropping and reduced tillage, this framework contributes to achieving GBF Target 1 (Plan and Manage all Areas To Reduce Biodiversity Loss_) and strengthens GBF Target 10, as well as helping to ensure that high-quality data are available to guide biodiversity-friendly practices.

Innovation in Human-Centric Environments

Two methodologies in this collection explore how mitigation can be integrated into industrial and urban settings. The methodology for Carbon Capture and Sequestration by Crops in Agricultural Facilities (Amit Sharma and Yen-Hsun Su) introduces indoor plants as a carbon capture solution for homes and offices. While small in scale compared to vast wetlands, this approach contributes to GBF Target 11 (Restore, Maintain and Enhance Nature's Contributions to People) by restoring nature's benefits to human well-being within the built environment.

On an industrial level, Replacing Fossil-Fuel-Based Hydrogen Production with Renewable-Based Green Hydrogen (Jyh-Ming Ting) presents a roadmap for decarbonizing high-emission sectors. By utilizing renewable-powered electrolysis, this methodology mitigates the ecological pressure of fossil fuel extraction and reduces air pollutants, aligning with GBF Target 14 (Integrate Biodiversity in Decision-Making at Every Level) by integrating biodiversity safeguards into industrial decision-making.

The Satoyama Vision: Coexistence and Connectivity

Running through all these methodologies is the philosophy of the International Partnership for the Satoyama Initiative (IPSI), a multi-stakeholder network that advances the Satoyama Initiative by sharing knowledge and supporting action in socio-ecological production landscapes and seascapes. These frameworks aim to prioritize socio-ecological production landscapes and seascapes (SEPLS), where human activities like farming and fishing are managed to align with natural processes. They encourage the co-production of knowledge—blending modern science with traditional ecological knowledge—to empower local communities and enhance rural resilience.

Conclusion

The methodologies compiled here offer more than technical equations; they provide practical approaches for an innovative and restorative economy. While there has been much talk about the need for synergies between climate action and biodiversity conservation, innovative approaches like these are essential to move beyond rhetoric. They help determine credible ways to mitigate climate change while also recognizing and protecting the intrinsic value of nature. Whether through the precise mapping of a seagrass meadow or the monitoring of soil organic carbon in a rotated field, these frameworks aim to ensure that climate actions are scientifically credible, socially inclusive, and ecologically sound.

This compilation is intended for project developers, policymakers, and conservationists who recognize that a sustainable future requires us to solve multiple environmental challenges simultaneously. It is the creativity and inventiveness exhibited by the methodology developers that made this book enjoyable to be part of, and it is my great hope that its contents will reach a global audience, helping and inspiring others to build upon these foundations for resilient landscapes and seascapes.

Mr. Andre Mader
Institute for Global Environmental Strategies (IGES), Japan

Satoyama Mace Initiative: Bridging Indigenous Stewardship, SEPLS, and Carbon Finance for a Regenerative Future

Yen-Hsun Su and Shu-Mei Wang
SEPLS Carbon Credit Regional Revitalization Center

The Satoyama Mace Initiative (SMI) is an internationally recognized, systems-based platform dedicated to advancing climate action, biodiversity conservation, and community resilience through the integration of Indigenous knowledge systems, Socio-Ecological Production Landscapes and Seascapes (SEPLS), and carbon finance mechanisms. Rooted in the philosophy of harmonious coexistence between humans and nature, Satoyama Mace Initiative seeks to transform the global carbon economy into a vehicle for ecological regeneration, cultural preservation, and equitable development.

Endorsed under the framework of the International Partnership for the Satoyama Initiative under the United Nations University Institute for the Advanced Study of Sustainability, Satoyama Mace Initiative operates as a collaborative, transdisciplinary initiative aligned with global sustainability agendas, including the Kunming-Montreal Global Biodiversity Framework (KMGBF), the Paris Agreement, and the Sustainable Development Goals (SDGs). Through its IPSI Collaborative Activities, Satoyama Mace Initiative contributes to global knowledge exchange, methodological innovation, and field-based implementation of integrated climate-biodiversity solutions.

From Satoyama to Global Systems Innovation

The concept of Satoyama originates from traditional Japanese rural landscapes where human livelihoods and ecosystems coexist in dynamic balance. This concept has evolved into the broader framework of SEPLS, encompassing diverse ecosystems worldwide where communities actively shape and sustain biodiversity through production activities such as agriculture, forestry, and fisheries.

However, many SEPLS—particularly those stewarded by Indigenous Peoples and local communities—are under increasing pressure from climate change, economic marginalization, and land-use transformation. Despite their critical role in maintaining biodiversity and carbon sinks, these landscapes often lack access to sustainable financial mechanisms that can support long-term stewardship.

The Satoyama Mace Initiative addresses this gap by introducing a new paradigm: carbon credit-based sustainable finance grounded in SEPLS and Indigenous rights.

Core Vision: Carbon Finance as a Regenerative Flow

At its core, Satoyama Mace Initiative envisions carbon credit systems not merely as offset markets, but as regenerative financial flows that directly support ecosystem conservation and community livelihoods. This approach reframes carbon credits as:

- ✓ Ecological value carriers, reflecting biodiversity and ecosystem services
- ✓ Social equity instruments, recognizing Indigenous land rights and stewardship
- ✓ Economic enablers, providing long-term, sustainable income streams

Through this framework, Satoyama Mace Initiative aims to ensure that carbon finance returns to the landscapes and communities that generate it, rather than being extracted by external actors.

Indigenous-Centered and Rights-Based Approach

A defining feature of the Satoyama Mace Initiative is its strong emphasis on Indigenous participation, rights, and leadership. Satoyama Mace Initiative recognizes that Indigenous Peoples are among the most effective stewards of biodiversity and carbon-rich ecosystems, yet are often excluded from global carbon markets.

To address this, Satoyama Mace Initiative integrates:

- ✓ Indigenous carbon rights frameworks
- ✓ Free, Prior, and Informed Consent (FPIC) principles
- ✓ Community-driven project design and governance
- ✓ Benefit-sharing mechanisms ensuring equitable distribution of carbon revenues

By embedding these safeguards, Satoyama Mace Initiative ensures that carbon projects do not become instruments of exploitation, but rather platforms for empowerment and self-determination.

System-of-Systems MRV Innovation

One of the most innovative aspects of Satoyama Mace Initiative is its System-of-Systems approach to Monitoring, Reporting, and Verification (MRV). This framework integrates:

- ✓ Satellite-based remote sensing technologies
- ✓ Ground-based ecological and socio-economic data
- ✓ AI-driven analytics and modeling
- ✓ Community-based monitoring systems

Recent developments include collaboration with Taiwan's space sector and academic institutions to establish a space-based MRV system, enhancing transparency, accuracy, and scalability. This system enables real-time monitoring of carbon fluxes, biodiversity indicators, and land-use dynamics across SEPLS landscapes.

Such innovation not only strengthens the scientific credibility of carbon credits but also reduces

transaction costs and barriers to entry for community-based projects.

Methodological Breakthroughs Aligned with KMGBF

The Satoyama Mace Initiative has developed and launched carbon mitigation methodologies aligned with the Kunming-Montreal Global Biodiversity Framework (KMGBF). These methodologies integrate:

- ✓ Carbon sequestration and emissions reduction
- ✓ Biodiversity conservation indicators
- ✓ Ecosystem integrity metrics
- ✓ Socio-cultural values

By moving beyond traditional carbon accounting, Satoyama Mace Initiative methodologies capture the multi-dimensional value of SEPLS, enabling a more holistic and credible form of carbon crediting. These methodologies have undergone international review processes, positioning Satoyama Mace Initiative as a pioneer in biodiversity-integrated carbon markets.

Market Integration and Global Recognition

A major milestone for Satoyama Mace Initiative is the successful recognition and listing of its carbon credits on international trading platforms such as the AirCarbon Exchange (ACX) and Climate Impact X (CIX). This achievement demonstrates the initiative's ability to bridge local ecological action with global carbon markets.In addition, Satoyama Mace Initiative has gained international visibility and credibility through:

- ✓ Recognition in global media and press releases
- ✓ Awards such as the 2025 MUSE Creative Awards for CSR and strategic programs
- ✓ Endorsements highlighting its alignment with global sustainability goals
- ✓ Symbolic recognition, including a papal blessing affirming its universal values

These milestones underscore the growing relevance of Satoyama Mace Initiative as a next-generation climate solution integrating science, culture, and finance.

Field Implementation: From Concept to Practice

Beyond frameworks and methodologies, Satoyama Mace Initiative is actively implementing projects on the ground. One notable example is the transformation of sorghum fields in Syuejia, Taiwan, into a model for rural carbon sequestration and regeneration. This project demonstrates how traditional agricultural systems can be enhanced to generate carbon credits while revitalizing local economies.

Other initiatives include:

- ✓ Bio-integrated systems linking carbon cycles with sustainable hydrogen innovation
- ✓ Artistic and technological interventions, such as luminous anthurium installations, to raise

awareness of climate action

- ✓ Regional revitalization programs connecting agriculture, culture, and carbon markets

These projects illustrate SMI's commitment to integrating science, culture, and community action in real-world contexts.

A Platform for Global Collaboration

The Satoyama Mace Initiative is not a single project, but a global platform for collaboration. It invites participation from:

- ✓ Indigenous communities and local stakeholders
- ✓ Governments and policymakers
- ✓ Academic and research institutions
- ✓ Private sector and CSR partners
- ✓ International organizations and NGOs

Through this multi-stakeholder approach, Satoyama Mace Initiative aims to co-create scalable solutions that can be adapted to diverse SEPLS contexts worldwide.

Toward a New Carbon Economy

The global carbon market is at a critical crossroads. While it holds immense potential, it also faces challenges related to credibility, equity, and impact. The Satoyama Mace Initiative offers a transformative pathway by:

- ✓ Embedding biodiversity and social values into carbon accounting
- ✓ Ensuring transparency through advanced MRV systems
- ✓ Prioritizing community benefits and Indigenous rights
- ✓ Linking local action with global financial systems

In doing so, Satoyama Mace Initiative contributes to the emergence of a new carbon economy—one that is regenerative, inclusive, and aligned with planetary boundaries.

Conclusion

The Satoyama Mace Initiative represents a bold and timely response to the intertwined crises of climate change, biodiversity loss, and social inequality. By integrating Indigenous wisdom, SEPLS stewardship, and innovative carbon finance, it redefines what carbon markets can achieve. Rather than treating nature as a commodity, Satoyama Mace Initiative positions it as a living system—one that must be respected, restored, and sustained through collaborative effort and equitable value sharing.

As the world seeks scalable and credible solutions for a sustainable future, the Satoyama Mace Initiative stands as a model of integration—bridging local landscapes and global systems, tradition and innovation, ecology and economy.

KMGBF-Aligned Carbon Mitigation Methodologies: Integrating Climate, Biodiversity, and Socio-Ecological Systems

Prof. Wei-Sheng Chen
National Cheng Kung University

The KMGBF-Aligned Carbon Mitigation Methodologies, developed under the Satoyama Mace Initiative, represent a next-generation framework for climate mitigation that integrates carbon accounting, biodiversity conservation, and socio-ecological resilience. Aligned with the Kunming–Montreal Global Biodiversity Framework (KMGBF), this methodological system advances a paradigm shift from conventional carbon offsetting toward high-integrity, nature-positive, and socially inclusive carbon finance.

Robust Scientific Foundation and MRV Integrity

The methodologies are developed in accordance with internationally recognized standards, including the Clean Development Mechanism (CDM) and Climate Action Reserve (CAR) protocols. By incorporating these established frameworks, the methodologies ensure scientific rigor, comparability, and compatibility with global carbon markets.

At the core of the system is a robust Measurement, Reporting, and Verification (MRV) architecture. This includes standardized baseline setting, additionality assessment, leakage control, and uncertainty management. The MRV system is further strengthened through a System-of-Systems approach, integrating satellite-based monitoring, field measurements, biogeochemical modeling, and data-driven analytics. This ensures a high level of transparency, accuracy, and environmental integrity, addressing long-standing concerns in carbon markets regarding credibility and double counting.

Enabling Climate Finance in Developing Regions

A key objective of the KMGBF-aligned methodologies is to expand equitable access to carbon finance, particularly in developing countries, including Least Developed Countries (LDCs) and Small Island Developing States (SIDS). These regions often possess rich biodiversity and significant carbon sequestration potential, yet face barriers in accessing carbon markets due to technical, financial, and institutional constraints.

By providing standardize yet adaptable methodological tools, this framework enables local stakeholders—especially Indigenous Peoples and rural communities—to participate in carbon markets while maintaining control over their landscapes. The methodologies are designed to deliver measurable

co-benefits, including:

- ✓ Climate mitigation through emission reductions and carbon sequestration
- ✓ Biodiversity conservation and ecosystem restoration
- ✓ Enhanced livelihoods and socio-economic resilience
- ✓ International Review and Scientific Governance

The development and validation of the methodologies underwent a rigorous international review process, coordinated by Prof. Wei-Sheng Chen of National Cheng Kung University and Mr. Andre Mader of the Institute for Global Environmental Strategies.

The review panel included experts from leading international organizations, as well as academic institutions across nine countries. The process resulted in an approval rate of 52.9%, reflecting a highly selective and quality-driven evaluation standard.

Special acknowledgment is extended to Andre Mader, whose extensive experience in biodiversity governance and Indigenous engagement significantly contributed to strengthening the methodologies' integration of ecological and social dimensions.

Portfolio of Methodologies

The KMGBF-aligned framework comprises a diverse portfolio of methodologies addressing key sectors and ecosystem types:

- ✓ **Methane Avoidance from Organic Waste**
  This methodology quantifies emissions reductions achieved by processing organic waste (e.g., composting) instead of allowing unmanaged decay. It enhances soil fertility and soil organic carbon while preventing methane emissions.
- ✓ **Biochar Utilization for Carbon and Biodiversity**
  This approach enables the conversion of agricultural residues into biochar through controlled pyrolysis, improving soil health, increasing crop productivity, and creating long-term carbon sinks while supporting biodiversity.
- ✓ **Carbon Capture and Sequestration in Agricultural Systems**
  Designed for both controlled-environment and open-field agriculture, this methodology quantifies carbon capture through enhanced biomass production and soil carbon accumulation, supporting climate-smart and regenerative agriculture.
- ✓ **Crop Rotation in Integrated Land-Use Systems**
  This methodology promotes diversified cropping systems across large agricultural landscapes, enhancing soil carbon, improving water management, and increasing ecosystem resilience through integrated land-use planning.
- ✓ **Wetland and Seagrass Restoration**
  Addressing coastal and marine ecosystems, this methodology quantifies carbon sequestration and

emission reductions from restoring wetlands and seagrass beds, while also strengthening coastal resilience and biodiversity.

- ✓ **Green Hydrogen Transition**
  This methodology supports the replacement of fossil-fuel-based hydrogen production with renewable-based green hydrogen, contributing to decarbonization in industrial sectors.

Modular Architecture for Scalability and Integrity

To enhance flexibility and interoperability, the framework incorporates a series of technical modules that function as standardized building blocks. These modules support specific components of project implementation, including:

- ✓ Estimation of carbon sequestration using indoor plants
- ✓ Quantification of carbon stock changes and GHG emissions in biodiversity ecosystems through System-of-Systems MRV
- ✓ Soil sampling, preservation, and greenhouse gas analysis

This modular structure ensures consistency across projects, facilitates data integration, and prevents double counting by clearly defining system boundaries and accounting rules.

Integration of Biodiversity and Indigenous Knowledge

A defining characteristic of the KMGBF-aligned methodologies is the integration of biodiversity indicators and Indigenous knowledge systems. By aligning with global biodiversity targets, the framework ensures that carbon projects contribute to ecosystem integrity and nature-positive outcomes, rather than focusing solely on carbon metrics.

The methodologies also emphasize inclusive participation and co-production of knowledge, enabling Indigenous Peoples and local communities to play a central role in monitoring, governance, and benefit-sharing.

Toward a High-Integrity Carbon Market

The KMGBF-Aligned Carbon Mitigation Methodologies respond to critical challenges in existing carbon markets, including concerns about environmental integrity, transparency, and social equity. By embedding scientific rigor, biodiversity integration, and social safeguards, the framework establishes a new benchmark for high-integrity carbon credits.

In conclusion, this methodology framework represents a significant step toward a holistic and regenerative carbon economy—one that not only mitigates climate change but also restores ecosystems, empowers communities, and supports sustainable development across diverse socio-ecological landscapes.

SATOYAMA INITIATIVE

Methodology

Me0001

Avoidance of Methane Emissions from the decay of organic waste through resource processing

Version 1.0
Published 05 January 2026
GBF 2、7、8、10、11、15、16、19

Version 1.0 of this methodology was developed by Prof. Chiu-Chung Young (National Chung Hsing University).

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1 Source

This methodology references the following CDM tools:

- AMS-III.F: Avoidance of methane emissions through composting – Version 12.0
- AMS-III.D: Methane recovery in animal manure management systems
- AMS-III.E: Avoidance of methane production from decay of biomass through controlled combustion
- AMS-III.G: Landfill methane recovery
- AMS-III.H: Methane recovery in wastewater treatment
- AMS-III.AO: Methane recovery through controlled anaerobic digestion
- Tool: Emissions from solid waste disposal sites
- Tool: Project and leakage emissions from composting
- Tool: Baseline, project and/or leakage emissions from electricity consumption
- Tool: Tool to calculate CO_2 emissions from fossil fuel combustion

2 Summary Description of the Methodology

This methodology reduces methane emissions by diverting biomass and organic waste (such as manure or agricultural waste) from anaerobic decay in landfills or unmanaged waste systems to controlled resource processing system that process organic waste into organic fertilizer. The project avoids CH_4 formation and generates organic fertilizer as a soil amendment.

Resource processing include controlled treatment of biomass or other organic matter is introduced through “aerobic treatment by composting” or “enzymatic/mechanical/thermal/biological treatment” and proper soil application of the organic fertilizer.

Enzymatic resource processing is a new technology based on specific enzyme products, and with the combined use of machinery, organic wastes can be turned into organic fertilizers within 3 hours.

3 Relation to Strategy and Plan of Action 2023 -2030 of the International Partnership for the Satoyama Initiative

This methodology contributes explicitly to IPSI's Strategic Objectives through sustainable waste transformation, community involvement, enhancement of soil health, and circular resource utilization.

(1) Promoting Sustainable Agriculture

This methodology transforms organic waste into organic fertilizer through resource processing (e.g., composting or enzymatic treatment), enhancing soil fertility, increasing soil organic carbon, and preventing methane emissions. This aligns with IPSI's goal of promoting sustainable agriculture and enhancing ecosystem services.

(2) Circular Economy and Sustainable Resource Use

By repurposing waste for agricultural use and reducing dependence on chemical fertilizers, the methodology supports IPSI's emphasis on circular practices and sustainable resource management.

(3) Biodiversity Conservation and Ecosystem Function Enhancement

Organic fertilizer improves soil structure and microbial activity, thereby strengthening soil ecosystem functions, indirectly supporting IPSI's objectives for biodiversity protection and ecosystem function restoration.

(4) Climate Change Mitigation and GHG Reduction

Diverting waste to controlled treatment systems prevents methane emissions, contributing to GHG mitigation and climate resilience, which is consistent with IPSI's climate-related goals.

(5) Community Well-Being and Local Participation

Farmers participating in resource processing gain access to safe and cost-effective organic fertilizer while reducing environmental pollution, enhancing local community welfare, and fulfilling IPSI's objective of supporting community involvement and equitable sharing of ecosystem benefits.

Table 1 IPSI Strategic Objectives Mapping Table

IPSI Objective	Relevance	Methodology Components
Obj.1 – Knowledge Co-Production	High	MRV system; monitoring; SOC assessment; SOP training
Obj.2 – Institutional Frameworks	Medium–High	QA/QC system; local government coordination; operator training
Obj.3 – Area-Based Conservation	Medium	Soil rehabilitation; reduction of open dumping
Obj.4 – Ecosystem Restoratio	High	SOC enhancement; organic fertilizer application
Obj.5 – Sustainable Value Chains	High	Circular economy creation; value-added fertilizer market

4 Relation to Kunming-Montreal Global Biodiversity Framework (GBF)

The vision of the Kunming-Montreal Global Biodiversity Framework is a world of living in harmony with nature where "by 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people."

4.1 Description

The methodology supports GBF targets by reducing emissions and restoring organic waste cycles through nature-based resource processing solutions.

4.2 Basic Information

Table 2 Basic Information

Rationale
Enhance soil and reduce methane emissions by replacing anaerobic decay with aerobic resource processing which inclube enzymatic/mechanical/thermal/biological treatment.
Objectives
(a) Effectively reduce methane emissions generated by the disposal of organic waste, helping to achieve carbon reduction targets. (b) Promote a circular economy and facilitate sustainable use of resources. (c) Improve waste management efficiency, thereby reducing environmental pollution and public health risks. (d) Effectively provide large volumes of organic fertilizer for agricultural applications using a more economical approach.
Activities and/or practices employed
On-farm resource processing, waste diversion from landfill, and application of organic fertilizer to agricultural land. The carbon sink formed by the increase in soil organic carbon due to the application of organic fertilizers can be calculated using other methodologies such as "VM0042: Improved agricultural land management V2.1" and "Soil organic carbon framework methodology".
Monitoring methodology
In situ monitoring of resource processing conditions, waste mass, and soil application according to CDM tools.

4.3 Landscape & Seascape Approaches [1]

Table 3 Specifically, biochar contributes to the following targets [2,3]

1. Reducing threats to biodiversity
TARGET 2: Restore 30% of all Degraded Ecosystems
Possible landscape & seascape -related indicators
Restoration of degraded agricultural and wetland areas often leads to increased carbon storage.
TARGET 7: Reduce Pollution to Levels That Are Not Harmful to Biodiversity
Possible landscape & seascape -related indicators
This project reduces agricultural inputs such as chemical fertilizers, indirectly contributing to GHG mitigation and soil carbon enhancement through: (1) Reduces nitrous oxide (N_2O) emissions (2) Encourages substitution with organic inputs like compost, improving soil structure and carbon storage
TARGET 8: Minimize the Impacts of Climate Change on Biodiversity and Build Resilience
Possible landscape & seascape -related indicators
This project emphasizes the enhancement of carbon storage and natural carbon sinks such as soil, forests, and wetlands, and promotes Nature-based Solutions (NbS) through: (1) Directly addresses soil carbon sequestration (2) Encourages agricultural practices that increase soil organic carbon and reduce GHG emissions
2. Meeting people's needs through sustainable use and benefit-sharing
TARGET 10: Enhance Biodiversity and Sustainability in Agriculture, Aquaculture, Fisheries, and Forestry
Possible landscape & seascape -related indicators
This project promotes climate-resilient and biodiversity-friendly practices in production systems that reduce emissions and improve soil health through: (1) Supports the use of organic amendments and conservation agriculture (2) Linked to improving soil carbon content through sustainable land management
TARGET 11: Restore, Maintain and Enhance Nature's Contributions to People
Possible landscape & seascape -related indicators
Recognizes ecosystem services such as climate regulation and carbon storage as critical contributions to human well-being. (1) Soil carbon sequestration is considered a key NCP (2) Promotes restoration of ecosystem functions through compost use and soil management
3. Tools and solutions for implementation and mainstreaming

[1] available at: https://satoyamainitiative.org/wp-content/uploads/2019/06/Landscape-Approaches-Manual_20240118.pdf
[2] available at: https://www.cbd.int/gbf
[3] available at: https://www.cbd.int/gbf/targets

TARGET 15: Businesses Assess, Disclose and Reduce Biodiversity-Related Risks and Negative Impacts
Possible landscape & seascape -related indicators
Encourages transparency in corporate environmental performance, including GHG emissions and soil management.
TARGET 16: Enable Sustainable Consumption Choices To Reduce Waste and Overconsumption
Possible landscape & seascape -related indicators
Advocates for circular practices, such as the reuse of organic waste (e.g., organic fertilizer), to reduce emissions from synthetic fertilizer use.
TARGET 19: Mobilize $200 Billion per Year for Biodiversity From all Sources, Including $30 Billion Through International Finance
Possible landscape & seascape -related indicators
The methodology mobilizes financial resources for biodiversity-positive climate mitigation via carbon crediting. Methane reduction and soil carbon improvement generate verified credits, attracting private investment and supporting local communities, contributing to Target 19's ambition of expanding biodiversity financing.

5 DEFINITIONS

The definitions apply to this methodology are as follows. In addition, all definitions follow the CDM Glossary of Terms and the definitions included in AMS-III.F Version 12.0.

(1) Enzymatic treatment: The solid enzyme product for organic waste treatment contains at least one of hydrolase, oxidoreductase, transferase, synthetase and lyase, which is combined according to different organic wastes and refined with a solid carrier.

(2) Resource processing: Controlled treatment of biomass or other organic matter is introduced through "aerobic treatment by composting" or " enzymatic/mechanical/thermal/biological treatment" and proper soil application of the organic fertilizer.

6 APPLICABILITY CONDITIONS

(1) This methodology is applicable to the resource processing of the organic fraction of municipal solid waste and biomass waste from agricultural or agro-industrial activities including manure.

(2) This methodology includes construction and expansion of treatment facilities as well as activities that increase capacity utilization at an existing facility. For project activities that increase capacity utilization at existing facilities, project participant(s) shall demonstrate that special efforts are made to increase the capacity utilization, that the existing facility meets all applicable laws and regulations and that the existing facility is not included in a separate CDM project activity. The special efforts should be identified and described.

(3) This methodology is also applicable for co-composting wastewater and solid biomass waste, where wastewater would otherwise have been treated in an anaerobic wastewater treatment system without biogas recovery. The wastewater in the project scenario is used as a source of moisture and/or nutrients to the biological treatment process e.g composting of empty fruit bunches (EFB), a residue from palm oil production, with the addition of palm oil mill effluent (POME) which is the wastewater co-produced from palm oil production.

(4) In case of co-composting, if it cannot be demonstrated that the organic matter would otherwise been left to decay anaerobically, baseline emissions related to such organic matter shall be accounted for as zero, whereas project emissions shall be calculated according to the procedures presented in this methodology for all co-composted substrates.

(5) The location and characteristics of the disposal site of the biomass, animal manure and co-composting wastewater in the baseline condition shall be known, in such a way as to allow the estimation of its methane emissions, using the provisions of AMS-III.G, AMS-III.E (concerning stockpile), AMS-III.D “Methane recovery in animal manure management systems” or AMS-III.H respectively.

(6) Blending materials may be added in the project scenario to increase the efficiency of the composting process (e.g. to achieve a desirable C/N ratio or free air space value), however, only monitored quantity of solid waste or manure or wastewater diverted from the baseline treatment system is used for emission reduction calculation. Project activities for composting of animal manure shall also meet the requirements under paragraphs 3 and 4(c) of the latest version of AMS-III.D.

(7) For solid wastes diverted from a solid waste disposal site, the following requirement shall be checked ex ante at the beginning of each crediting period:

    (a) Establish that identified landfill(s)/stockpile(s) can be expected to accommodate the waste to be used for the project activity for the duration of the crediting period; or

    (b) Establish that it is common practice in the region to dispose of the waste in solid waste disposal site (landfill)/stockpile(s).

(8) The project participants shall clearly define the geographical boundary of the region referred in paragraph (7)(b), and document it in the CDM-PDD. In defining the geographical boundary of the region, project participants should take into account the source of the waste i.e. if waste is transported up to 50 km, the region may cover a radius of 50 km around the project activity. In addition, it should also consider the distance to which the final product after composting will be transported. In either case, the region should cover a reasonable radius around the project activity that can be justified with reference to the project circumstances but in no case it shall be more than 200 km. Once defined, the region should not be changed during the crediting period(s).

(9) In case produced compost is handled aerobically and submitted to soil application, the proper conditions and procedures (not resulting in methane emissions) must be ensured.

(10) In case produced compost is treated thermally/mechanically, the provisions in AMS-III.E related to thermal/mechanical treatment shall be applied.

(11) In case produced compost is stored under anaerobic conditions and/or delivered to a landfill, emissions from the residual organic content shall to be taken into account and calculated as per the latest version of the methodological tool “Emissions from solid waste disposal sites”.

7 PROJECT BOUNDARY

7.1 Temporal Boundaries

The temporal boundary for this project is set at 10 years, starting from the implementation date and covering the full duration of monitoring and emission reduction accounting. The implementation date is the first day on which organic waste is physically diverted from the baseline disposal pathway (such as disposal in a solid waste disposal site or treatment in an anaerobic wastewater management system) and routed into the project's resource-recovery treatment system (e.g., aerobic composting, enzymatic, mechanical, thermal, or biological processing) for the purpose of controlled treatment and mitigation of methane emissions.

7.2 Geographic Boundaries

The project boundary is the physical, geographical site:

(a) Where the solid waste would have been disposed and the methane emission occurs in absence of the proposed project activity;
(b) In the case of projects co-composting wastewater, where the co-composting wastewater would have been treated anaerobically in the absence of the project activity;
(c) Where the treatment of biomass through resource processing takes place;
(d) Where the products from resource processing (organic fertilizer) is handled, disposed, submitted to soil application, or treated thermally/mechanically;
(e) And the itineraries between them (a, b, c and d) where the transportation of waste, wastewater, where applicable manure, product of treatment (organic fertilizer) occurs.

7.3 Carbon Pools

This methodology comprises measures to avoid the emissions of methane to the atmosphere from biomass or other organic matter that would have otherwise been left to decay anaerobically in a solid waste disposal site (SWDS), or in an animal waste management system (AWMS), or in a wastewater treatment system (WWTS).

In the project activity, controlled aerobic treatment by resource processing of biomass is introduced.

The carbon pool includes the organic carbon in resource processed biomass and soil carbon in fields applied with organic fertilizer.

7.4 Sources of Greenhouse Gases (GHGs)

(1) Methane (CH_4) from anaerobic decomposition of organic waste.
(2) CO_2, CH_4 and N_2O from resource processing includes electricity and/or fuel consumption.

8 BASELINE SCENARIOS

8.1 Determination of the Most Plausible Baseline Scenario

Without the project, waste would decay in unmanaged systems like landfills or lagoons, producing CH_4.

(1) The baseline scenario is the situation where, in the absence of the project activity, biomass and other organic matter (including manure where applicable) are left to decay within the project boundary and methane is emitted to the atmosphere.
(2) The baseline emissions are the amount of methane emitted from the decay of the degradable organic carbon in the biomass solid waste or manure. When wastewater is co-composted, baseline emissions include emissions from wastewater co-composted in the project activity. The yearly Methane Generation Potential for the solid waste is calculated using the first order decay model as described in the latest version of the methodological tool "Emissions from solid waste disposal sites". Baseline emissions from the manure composted are calculated as per the procedures of AMS-III.D. Where bedding material is used in the baseline/project activity, the calculation shall be based on the method of paragraph 16(a) (i.e. based on animal population) of AMS-III.D (ver. 20.0). Where no bedding material is used in baseline/project activity, any of the methods provided in paragraph 16(a) and 16(b) of AMS-III.D may be used.
(3) Baseline emissions shall exclude only the portion of methane emissions that, under applicable national or local laws, regulations, or mandatory safety requirements, is legally required and demonstrably collected, combusted, flared, fuelled, or otherwise abated at the landfill site. The existence of gas collection or control systems alone shall not justify excluding all methane emissions from the baseline; methane that would remain released in the absence of the project shall continue to be included in the baseline emissions.

8.2 Reassessment of the Baseline Scenario

Baseline may be reassessed if waste disposal practices or legal conditions change significantly.

MCF factor of 0.81 may be applied in the baseline emissions calculations using the methodological tool "Emissions from solid waste disposal sites" on account of existence of suppressed demand situation as described in the "Guidelines on the consideration of suppressed demand in CDM methodologies", under the following conditions:

(a) It can be demonstrated that waste is being dumped in an uncontrolled manner in human settlement areas under the current practice due to a lack of organised waste collection and disposal system; and
(b) It can be demonstrated that only the municipal solid waste is being treated under the project and wastes from other sources such as agricultural or agro-industrial wastes are not being treated under the CDM project; and
(c) It can be demonstrated that entire portion of the waste treated under the project activity would comply with the above two conditions.

9 ADDITIONALITY

If the total annual greenhouse gas (GHG) emission reductions of the project are less than or equal to 20,000 tonnes of CO_2 equivalent (tCO_2e), the additionality analysis in the project design document may be limited to an assessment of regulatory additionality.

In most countries and regions, the resource recovery of organic waste is not mandated by law. As a result, large quantities of organic waste remain untreated and unrecycled, leading to significant methane emissions and other greenhouse gas impacts. Centralized processing in dedicated facilities, combined with new technologies for organic waste resource recovery, can substantially reduce these emissions.

The analysis of regulatory additionality includes: whether the project is mandated by government regulations or policies; identification of applicable local laws and policies relevant to the project activity; evaluation of the reasonableness of the project activity; assessment of any potential legal or policy changes; and determination of whether the project activity exceeds regulatory requirements. Relevant documentation or evidence should be provided to support the analysis.

9.1 Methodological Novelty and Need for a New Approach

Existing methodologies such as AMS-III.F and VM0042 do not cover rapid-cycle enzymatic and multi-stage biological treatments (e.g., TTT technology) capable of converting organic waste into stable fertilizer within hours. This methodology fills that gap by integrating methane avoidance with soil carbon enhancement. Therefore, the methodology is required to cover advanced resource-processing pathways not supported in existing protocols.

10 QUANTIFICATION OF GREENHOUSE GAS EMISSION REDUCTIONS AND REMOVALS

10.1 Baseline Emissions

Estimated using CH_4 generation models for landfills and anaerobic systems.

$$BE_y = BE_{CH4,SWDS,y} + BE_{ww,y} + BE_{CH4,manure,y} - MD_{y,reg} \times GWP_{CH4} \qquad \text{Equation (1)}$$

Where:

BE_y	= Baseline emissions in the year y (tCO_2e)
$BE_{CH4,SWDS,y}$	= Yearly methane generation potential of the solid waste composted by the project activity during the years x from the beginning of the project activity (x=1) up to the year y estimated as per the latest version of the methodological tool "Emissions from solid waste disposal sites" (tCO_2e). The tool may be used with the factor "f=0.1" taking into account the methane oxidation effect by the upper layer of the landfill. With the definition of year x as 'the year since the project activity started diverting wastes from landfill disposal, x runs from the first year of crediting period (x=1) to the year for which emissions are calculated (x=y)'
$MD_{y,reg}$	= Amount of methane that would have to be captured and combusted in the year y to comply with the prevailing regulations (tonne)
$BE_{CH4,manure,y}$	= Where applicable, baseline emissions from manure composted by the project activities, as per the procedures in AMS-III.D (tCO_2e)
$BE_{ww,y}$	= Where applicable, baseline emissions from the wastewater co-composted, calculated as per the procedures in AMS-III.H (tCO_2e)
GWP_{CH4}	= Global Warming Potential for CH_4 applicable to the crediting period (t CO_2e/t CH_4)

10.2 Project Emissions

(1) Project emissions from resource process (PE_y) can be determined as per the latest version of the methodological tool "Project and leakage emissions from composting". PE_y is equivalent to parameter $PE_{COMP,y}$ in the tool.

(2) The project emissions and/or removals can be quantified in accordance with the equirements and guidance of ISO 14064-2.

10.3 Emission reductions due to rewetting and fire management (Fire Reduction Premium)

Not applicable.

10.4Leakage

(1) If the project technology is the equipment transferred from another activity or if the existing equipment is transferred to another activity, leakage effects shall be considered (LEy).

(2) In case organic fertilizer is subject to anaerobic storage or disposed of in a SWDS, leakage shall be estimated to account for methane emissions from the anaerobic decay of organic fertilizer. The relevant procedures in the leakage part of the methodological tool "Project and leakage emissions from composting" shall be followed.

10.4.1 Activity-shifting leakage and market leakage

(1) If the project technology is the equipment transferred from another activity or if the existing equipment is transferred to another activity, leakage effects are to be considered (LEy).
(2) If the project activity causes changes in the use of feedstocks or energy that indirectly increase emissions in other stages of the production or consumption chain, these effects must also be assessed. Finally, if the project activity leads to changes in land use that reduce carbon sequestration capacity or increase greenhouse gas emissions, such impacts shall be recognized as potential sources of leakage.
(3) Waste traceability from collection to processing is ensured through weighbridge data, manifests, and verification records. Local authorities confirm baseline practices to prevent shifting to unmanaged dumping.

10.4.2 Ecological leakage

In case organic fertilizer is subject to anaerobic storage or disposed of in a SWDS, leakage shall be estimated to account for methane emissions from the anaerobic decay of organic fertilizer. The relevant procedures in the leakage part of the methodological tool "Project and leakage emissions from composting" can be followed.

10.4.3 Market Leakage

Organic fertilizer production replaces synthetic fertilizer use, typically reducing net emissions. Fertilizer distribution is monitored to avoid cross-regional shifts that could increase upstream emissions.

Deep landfill (>5m) is most likely the technology for disposing MSW in the scenario of constrained availability of area/space within or close to urban areas and where waste scavenging does not occur. And it is also the least cost alternative for providing comparable level of service to the project technology for treating the waste i.e. composting in this case. MCF value is chosen from the definition provided in 2006 IPCC Guideline applicable to unmanaged deep landfills that do not have controlled placement of waste (i.e. waste directed to specific deposition areas, a degree of control of scavenging and a degree of control of fires) and do not include any cover material, mechanical compacting and levelling of the waste.

10.5 Net GHG Emission Reductions and Removals

10.5.1 Calculation of net GHG emissions reductions

$$ER_y = BE_y - (PE_y + LE_y) \qquad \text{Equation (2)}$$

Where:
ER_y = Emission reduction in the year y (tCO_2e)
PE_y = Project emissions in the year y (tCO_2e)
LE_y = Leakage emissions in year y (tCO_2e)

10.5.2 Estimation of uncertainty

In accordance with AMS-III.F and the "General guidance on leakage and uncertainty for small-scale project activities," an uncertainty assessment was conducted for the baseline emissions estimation:

The baseline emissions (BE_y) are calculated using the following equation:

$$BE_y = BE_{CH4,SWDS,y} + BE_{ww,y} + BE_{CH4,manure,y} - MD_{y,reg} \times GWP_{CH4}$$

Table 4 Key Parameters and Sources of Uncertainty

Parameter	Description	Data Source	Estimated Uncertainty (±%)	Notes
$BE_{CH4,SWDS,y}$	Methane emissions from solid waste disposal sites	IPCC 2006 Guidelines, local data	30–50%	High variability due to degradation parameters (e.g., DOC, MCF)
$BE_{ww,y}$	Methane emissions from wastewater	IPCC defaults, monitoring data	20–40%	Influenced by COD/BOD levels and treatment system types
$BE_{CH4,manure,y}$	Methane emissions from manure management	IPCC, national inventory data	15–30%	Depends on animal type and manure handling systems
$MD_{y,reg}$	Amount of methane recovered	On-site measurement (flow meter)	10–20%	Depends on metering accuracy and calibration
GWP_{CH4}	Global warming potential of methane	IPCC AR5 or AR6	Fixed	Typically not subject to uncertainty in calculations

Combined Uncertainty Calculation

Assuming independence between parameters, the combined relative uncertainty of baseline emissions is calculated using the root-sum-square method:

$$U_{BEy} = \sqrt{(U_{SWDS}^2 + U_{ww}^2 + U_{manure}^2 + U_{MD}^2)}$$

Using conservative estimates:

- U_{SWDS} = 40%
- U_{ww} = 30%
- U_{manure} = 25%
- U_{MD} = 15%
- $U_{BEy} = \sqrt{(0.4^2 + 0.3^2 + 0.25^2 + 0.15^2)} \approx 57\%$

The total uncertainty of baseline emissions is estimated at approximately 57%, mainly due to the use of default emission factors and variable waste characteristics. Despite this, the project activity remains conservative, as the expected baseline emissions significantly exceed the project emissions. The estimated emission reductions are therefore considered robust and credible.

10.5.3 Calculation of carbon credits

$$\text{Carbon credits } (tCO_2e) = ER_y(tCO_2e)$$

According to equation (2)

$$ER_y = BE_y - (PE_y + LE_y)$$

Where:

ER_y = Emission reduction in the year y (tCO_2e)
PE_y = Project emissions in the year y (tCO_2e)
LE_y = Leakage emissions in year y (tCO_2e)

10.6 Cost Efficiency Analysis

Methane avoidance will be permanent when organic fertilizer is applied under aerobic conditions. To safeguard benefits in line with ISO 14064-2, the project will:

(1) Verify soil aeration and drainage during application.
(2) Maintain a 10–20% buffer pool against reversals.
(3) Conduct SOC sampling every 3–5 years.
(4) Apply corrective measures if SOC declines or anaerobic risks arise.
(5) Document soil management practices for transparency and verification.

This ensures both methane avoidance and soil carbon gains remain durable and verifiable.

11 MONITORING

11.1 Data and Parameters Available at Validation

Data/Parameter:	$EF_{ELEC,\,y}$	
Data unit:	$kgCO_2e$/ kWh、tCO_2/MWh	
Description:	Electricity or grid emission coefficient in year y	
Source of data:	Government's latest annual electricity emission coefficient	Calculate the mixed margin (CM) emission factor for the current year based on the international CDM tool 07 " Tool to calculate the emission factor for an electricity system "
Measurement procedures(if any)	annual	Ex ante calculation, confirmed when the project plan is finalized
Monitoring frequency:	-	-
QA/QC procedures:	-	-
Any comment:	-	

Data/Parameter:	
Data unit:	
Description:	Parameters related to emissions from electricity and/or fuel consumption
Source of data:	
Measurement procedures(if any)	As per the procedure in the “Methodological tool: Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation” and/or “Tool to calculate project or leakage CO2 emissions from fossil fuel combustion”. Alternatively it shall be assumed that all relevant electrical equipment operate at full rated capacity, plus 10% to account for distribution losses, for 8760 hours per annum
Monitoring frequency:	
QA/QC procedures:	-
Any comment:	-

Data/Parameter:	
Data unit:	
Description:	Parameters related to methane emissions from anaerobic disposal in a solid waste disposal site of the solid waste (excluding manure)/compost
Source of data:	
Measurement procedures(if any)	As per the latest version of the CDM methodological tool "Emissions from solid waste disposal sites
Monitoring frequency:	
QA/QC procedures:	-
Any comment:	-

Data/Parameter:	
Data unit:	
Description:	Parameters related to baseline methane emissions from animal manure
Source of data:	
Measurement procedures(if any)	As per the relevant provisions in CDM AMS-III.D
Monitoring frequency:	
QA/QC procedures:	-
Any comment:	-

Data/Parameter:	
Data unit:	
Description:	Parameters related to baseline emissions from wastewater co-composted
Source of data:	
Measurement procedures(if any)	As per the relevant provisions in CDM AMS-III.H
Monitoring frequency:	
QA/QC procedures:	-
Any comment:	-

11.2 Data and Parameters Monitored

Data/Parameter:	$TWCOM_y$
Data unit:	Tons
Description:	Total quantity of waste resource processed in year y at the facility
Source of data:	
Measurement procedures(if any)	Use a weighbridge or any other applicable and calibrated weighing device, e.g. belt-scales In the case of increase of capacity utilization of existing resource processing facilities, it is used for the calculation of the factor r
Monitoring frequency:	Monthly
QA/QC procedures:	Weighbridge or any other applicable weighing device is subject to periodic calibration (in accordance with stipulation of the weighing device supplier)
Any comment:	-

Data/Parameter:	$TWCOM_y$
Data unit:	Tons
Description:	Total quantity of waste resource processed in year y at the facility
Source of data:	
Measurement procedures(if any)	Use a weighbridge or any other applicable and calibrated weighing device, e.g. belt-scales In the case of increase of capacity utilization of existing resource processing facilities, it is used for the calculation of the factor r
Monitoring frequency:	Monthly
QA/QC procedures:	Weighbridge or any other applicable weighing device is subject to periodic calibration (in accordance with stipulation of the weighing device supplier)
Any comment:	-

11.3 Description of the Monitoring Plan

(1) In case of increase of capacity utilization of existing resource processing facilities, the emission reduction achieved by the project activity will be measured as the difference between the baseline emission and the sum of the project emission and leakage, multiplied by the factor r as follows:

$$ER_y = (BE_y - PE_y - LE_y) \times (1 - r)$$

(2) The value for r is defined as:

$$r = WCOMBAU/TWCOMy \qquad \text{Equation (4)}$$

Where:

$TWCOMy$ = Total quantity of waste resource processed in year y (tonnes) at the facility

$WCOMBAU$ = Registered annual amount of waste v (tonnes) at the facility on a business as usual basis calculated as the highest amount of annual organic fertilizer production in the last five years prior to the project implementation.

(3) For project activities involving the enhancement of the utilization of existing waste treatment facility capacity, the verification process shall include the following steps:

(a) Historical Data Collection: Collect historical records of the facility's annual waste treatment volumes for the five years prior to project implementation, with detailed breakdowns for each year.
(b) Cross-Verification: To ensure the accuracy of the historical data, supporting documents such as compost sales invoices, delivery records, or other verifiable evidence shall be provided to reconcile the actual waste treated and the outputs produced.
(c) Document Review: The collected data and supporting evidence shall be submitted to the designated validator or relevant third-party review body for document review and cross-checking, to confirm data consistency and compliance.
(d) On-Site Verification (if necessary): The validator may, as needed, conduct on-site verification, including spot checks of facility operation records and relevant source documents, to further confirm the authenticity of the historical data.
(e) Final Verification Report: Following document review and any necessary on-site verification, the validator shall issue a verification report confirming that the historical data relied upon by the project are accurate and reliable, and suitable for use as the basis for subsequent project emission reductions calculations.

(4) The operation of resource processing facilities shall be documented in a quality control program, monitoring the conditions and procedures that ensure the aerobic condition of the waste during the resource processing (e.g. temperature and moisture during different resource processing stages).

(5) Soil application of the compost in agriculture or related activities will be monitored. This includes documenting the sales, delivery, and receipt of the final compost product at user sites. In addition, an in situ verification shall be conducted at a representative sample of user sites to ensure proper soil application that maintains aerobic conditions. The verification process may include:

(a) Visual inspection to confirm the compost is incorporated into the soil and not left on the surface.
(b) Confirmation that the application method allows sufficient soil aeration for further decay.
(c) Recording basic site conditions, such as soil type, crop type, and recent weather conditions, that could affect aerobic conditions.
(d) Documentation of any deviations from the recommended application procedure and follow-up actions.
(e) The conditions for proper soil application ensuring aerobic conditions shall be established by a local agronomic expert, taking into account soil conditions, crop types, and weather conditions.

(6) The monitoring requirements in the CDM methodological tool "Project and leakage emissions from composting" shall be followed. Additional parameters, where relevant, shall be monitored as indicated in the tables below. The applicable requirements specified in the "General Guidelines for SSC CDM methodologies" (e.g. calibration requirements and sampling requirements) are also an integral part of the monitoring guidelines specified below and therefore shall be referred by the project participants during the project crediting period.

11.4 Data, Parameters, and Description of the Monitoring Plan to Practice the Strategy and Plan of Action 2023 -2030 of the International Partnership for the Satoyama Initiative

（1）Soil organic carbon (SOC) and soil health indicators.
（2）Quantity of organic waste processed and organic fertilizer applied.
（3）Biodiversity-related soil metrics (microbial biomass, enzyme activity).
（4）Substitution rate of chemical fertilizers.
（5）Methane emissions avoided and project GHG emissions.
（6）Community participation indicators, fertilizer adoption rates, and improvements in local environmental conditions.

These parameters allow the project to demonstrate measurable contributions to sustainable agriculture, circular resource use, biodiversity enhancement, climate mitigation, and community well-being, all of which align closely with the IPSI Strategy and Plan of Action 2023–2030.

11.5 Data, Parameters, and Description of the Monitoring Plan to Practice the Kunming-Montreal Global Biodiversity Framework

The use of organic fertilizers (e.g., compost, manure, green manure) aligns closely with many of the key principles of the Satoyama Initiative, particularly in enhancing the resilience of Socio-Ecological Production Landscapes and Seascapes (SEPLS). It supports biodiversity, traditional knowledge, community involvement, and sustainable livelihoods.

11.6 Key Performance Indicator

The Kunming-Montreal Global Biodiversity Framework has 23 action-oriented global targets for urgent action over the decade to 2030. The actions set out in each target need to be initiated

immediately and completed by 2030. Together, the results will enable the achievement of the outcome-oriented goals for 2050. Actions to reach these targets should be implemented consistently and in harmony with the Convention on Biological Diversity and its Protocols and other relevant international obligations, considering national circumstances, priorities, and socioeconomic conditions.

Table 5 Scores for landscape & seascape indicators

Possible landscape & seascape -related indicators - soil organic carbon	
Restoration of degraded agricultural and wetland areas often leads to increased carbon storage EX: This indicator intends to capture the extent to which the mosaic nature of the land/ seascape is maintained. This is linked to the understanding that the higher the mosaic nature of a landscape, the more its capacity to be resilient to natural shocks.	
Setting Resource	
1. TARGET 2: Restore 30% of all Degraded Ecosystems 2. Encourages agricultural practices that increase soil organic carbon and reduce GHG emissions /TARGET 8: Minimize the Impacts of Climate Change on Biodiversity and Build Resilience 3. Promotes restoration of ecosystem functions through compost use and soil management/ TARGET 11: Restore, Maintain and Enhance Nature's Contributions to People (EX:1. Reducing threats to biodiversity/ TARGET 1: Plan and Manage all Areas To Reduce Biodiversity Loss)	
Guiding questions for target-setting (Questions for scoring)	
1. SOC promotes the aggregation of soil particles, enhancing aeration and water retention. 2. SOC serves as an energy source for soil microorganisms, facilitating nutrient cycling. 3. Organic carbon helps retain essential cations like potassium, calcium, and magnesium, reducing nutrient leaching. 4. SOC improves the soil's ability to retain water and supply nutrients, creating a better environment for plant growth. 5. Soils with higher SOC are more resilient to drought, acidification, and erosion. (EX: What measures are necessary to ensure the preservation and protection of the rights of indigenous peoples and local communities while implementing this target?)	
Scores (point scale or number value)	Key performance indicator of Score
Scoring with a 5-point scale (5) Very high (>10%) (4) High (5.1-10.0%) (3) Moderate (2.1-5.0%) (2) Low (0.5-2.0%) (1) Very low (<0.5%) Example of scoring with a 5-point scale (5) High diversity (4) Improved to some extent (3) No change rich diversity (2) Poor diversity (1) Low	(3) Ex: > 4

12 Integration with Stakeholder Engagement & IPLC Participation

The project must ensure:

(1) Meaningful participation of local communities and Indigenous Peoples

(2) FPIC where applicable

(3) Documentation of traditional knowledge in soil stewardship

(4) Benefit-sharing mechanisms such as access to organic fertilizer and capacity-building

(5) A functional grievance and feedback system

This supports GBF Targets 21–22 and IPSI Principle ii.

13 Risk Assessment and Permanence Assurance

Risks considered

(1) Natural risks: typhoon, flood, extreme rainfall.

(2) Operational risks: equipment failure, labor shortages.

(3) Market risks: price volatility affecting output demand.

(4) Policy risks: evolving waste-management regulations.

(5) SOC reversal risks: improper soil management, erosion.

Mitigation strategies

(1) Backup processing capacity.

(2) Multi-source feedstock agreements.

(3) Emergency facility operation plans.

(4) Operator training and QA/QC systems.

(5) Regular policy reviews.

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APPENDIX

Enzymatic resource processing is a technology based on Tetanti's targeted enzyme products, and with the combined use of machinery, organic wastes can be turned into organic fertilizers within 3 hours.

The introduce of TTT technology and the target enzymes, AIMZYME:

(1) The innovative "Targeted Enzyme, AIMZYME" is a group of enzymes with specific functions, which directly and precisely act on the target in the organic waste that needs to be treated. Academician Young possess over 8,000 strains and 2,500 species of functional bacterial stock, which is the source of the various targeted enzymes.
(2) AIMZYME are active proteins that act as catalysts, which can speed up the catalysis of organic substances by biochemical reactions, with the combined use of specific equipment, organic wastes can be turn into organic fertilizer through enzymatic multi-reactions.
(3) Toxic matters in organic wastes are detoxified and/or deodorized through the degradation, synthesis, transformation and/or polymerization reactions by AIMZYME.
(4) Pathogens, insect eggs and grass seeds are mostly exterminated at 80° C through TTT technology.
(5) TTT technology only requires 3 hours to produce organic fertilizers. The organic fertilizer is stable and ready-to-use without the need of post-maturization.
(6) TTT technology is efficient and cost effective, it greatly improves the maturization process of organic matter over 100 folds and can reduce pollution and increase product safety. The production process solves the odor, waste water, large area demand and time-consuming problems that are normally associated with traditional composting
(7) Applying organic fertilizer can improve soil fertility, benefit plant growth, while also increasing soil carbon storage.

For more information, please visit the Tetanti website: https://www.ttt3tops.com/en/

DOCUMENT HISTORY

Version	Date	Changes & Comment
v1.0	25 November 2025	Initial submission

SATOYAMA INITIATIVE

Methodology

Me0002

Biodiversity Methodologies for Biochar Utilization in Soil and Non-Soil Applications

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1 Source

This methodology is based on the following sources: [1]

- CDM methodology AMS-III.L: Avoidance of methane production from biomass decay through controlled pyrolysis, v2.0
- CDM methodology Small-Scale Methodology AMS-III.E: Avoidance of methane production from decay of biomass through controlled combustion, gasification or mechanical/thermal treatment, v17.0
- CDM methodology AMS-III.BG: Emission reduction through sustainable charcoal production and consumption, v3.0
- CDM Executive Board report EB23 Annex 18: Definition of Renewable Biomass

The following has also informed the development of the methodology:

- Intergovernmental Panel on Climate Change (IPCC) (2019) Appendix 4: Method for Estimating the Change in Mineral Soil Organic Carbon Stocks from Biochar Amendments: Basis for Future Methodological Development
- International Biochar Initiative (IBI) Standardized Product Definition and Product Testing Guidelines for Biochar That Is Used in Soil, v2.1
- European Biochar Certificate (EBC) Guidelines for a Sustainable Production of Biochar, v10.1

This methodology uses the latest versions of the following CDM tools:[2] [3]

- CDM Tool 03: Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion, v03.0
- CDM Tool 05: Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation, v03.0
- CDM Tool 09: Tool to determine the baseline efficiency of thermal or electric energy generation systems, v03.0
- CDM Tool 12: Project and leakage emissions from transportation of freight, v01.1.0
- CDM Tool 16: Project and leakage emissions from biomass, v04.0

[1] Clean Development Mechanism (CDM) methodologies and Climate Action Reserve (CAR) protocols.
[2] CDM tools are available at: cdm.unfccc.int/methodologies/ARmethodologies/approved
[3] CAR tools are available at: https://www.climateactionreserve.org/how/protocols/

2 Summary Description of the Methodology

This globally applicable methodology outlines the criteria and procedures for quantifying greenhouse gas (GHG) reductions achieved through improved waste treatment and disposal (WTD) of waste biomass. The project consists of five main components:

1. Generation of waste biomass
2. Production of biochar and
3. Application of biochar in soil or non-soil settings.
4. Quantification of GHG emission reductions or removals
5. Calculation of VCUs

The project requires the installation and operation of a new (greenfield) biochar production site. Only biochar that is ultimately applied to qualifying soil or non-soil applications will be counted towards GHG benefits. The official start date of the program is defined as the date of first biochar production.

The baseline scenario assumes continuation of existing WTD practices, where waste biomass will decay naturally or be burned for non-energy purposes. To ensure the conservative nature of the methodology, this methodology does not consider emission reductions associated with changes in WTD practices at the procurement stage. Therefore, it assumes zero net GHG emissions at the procurement stage in the baseline scenario.

A comprehensive monitoring and accounting framework is used to track the GHG impacts of the entire biochar value chain, including the sourcing, production and application stages. The methodology also explores the permanence of biochar, considering factors such as decay rates and potential risks of reversal, both natural and anthropogenic.

Monitoring is required for both the baseline and case scenarios. Emissions from the production stage are calculated using one or more monitored parameters (such as production temperature and physical and chemical properties of biochar) or, where appropriate, using preset values provided in the methodology.

3 Relation to Strategy and Plan of Action 2023 -2030 of the International Partnership for the Satoyama Initiative

This project aligns with the IPSI Strategy and Plan of Action 2023–2030 by integrating biochar production and application into sustainable land management. The following points describe how the project corresponds to the IPSI Six Ecological and Socio-Economic Perspectives:

Perspective 1: Resource use within the carrying capacity and resilience of the environment

Biochar production does not alter traditional farming practices and uses only local agricultural residues, ensuring resource use remains within environmental limits and enhancing farmland resilience.

Perspective 2: Cyclic use of natural resources

Agricultural residues are converted into biochar and returned to the land, creating a circular system that reduces waste and promotes sustainable resource management.

Perspective 3: Recognition of the value and importance of local and indigenous traditions and culture

Traditional farming practices are maintained and integrated with biochar technology, respecting and enhancing local knowledge and cultural values.

Perspective 4: Multi-stakeholder participation and collaboration in sustainable and multi-functional management of natural resources and ecosystem services

The methodology fosters collaboration through knowledge sharing, technical support, and engagement of farmers, cooperatives, and experts in biochar activities.

Perspective 5: Contributions to sustainable socio-economies including poverty reduction, food security, sustainable livelihood and local community empowerment

Improved soil productivity, enhanced carbon revenue through access to carbon markets, and diversified income streams strengthen local livelihoods and empower communities.

Perspective 6: Improved community resilience to achieve multiple benefits

The project must report, per crediting cycle, a concise IPSI scorecard summarizing actions and evidence for the five Strategic Objectives (knowledge co-production, institutional capacity, area-based conservation, ecosystem restoration, and sustainable value chains), with cross-references to the monitoring records in Section11.3.

4 Relation to Kunming-Montreal Global Biodiversity Framework (GBF)

The vision of the Kunming-Montreal Global Biodiversity Framework is a world of living in harmony with nature where "by 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people[4].

4.1 Description

This methodology integrates the production and application of biochar into soil and non-soil Applications in alignment with the Kunming-Montreal Global Biodiversity Framework.

Biochar functions as a nature-based solution that provides stable long-term carbon sequestration, improves soil quality, and strengthens agricultural resilience. By enabling quantifiable GHG emission reductions and removals, it contributes to ecosystem restoration, pollution reduction, and sustainable resource use.

Under this methodology, biochar production preserves traditional farming while promoting sustainable management, with carbon sequestration directly accounted to enable carbon market access and deliver clear benefits. A robust framework for measurement, monitoring, and knowledge transfer supports capacity building and generates ecological, social, and economic gains.

4.2 Basic Information

Table 1: Basic Information

Rationale
Biochar under this methodology supports reducing pollution, enhancing climate resilience, promoting sustainable agriculture, improving ecosystem services, and enabling capacity building and knowledge sharing for local benefits.
Objectives
● Achieve measurable GHG emission reductions and removals through the production and application of biochar. ● Preserve traditional farming practices while advancing sustainable management approaches. ● Facilitate access to carbon markets and deliver direct economic benefits to local communities.
Activities and/or practices employed
● Apply biochar to approved soil and non-soil applications to ensure long-term carbon sequestration. ● Monitor and account for carbon sequestration to generate verified credits in carbon markets ● Implement a robust framework for measurement and reporting of GHG emission reductions and removals

[4] available at: https://www.cbd.int/gbf/targets

Monitoring methodology
Monitoring combines ecological field surveys, satellite remote sensing, and participatory community-based monitoring. Indicators track land-use change, species richness, carbon stocks, and ecosystem health.

4.3 Landscape & Seascape Approaches [5]

Table 2: Specifically, biochar contributes to the following targets [6][7]

1. Reducing threats to biodiversity
TARGET 7: Reduce Pollution to Levels That Are Not Harmful to Biodiversity
Possible landscape & seascape -related indicators
● Applying biochar reduces the leaching of nutrients and decreases the reliance on chemical fertilizers and pesticides. ● This mitigates nutrient runoff and groundwater contamination, helping to lower pollution levels that threaten biodiversity and ecosystem services.
TARGET 8: Minimize the Impacts of Climate Change on Biodiversity and Build Resilience
Possible landscape & seascape -related indicators
● Biochar acts as a carbon sink, capturing and storing atmospheric CO_2, thereby contributing to climate change mitigation. ● Its use in agriculture also enhances soil moisture retention and crop resilience under changing climatic conditions, aligning with nature-based climate adaptation strategies.
2. Meeting people's needs through sustainable use and benefit-sharing
TARGET 10: Enhance Biodiversity and Sustainability in Agriculture, Aquaculture, Fisheries, and Forestry
Possible landscape & seascape -related indicators
● By integrating biochar into agricultural systems, farmers can adopt more biodiversity-friendly and sustainable practices. ● Agroecological transitions by reducing pesticide input dependency and improving soil biodiversity, thereby contributing to long-term agricultural sustainability and food security.
TARGET 11: Restore, Maintain and Enhance Nature’s Contributions to People
Possible landscape & seascape -related indicators
● Biochar can enhance ecosystem services such as carbon storage, water regulation, and soil fertility. ● It reduces agricultural waste, limits carbon losses during pyrolysis. ● It improves soil carbon stability, and promotes crop biomass production.

[5] available at: https://satoyamainitiative.org/wp-content/uploads/2019/06/Landscape-Approaches-Manual_20240118.pdf
[6] available at: https://www.cbd.int/gbf
[7] available at: https://www.cbd.int/gbf/targets

● These benefits support human well-being and biodiversity by restoring the natural functions of the land.
3. Tools and solutions for implementation and mainstreaming
TARGET 19: Resource mobilization
Possible landscape & seascape -related indicators
● Broadening stakeholder participation (incl. women and youth) to expand local implementation capacity; ● Establishing regional training programs to build technical and managerial skills for MRV and project delivery; ● Operating a centralized, publicly accessible database/registry interface for MRV and crediting, enabling transparent information flow and partner engagement; ● Facilitating partnerships among farmers' groups, cooperatives, and local institutions to channel resources to field activities.
TARGET 20: Strengthen Capacity-Building, Technology Transfer, and Scientific and Technical Cooperation for Biodiversity
Possible landscape & seascape -related indicators
● Strengthening farmers' understanding and application of biochar technology can transform agricultural waste into soil nutrients and promote the recycling of local resources. ● Biochar production can provide farmers with additional income or be supplied to neighboring communities, promoting regional resource sharing and sustainable development. ● This approach promotes the transfer of local knowledge and technology. ● It meets the needs of capacity building and technical cooperation in biodiversity-related actions.
TARGET 21: Ensure That Knowledge Is Available and Accessible To Guide Biodiversity Action
Possible landscape & seascape -related indicators
● The target emphasizes equitable and inclusive participation, particularly among Indigenous Peoples, local communities, women, and youth. ● The methodology responds to this by recognizing that many farmers still lack a systematic understanding and clear information about biochar production, benefits, and applications. To address this, the project shall establish a biochar technology approach and public platform that integrates data on raw material sourcing, application sites, ecological impacts, and soil improvements. ● This participatory system is designed not only to enhance knowledge access, but also to promote dialogue between traditional knowledge and modern science, and to strengthen rural engagement—including women and youth—in biodiversity-related actions. By embedding these inclusive mechanisms, the methodology supports FPIC-aligned engagement where relevant, and ensures that the climate and ecological benefits of biochar are co-developed with local stakeholders across social and generational lines.

Through these contributions, biochar serves as a practical and scalable solution that addresses multiple goals within the Kunming-Montreal Global Biodiversity Framework, highlighting the importance of sustainable agricultural innovation in biodiversity conservation.

To operationalize this contribution at the project level, this methodology requires project proponents to implement standardized species and habitat mapping protocols as part of their biodiversity monitoring framework. These must include:

- Field-based species richness surveys using quadrats, line transects, or point counts, depending on land type;
- GPS-based georeferencing of biodiversity observations, which are integrated into a centralized biodiversity monitoring database;
- Habitat classification using internationally recognized schemes (e.g., FAO-LCCS, IUCN Habitat Classification), supported by remote sensing to detect land-use change over time;
- GIS-based spatial analysis and map generation, updated at least every five years, to visualize species presence and ecosystem extent.

Project proponents shall implement standardized species and habitat mapping protocols as part of the monitoring framework, including:

- field-based species richness surveys (quadrats/line transects/point counts, method selected by land type);
- GPS-based georeferencing of observations, integrated into a centralized biodiversity database;
- habitat classification using recognized schemes (e.g., FAO-LCCS, IUCN Habitat Classification) supported by remote sensing for land-use change detection;
- GIS-based maps, updated at least every five (5) years, visualizing species presence and ecosystem extent.

All biodiversity data must be validated by qualified personnel, archived, and reported in standardized formats to ensure traceability and third-party verifiability.

Where relevant, IPSI actions reported in Section 3 are cross-walked to GBF targets in this section, ensuring consistency between biodiversity outcomes and socio-ecological benefits.

5 DEFINITIONS

This paragraph references VM0044 METHODOLOGY FOR BIOCHAR UTILIZATION IN SOIL AND NON-SOIL APPLICATIONS and Biochar Standards, and has been modified and rewritten in this article. [8][9]

Anaerobic decomposition

Anaerobic decomposition refers to the microbial degradation of organic material in oxygen-free conditions. The process primarily releases methane (CH_4), along with lesser quantities of carbon dioxide (CO_2). Common examples include marine sediment and livestock waste lagoons.

Biochar

Biochar refers to a solid and stabilised form of carbon produced through the thermochemical conversion of biomass under oxygen-limited conditions. This conversion may occur via pyrolysis—where oxidising agents are excluded entirely—or gasification, in which the concentration of oxidants remains sufficiently low to facilitate the production of synthesis gas (syngas). In this document, the two processes are treated interchangeably. Biochar is regarded as a carbon sink when its application, whether in soil (e.g., as a soil amendment in agricultural systems) or in non-soil contexts (e.g., incorporation into cement or asphalt), demonstrably ensures long-term carbon persistence.

Biomass

Biomass refers to a material that is derived from, or produced by, a living organism.

Chain of custody

The chain of custody refers to a structured system for recording and overseeing every step, beginning with the acquisition of biomass feedstock (such as residual or discarded biomass) and continuing through to the stage where biochar is ultimately applied, whether in soils or alternative settings. It covers the framework by which materials, outputs, and all relevant data are conveyed, tracked, and managed throughout each segment of the supply chain involved.

Dry matter basis

The term dry matter or dry weight refers to the total mass of a substance after all moisture has been removed. Dry matter basis refers to a measurement approach that expresses the moisture content in a solid material as a percentage of the weight of that material when fully dried.

[8] available at: https://biochar-international.org/standard-certification-training/biochar-standards/

[9] VM0044 METHODOLOGY FOR BIOCHAR UTILIZATION IN SOIL AND NON-SOIL APPLICATIONS

In biochar quality assessment, procedures for calculating dry matter basis typically follow established product testing protocols such as those outlined by the International Biochar Initiative (IBI). Specifically, the dry weight of biochar is determined using methods equivalent to the ASTM D1762-84 standard for chemical analysis of wood charcoal (see Table 1 of the IBI Testing Guidelines).

For cases where it is necessary to assess moisture levels in feedstock materials prior to biochar production, reference can be made to ASTM D4442-20, which involves drying samples to a constant weight in a ventilated oven at 102 to 105 °C.

Dynamic baseline

A dynamic baseline refers to a reference point or condition that changes over time, rather than remaining fixed. It is used to evaluate the impact of an intervention or to track performance by comparing it against a shifting, evolving standard that reflects real-world changes.

Feedstock

Feedstocks refers to materials undergoing thermochemical conversion to produce biochar. To qualify under this methodology, feedstock materials must be biomass in origin and must adhere to the specified applicability criteria.

Freight

Freight refers to any transported goods or materials, including discarded biomass and biochar. In this framework, the movement of such materials is treated as freight transportation. To ensure accurate tracking and reporting, transport activities are classified by vehicle type and consistent travel routes, grouping trips that share the same departure and arrival points.

Gasification

Gasification refers to a technological process that converts carbon-based raw materials into fuel gas. This process typically occurs within a gasifier at temperatures exceeding 700 °C.

High-carbon fly ash from biomass

High-carbon fly ash (HCFA) from biomass refers to a secondary output generated during biomass-based energy production, which in many cases is routed back into the operational cycle. This material is typically produced by boiler systems operating in sawmills and other forestry-related facilities. HCFA is mainly composed of ash combined with carbonized matter. Biomass ash and its various fractions, such as bottom ash and fly ash, may exhibit physicochemical traits comparable to those of biochar materials. Among these, certain fractions with elevated organic carbon levels are identified as “high-carbon fly ash” (adapted from IBI Biochar Testing Guidelines Section 5.8).

High technology production site

A high-technology production site refers to a biochar manufacturing facility that satisfies all of the following conditions as set forth in the *European Biochar Certificate (EBC) Guidelines for the Sustainable Production of Biochar* [10] (referred to herein as the EBC Production Guidelines): (a) the pyrolytic gases (GHGs) generated during the pyrolysis process must be either captured or combusted—no GHGs may be released directly into the atmosphere;
(b) at least 70 percent of the thermal energy produced during pyrolysis must be effectively utilized [11] (accounting for losses in heat transfer) so that both energy recovery and biochar production are achieved [12] ; (c) pollution-control measures, such as a thermal oxidizer or equivalent emission-control systems, must be in place and must comply with applicable local, national, or international emission limits [13]; and (d) the production temperature must be continuously measured and documented.

If any of these criteria are not fulfilled, the facility is classified as a low-technology production site.

Long-lived biochar products

Long-lived biochar products refer to carbon storage resulting from non-soil applications of biochar, in cases where the project proponent can substantiate, with evidence from peer-reviewed literature, that the average lifespan corresponds to the average number of years the product remains in use. The proponent must further demonstrate that the biochar embedded in such non-soil applications is not subject to combustion at the end of the product's life cycle.

Low technology production site

Low technology production site refers to a site that does not satisfy all the criteria outlined under the definition of a high technology production site.

Organic carbon concentration

Organic carbon concentration refers to the proportion of organic carbon that is permanently stored in the biochar, expressed as a percentage of the biochar's mass on a dry matter basis.

Overstocked forest

Overstocked forest refers to a condition in which an excessive number of stems of a given species and size class results in intense competition for growth resources, thereby inhibiting tree growth, inducing physiological stress, and increasing susceptibility to insect infestations, disease, and wildfire-related mortality (Helms, 1998).

[10] available at https://www.european-biochar.org/en/ct/2-EBC-guidelines-documents.
[11] The 70% value is adapted from the EBC Production Guidelines.
[12] As an example, proof of this energy utilization requirement shall be demonstrated by calculating the lower heating value of the feedstock and the amount of biochar produced (adapted from the EBC Production Guidelines).
[13] In case of overlapping standards, the strictest regulations shall be fulfilled.

Pyrolysis

Pyrolysis refers to the thermochemical decomposition of Biomass material or compounds under inert conditions in an oxygen-deficient environment (oxidants are excluded).

Verified Carbon Unit

Verified Carbon Unit (VCU) refers to a carbon credit issued under the Verified Carbon Standard, with each VCU representing one tonne of CO_2 equivalent (tCO_2e) reduced or removed, verified to be real, additional, permanent, and not double-counted.

Waste biomass

Waste biomass refers to biomass materials, by-products, residues, and waste flows originating from agriculture, forestry, associated industries, the circular economy, and animal manures, together with all additional categories specified in Table 1. Any biomass residue that satisfies the feedstock eligibility conditions set forth in this methodology is considered suitable for biochar production and must comply with the defined sustainable feedstock criteria (see Section 6).

6 APPLICABILITY CONDITIONS

The proposed initiative entails the establishment and operation of a newly constructed biochar production site. The implementing entity is responsible for securing appropriate waste biomass, converting it into biochar through thermochemical processes, and ensuring that the resulting material is applied in qualified soil or non-soil contexts. Notably, GHG mitigation benefits will be recognized solely for the portion of biochar demonstrably utilized in approved end-use applications.

Technological Scope and Applicability Conditions

The project activities must satisfy the following technological criteria:

1. This methodology applies in cases where biochar is derived from qualified waste biomass through approved thermochemical conversion techniques, including pyrolysis, gasification, or the utilisation of biomass boilers[14]. The resulting biochar must subsequently be used in a recognised end-use context—either as a soil amendment or in non-soil applications. It is important to note that production methods such as torrefaction and hydrothermal carbonisation are explicitly excluded from the scope of this methodology[15].
2. The methodology accommodates biochar production across a spectrum of technological settings, encompassing both basic and advanced facilities, as categorised in Section 5 of this methodology. Variability in technological complexity does not affect eligibility, provided other requirements are met.
3. All production sites must implement a comprehensive health and safety protocol that safeguards workers from airborne particulates and other occupational risks associated with thermochemical processing

Eligible Feedstocks and Production Criteria

To qualify for use in biochar production under this framework, feedstocks must satisfy all of the following eligibility conditions:

1. The material must consist solely of biogenic waste biomass, and must not originate from crops cultivated specifically for biochar generation.
2. In the absence of the project, the biomass would otherwise have undergone natural decomposition or been openly burned for non-energy-related purposes.
3. The biomass must be sourced domestically and must not involve transboundary imports.16
4. The feedstock must comply with the sustainability criteria outlined in Table 1, which, while not Comprehensive, offers representative examples of acceptable biomass types.

[14] For the purpose of this methodology, the terms pyrolysis, gasification, and biomass boilers are used interchangeably.
[15] Both processes are excluded because they do not generate solid products that are significantly more persistent in soil than the original feedstock (Woolf et al., 2021).
[16] The methodology discourages transportation of waste biomass over long distances, especially among countries and between continents.

Table 3 outlines the classification of feedstock sources, the associated sustainability requirements applicable to each category, and provides illustrative — though not Comprehensive — examples of feedstocks considered acceptable within the scope of this methodology.

Table 3: List of Eligible Feedstocks for Biochar Production

Feedstock Sourcing Categories	Sustainability Criteria	Waste Biomass Illustrations (Not Comprehensive)
Agricultural waste biomass	a) When project proponents obtain agricultural waste biomass directly from fields—rather than from centralized biomass-processing facilities (e.g., food processing plants)—they must supply evidence showing that the project activity does **not** lead to a decline in soil carbon stocks or a reduction in crop yields, or that under the baseline scenario the agricultural residues would have been openly burned without energy recovery (for example, stubble burning). • Prunings derived from trees, vines, and shrubs • Agricultural harvest residues, such as straw, leaves, stalks, husks, pomace, and kernels • Residual materials from fruits and vegetables b) In the absence of supporting documentation, the removal of these feedstocks must be restricted to no more than 50% of the total residues in order to avoid soil degradation (Andrew, 2006; Battaglia et al., 2020).	a) Prunings from trees, vines, and shrubs b) Agricultural harvest residues, including straw, leaves, stalks, husks, pomace, and kernels c) Residual matter from fruits and vegetables
Food processing co-products	c) Residues must originate from food processing facilities. d) The amount of residues produced per unit of site output must not have been increased specifically for the purpose of biochar production.	a) By-products from washing, cleansing, peeling, centrifuging, and separation operations b) Residual matter from expired food products c) Processing residues from the food industry (e.g., fruit pulp, vegetable peels, grain husks, spent hops)
Forestry and wood processing	a) Wood-derived feedstock sourced directly from forests—as opposed to residues from mill operations—must	a) Processed timber intended for soil applications must not contain paint residues, solvents, or any chemical

	provide evidence that the biomass is harvested sustainably and does not contribute to deforestation or land degradation. Acceptable forms of verification include: approved sustainable forest management plans issued by competent state or regional authorities; recognized forest certification schemes such as the Programme for the Endorsement of Forest Certification (PEFC) or the Forest Stewardship Council (FSC); or compliance with the criteria for renewable biomass as outlined under the Clean Development Mechanism (CDM). (EB23 Annex 18). 17 b) For health and safety reasons, processed timber intended for use as feedstock in soil applications must be free from paint residues, solvents, and any other contaminants, including potentially toxic impurities (EBC, 2022; Hedley et al., 2020).	contaminants—such as wood preservatives or glues—to ensure compliance with health and safety standards. b) Trimmings, sawdust, and other secondary outputs derived from forest management or timber harvesting operations. c) By-products from forest-based industries, such as wood shavings from furniture manufacturing or residuals from the production of composite wood products. d) Biomass generated from thinning activities aimed at wildfire risk reduction or from areas officially designated by government agencies as overstocked. e) Woody material derived from the pruning or thinning of non-commercial vegetation, including shade trees, orchards, windbreaks, riparian buffers, silvopasture systems, or invasive species removal in rangelands. f) Diseased trees felled during routine plantation or woodland management activities. g) h) Burned woody biomass, along with post-consumer waste paper and cardboard.
Recycling economy	a) The feedstock used must adhere to the most recent applicable material standards or guidelines, ensuring that levels of heavy metals and other contaminants remain within the defined acceptable thresholds for the specific project context. (i.e., *IBI Biochar Testing Guidelines* or *EBC Production Guidelines*). The biomass is the non-fossil fraction of industrial or municipal waste (CDM *EB23 Annex 18*).	a) Landscape maintenance residues from public parks, golf courses, or roadside vegetation management, provided they are non-hazardous. b) Organic residues from food and beverage processing industries, such as fruit pulp or brewery spent grains. c) Sludge generated from the processing of agricultural biomass, such as effluent solids from sugarcane ethanol or palm oil mills.
Aquaculture plants	a) Only waste materials originating as by-products of aquaculture are	a) Seaweed, algae waste products, aquatic invasive species (Plantae

[17] available at: https://cdm.unfccc.int/EB/023/eb23_repan18.pdf

	eligible. b) To qualify as feedstock for biochar production, project proponents must provide evidence that invasive species waste—such as *Eichhornia crassipes* (water hyacinth)—was not intentionally introduced.	kingdom only)
Animal manure	a) Waste must originate from animal husbandry by-products.	a) Waste from sheep, duck, goose, and dairy cattle farms
High-carbon fly ash from biomass	a) The proportion of HCFA must not exceed 5% of the total annual volume of waste biomass processed by the bioenergy site. b) Project developers are required to demonstrate that a technology classified as "affirmative" was employed to recover biochar before the complete combustion of the biomass stream. c) Project developers must show that no fossil fuels were used to compensate for the calorific loss resulting from diverting biomass to the biochar production process. The final material meets the *IBI Biochar Testing Guidelines*[18].	d) By-products of cogeneration facilities

a) Biochar produced from either a single or a combination of approved feedstocks shall conform to the most recent standards set out in the IBI Biochar Testing Guidelines or the EBC Production Guidelines.
b) The transportation of biomass residues intended for conversion into biochar, as well as the distribution of the resulting biochar to its end-use sites—whether for soil enhancement or alternative applications—may utilize maritime or off-road transport methods, provided the journey does not exceed a cumulative distance of 200 kilometers. Should the required transport distance exceed this limit, road-based transportation methods must be used, consistent with established carbon accounting transport protocols under CDM *Tool 12: Project and leakage emissions from transportation of freight*.
c) Mineral-based additives, such as lime, rock-derived minerals, or combustion ashes, may be blended into the biochar formulation, provided their combined contribution does not exceed 10% of the total dry weight. If the additive content surpasses this threshold, the biochar producer is required to provide laboratory validation demonstrating that the final material conforms to internationally recognized biochar quality standards, such as those outlined by

[18] Section 5.8 of the IBI Biochar Standard v2.1. Available at: https://biochar-international.org/wp-content/uploads/2020/06/IBI_Biochar_Standards_V2.1_Final2.pdf

the *International Biochar Initiative (IBI)*, *Biochar Testing Guidelines* or *EBC Production Guidelines* thresholds for organic and inorganic contaminants.

Eligible biochar end-use application criteria

a) To maintain the long-term integrity of carbon stored in biochar, it must be utilized within one year of its production. Given that biochar is gradually prone to degradation, its climate benefits are assessed based on a 100-year carbon storage horizon. To ensure this durability, the application—whether for soil enrichment or other uses—must not be delayed beyond 12 months from the date of manufacture.

   Biochar can be deployed across a range of land categories, with the exception of wetlands. Permissible sites include croplands, grasslands, forests, and vegetated urban areas. Application may occur either on the soil surface or be incorporated into the subsurface:

   - For surface application, biochar is recommended to be combined with organic materials such as compost, livestock manure, or residues from anaerobic digestion.
   - For subsurface application, biochar may be incorporated directly into the soil or blended with appropriate soil conditioners.

   In all cases where biochar is introduced into soil systems, the following criteria must be met:

   - The biochar must meet recognized environmental and safety specifications, ensuring the absence of harmful substances like heavy metals or organic contaminants. Project developers are responsible for demonstrating compliance with established testing protocols, such as those issued by international bodies (e.g., IBI, EBC)[19] or national authorities.
   - The molar ratio of hydrogen to organic carbon (H:Corg) in the biochar must not exceed 0.7, which serves as an indicator of chemical stability and its suitability for long-term carbon storage in soils.

b) Biochar can also be incorporated into durable, non-agricultural materials such as concrete, asphalt, or other products that offer long-lasting carbon retention. However, this is limited to biochar produced in facilities that meet advanced production standards, as defined by relevant technical guidelines.

c) Developers must provide robust documentation supporting the stability and persistence of biochar or the products in which it is embedded. Acceptable forms of evidence include laboratory testing results, peer-reviewed research, or third-party evaluations assessing material longevity. This documentation must clearly specify the anticipated lifespan of the final product and verify that it conforms to applicable technical and performance standards at the national or international level.

[19] available at: https://www.european-biochar.org/media/doc/2/version_en_9_4.pdf

This methodology is not applicable under the following conditions

a) This methodology does not cover projects that involve using biochar as an energy source—such as fuel replacements for charcoal or coke—or in applications where its long-term carbon retention cannot be reliably verified.
b) Projects should avoid deploying biochar in scenarios where a significant portion is likely to be oxidized or combusted, especially in industrial settings with high fossil fuel dependency.
c) Non-soil applications of biochar that lead to substantial carbon loss—specifically where more than 50% of the original carbon content (dry weight basis) is degraded—will not be considered eligible. This includes certain activated carbon production processes that consume high amounts of fossil energy and compromise carbon stability.

7 PROJECT BOUNDARY

The spatial scope of the process (Figure 1) covers the following geographic areas:

1. the source of the initial waste biomass;
2. the processing of the waste biomass by chemical technology from the biochar production area;
3. the application of biochar in soil or non-soil applications.

Figure 1: Project Boundary

The Greenhouse Gases(GHGs) included in or excluded from the project boundary are shown in Table 4 below.

Table 4: GHG Sources Within and Outside the Project Boundary

Source		Justification/Explanation	Gas	Included?
Baseline	Feedstock production	Excluded, as waste biomass is classified as a renewable material under the defined eligibility criteria.	CO_2	×
			CH_4	×
			N_2O	×
	Feedstock transportation	Only CO_2 considered, in line with CDM Tool 12.	CO_2	○
		Negligible when distance is under 200 km.	CH_4	×
			N_2O	×
	Combustion, aerobic and anaerobic	Deprived of the project, any GHG emissions potentially resulting from the natural	CO_2	×
			CH_4	×

	decomposition of feedstocks	decomposition or uncontrolled burning of biomass are not included in the baseline. To ensure a conservative approach, baseline emissions are set to zero.	N_2O	×
Project	Feedstock production	Purpose-grown harvests are not eligible, so no feedstock production emissions apply. Waste biomass is deemed renewable under the CDM definition (EB23 Annex 18; see Table 1).	CO_2	×
			CH_4	×
			N_2O	×
	Pyrolysis, or thermochemical conversion (high technology systems)	High-technology systems must include pollution controls (preventing GHG emissions) and meet the required technology criteria.	CO_2	×
			CH_4	×
			N_2O	×
	Pyrolysis, or thermochemical conversion (low technology systems)	Low-technology systems use a default emission value derived from Cornelissen et al. (2016).	CO_2	×
			CH_4	○
			N_2O	×
	Electricity or fossil fuels used in the eligible thermochemical process	Included: emissions directly linked to the project activity.	CO_2	○
		Excluded under CDM Tool 03 and Tool 05.	CH_4	×
			N_2O	×
	Biochar transportation	Only CO_2 considered, in line with CDM Tool 12..	CO_2	○
		Negligible if within 200 km.	CH_4	×
			N_2O	×
	Pre-treatment of Feedstocks (e.g., grinding, drying)	Included: emissions directly associated with project activity.	CO_2	○
		Excluded under CDM Tool 03 and Tool 05.	CH_4	×
			N_2O	×
	Biochar application (e.g., preparation of biochar for final use)	Included: emissions directly associated with project activity.	CO_2	○
		Excluded under CDM Tool 03 and Tool 05.	CH_4	×
			N_2O	×

7.1 Temporal Boundaries

The project time horizon defines the period of time for monitoring, quantification and accounting of GHG emissions and removals. For projects that meet the biodiversity and climate targets under the Satoyama Initiative and the Kunming-Montreal Global Biodiversity Framework, the time horizon must be clearly defined to ensure environmental integrity and consistency of reporting.

The program start date is the date when the first verifiable GHG reduction or removal is achieved from the implementation of the activity, such as the initial production of biochar, land rewetting, or the start of ecosystem restoration work.

The accounting period is the duration over which GHG benefits from the qualifying activity can be accounted for and reported. Renewable or fixed periods (e.g. 10-30 years) may be selected depending on the nature of the activity and the durability requirements. Long-term plans must include monitoring of post-implementation impacts to capture reversals and ensure durability.

In all cases, the selected time horizon must be consistent with the monitoring approach and meet the requirements of the relevant voluntary or compliance carbon standard. It should also be consistent with the timescale used in the biodiversity framework

7.2 Geographic Boundaries

This methodology applies globally across all agricultural regions worldwide.

7.3 Carbon Pools

What are Carbon Pools?[20]

> Carbon pools are the places that can accumulate, store, and release carbon. The quantity of carbon in a pool at a specified time is called carbon stock and is measured in gigaton (GtC), where one gigaton equals one billion tonnes.
>
> Carbon fluxes are the processes that move carbon from one pool to another. A carbon pool acts as a sink if the amount of carbon accumulates more than released within a given period. The process by which carbon increases in a pool is called carbon sequestration.
>
> Carbon pools are stored in four major areas: Earth's crustal sedimentary rocks, oceans, terrestrial ecosystems, and the atmosphere. This article only describes terrestrial ecosystems.

[20] available at https://cid-inc.com/blog/how-scientists-measure-terrestrial-carbon-pools/

Terrestrial Carbon Pools[21]

The organic matter that makes up terrestrial carbon pools can be living matter like plants, animals, and microorganisms. Or dead matter like litter, decomposing animals, plants, and microbes in the soil, and harvested wood.
Thus the terrestrial carbon pool has two main components: aboveground and belowground or soil components. Forests, pastures, wetlands, and croplands are the major terrestrial carbon pools.

7.4 Sources of Greenhouse Gases (GHGs)

Agricultural cash crop areas are the production bases of food and cash crops, and agricultural activities are also one of the important sources of GHGs emissions.

Depending on different planting methods, crop varieties and management models, these areas will produce different types of GHGs, including carbon dioxide (CO2), oxygen (CH_4) and nitrous oxide (N2O).

Intensive farming characteristics, agricultural cash crop areas have high farming intensity, frequent fertilizer and water use, and high GHG emission intensity.

Table 5: Agricultural cash crop Sources of Greenhouse Gases (GHGs)

Gas	Primary Source
CO_2	• Soil disturbance and tillage: turning over and tilling promotes the decomposition of soil organic matter and releases CO_2. • Fuel use of agricultural machinery and irrigation equipment: such as tractors, water pumps and transport equipment. • Land use change: such as converting forest or fallow land into intensively managed orchards or vegetable fields. • Potential hotspots: Vegetable fields with frequent annual land preparation, large-scale orchard management areas.
CH_4	• Flooded rice fields: Under the oxygen-deficient water layer, soil microorganisms decompose organic matter to produce methane. • Organic matter application: Returning agricultural waste or livestock manure to the fields will further increase CH_4 emissions. • Potential hotspots: Rice areas cultivated in long-term flooding, especially during the first rice season.
N_2O	• Excessive nitrogen fertilizer application: Excessive or improper application of fertilizers such as urea and ammonium nitrate. • Alternating wet and dry soil conditions: easily stimulate nitrification and denitrification. • Potential hotspots: Vegetable fields, orchards (such as citrus, guava, mango, etc.), and sugarcane planting areas with high nitrogen fertilizer application.
Other	• indirect emission sources

[21] available at https://cid-inc.com/blog/how-scientists-measure-terrestrial-carbon-pools/

	• Crop residue burning: Burning rice straw, fruit tree prunings or sugarcane leaves releases CO_2, CH_4, N_2O and suspended particles. • Agricultural material manufacturing and transportation: Carbon footprint of production processes such as fertilizers, pesticides and plastic coverings. • Electricity for irrigation and other necessary systems: Especially high-energy groundwater extraction and storage (refrigeration) equipment.

Management behavior can significantly reduce carbon emissions. Good fertilizer management, irrigation methods (such as intermittent irrigation), and crop residue treatment can effectively reduce emissions.

Potential co-benefits can be dealt with in disguise. Through friendly farming and carbon farming strategies, not only can emissions be reduced, but also biodiversity and soil health can be promoted.

Agricultural activities — crop and livestock production — contribute to emissions in a variety of ways:[22]

- Various management practices on agricultural soils can lead to increased availability of nitrogen in the soil and result in emissions of N_2O. Specific activities that contribute to N_2O emissions from agricultural lands include the application of synthetic and organic fertilizers, the growth of nitrogen-fixing crops, the drainage of organic soils, and irrigation practices. Management of agricultural soils accounts for just over half of the GHG emissions from the Agriculture sector. Management of croplands and grasslands can also lead to emissions or sequestration of CO_2). These emissions and removals are included under the Land Use, Land-Use Change, and Forestry sector.
- Livestock, especially ruminants such as cattle, produce methane CH_4 as part of their normal digestive processes. This process is called enteric fermentation, and it represents over a quarter of the GHG emissions from the Agriculture sector.
- The way in which manure from livestock is managed also contributes to CH_4 and N_2O emissions. Different manure treatment and storage methods affect how much of these GHGs are produced. Manure management accounts for about 14% of the total GHG emissions from the Agriculture sector in the United States.
- Smaller sources of agricultural emissions include CO_2 from liming and urea application, CH_4 from rice cultivation, and burning crop residues, which produces CH_4 and N_2O.
- More information about emissions from agriculture can be found in the agriculture chapter in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*.[23]

[22] available at: https://www.epa.gov/ghgemissions/agriculture-sector-emissions
[23] available at: https://www.epa.gov/ghgemissions/agriculture-sector-emissions

8 BASELINE SCENARIOS

In the absence of project activities, waste biomass is left to rot or burned for purposes other than energy production.

8.1 Determination of the Most Plausible Baseline Scenario

The project proponent is required to submit reliable documentation demonstrating the baseline scenario for waste biomass. Acceptable forms of evidence may include, but are not limited to, annual government reports, documentation from waste disposal facilities, or records from production sites.

Proponents must provide spatial and temporal data, including:

- Historical land-use patterns (e.g., satellite imagery, aerial photos, or cadastral maps over the past 5–10 years).
- Historical carbon stock data (e.g., default IPCC values, national forest inventory, or peer-reviewed sources).
- Socio-economic data at regional or local level to demonstrate existing baseline practices and barriers to improved waste treatment.

8.2 Reassessment of the Baseline Scenario

If records are not available, the project proponent must rely on existing literature, regional survey data from comparable industries, or carry out a new survey to obtain the necessary information.

9 ADDITIONALITY

Project developers must complete the following step to confirm eligibility:

- **Legal Requirements**

The project must prove it goes beyond what is required by current regulations. This includes demonstrating that no laws or mandates require the implementation of the biochar-related activities.

10 QUANTIFICATION OF GREENHOUSE GAS EMISSION REDUCTIONS AND REMOVALS

This paragraph references VM0044 METHODOLOGY FOR BIOCHAR UTILIZATION IN SOIL AND NON-SOIL APPLICATIONS and Biochar Standards, and has been modified and rewritten in this article. [24][25]

Biochar can be derived from diverse feedstocks and produced through different technological methods. Life cycle assessment LCA studies show that its climate-mitigation benefits vary widely depending on multiple factors. For example, if fossil fuels such as diesel, gasoline, or propane are used for feedstock cutting, grinding, transport, or drying, the GHG benefits of both soil and non-soil biochar applications may be greatly reduced or even nullified (Hedley et al., 2020; Puettmann et al., 2017; Sahoo et al., 2021).

Biochar production technologies vary widely, resulting in different emission profiles that can include carbon dioxide (CO_2), methane (CH_4), and black carbon (soot). The carbon in biomass is part of the active natural carbon cycle and is generally considered carbon neutral, as the CO_2 released during production was recently absorbed from the atmosphere via photosynthesis. However, methane and soot have much higher global warming potentials than CO_2 (Amonette et al., 2021).

High technology production systems typically incorporate post-pyrolysis combustion techniques, such as routing exhaust gases through afterburners to control emissions, re-injecting gases into the system to boost efficiency, or utilizing surplus heat for electricity generation or other productive uses (refer to Section 5 for full definitions and eligibility criteria).

In contrast, low technology systems lack such advanced controls but must demonstrate their capacity to minimize CH_4 and soot emissions. Examples include systems that create a combustion zone above the pyrolysis zone using natural convection. This setup helps reduce excessive methane emissions, especially during startup and shutdown, which could otherwise undermine the long-term carbon sequestration benefits of biochar.

The GHG benefits of biochar may be enhanced if the syngas or bio-oil produced during pyrolysis displaces fossil-based energy sources like coal. However, if fossil fuels such as diesel or propane are consumed in the production process, these benefits could be offset. Moreover, the methodology excludes feedstocks and technologies that pose risks to human health or environmental quality, or cause soil contamination.

While most biochar is applied to soil, its non-soil applications—such as in asphalt or concrete—are becoming more prevalent. Thus, the total GHG impact of biochar depends not only on the feedstock

[24] available at: https://biochar-international.org/standard-certification-training/biochar-standards/
[25] VM0044 METHODOLOGY FOR BIOCHAR UTILIZATION IN SOIL AND NON-SOIL APPLICATIONS

and production method, but also on the fossil fuel inputs required for pre- and post-treatment stages, including electricity.

Due to the complexity and variability of biochar-related GHG accounting, existing certification programs like the European Biochar Certificate (EBC), along with this methodology, place restrictions on eligible feedstock types, technologies, and end-use products.

This methodology provides a comprehensive, scientifically robust, and verifiable framework for quantifying net GHG removals across the biochar lifecycle, including biomass sourcing, production, and application. Emissions are assessed based on annual fluxes of CO_2, CH_4, and N_2O, expressed in tonnes of CO_2 equivalent (CO_2e).

To allow for future inclusion of additional feedstocks and uses, the GHG accounting approach is designed as a flexible framework, enabling a comprehensive estimation of climate impacts across the entire biochar value chain. It covers:

- The sourcing stage, where waste biomass is obtained and collected;
- The production stage, where the biomass is prepared (if needed) and thermochemically converted into biochar; and
- The application stage, where the biochar is placed in a long-term end use (either in soils or in approved non-soil applications).

10.1 Baseline Emissions

10.1.1 Sourcing Stage

The baseline scenario refers to the situation in which, without the project activity, waste biomass within the project boundary in the year of biochar production would either be left to decompose or used for purposes other than energy generation.

In line with the CDM EB23 Annex 18 definition of renewable biomass, such waste biomass is categorized as recycled material. Because decay pathways for different feedstock types vary by region and over time, this methodology conservatively defines the default net baseline emission reduction (BESS,y) as zero.

10.1.2 Production Stage

In the baseline scenario for the production stage, no biochar is produced. Consequently, there are no GHG removals or related emissions to be accounted for.

10.1.3 Application Stage

In the baseline scenario for the application stage, no biochar is applied to soil or non-soil uses. Therefore, no GHG removals or related emissions are considered.

10.2 Project Emissions

10.2.1 Sourcing Stage

During the procurement phase, this approach relies on the collection of waste biomass. Therefore, the emissions from the procurement phase ($PE_{SS,y}$) are set to zero.

10.2.2 Production Stage

In the project scenario, the net GHG balance is determined by the organic carbon concentration during the biochar production phase. Equation 1 outlines the carbon balance for this phase by comparing the stable carbon retained in the biochar against emissions from feedstock pretreatment (where applicable) and from converting waste biomass into biochar. Emissions from feedstock drying and pretreatment energy use are included in the former, while the latter covers all other emissions associated with the production site. The resulting project-related emission removals during the biochar production process are as follows:

$$ER_{PS,y} = \sum_{t}\left(\left(\sum_{k} OCC_{t,k,y} \times Ef_c\right) - \left(\sum_{p} PE_{PS,t,p,y}\right)\right) \quad (1)$$

Where:

$ER_{PS,y}$ = Greenhouse gas (GHG) removals at production stage in year *y* (tCO_2e)

$OCC_{t,k,y}$ = Organic carbon concentration on a dry matter basis for biochar type *t* used for application type *k* in year *y* (tonnes)

$PE_{PS,t,p,y}$ = Production phase project emissions of production site *p* producing type t biochar in year *y* (tCO_2e)

Ef_c = CO_2 Emission factor, 44/12 is the conversion coefficient of carbon into CO_2, which means the relative atomic weight of CO_2/C, Coefficient to convert organic carbon to tCO_2e

Because production facilities and technologies differ in their ability to measure and report key parameters, this methodology offers two approaches—low-technology and high-technology—for determining the relevant parameters based on the specific characteristics of the production site. Furthermore, as the use of the produced biochar may vary between soil and non-soil applications, the differing decay rates associated with each application type must also be considered.

10.2.3 Option P.1: High Technology Production Site

The definition of high-technology production facilities is provided in Section 5. If any of the specified conditions are not fulfilled, the production site must be immediately classified as a low-technology facility.

For all high-technology facilities, the organic carbon concentration of the produced biochar must be determined through material analysis conducted by accredited laboratories using standardized procedures. Project proponents are required to determine the organic carbon concentration on a dry matter basis in accordance with the methods set out in the latest version of the *IBI Biochar Testing Guidelines* or *EBC Production Guidelines* or other internationally/nationally accredited standards.

Step 1: Estimate Organic carbon concentration ($OCC_{t,k,y}$) of biochar for high technology facilities

The total organic carbon concentration of the produced biochar serves as the basis for GHG calculations. This value is determined from the mass of biochar, its measured organic carbon concentration, and the decay rate of the biochar's organic carbon over a 100-year period (reflecting a 100-year permanence value aligned with the 100-year global warming potential horizon).

This methodology provides a predefined decay factor for biochar applied to soils. If a project proponent produces biochar for approved non-soil applications, they must either supply a verified persistence factor or apply a conservative predefined value (i.e., the soil decay factor).

The total organic carbon concentration on a dry-matter basis attributable to the project activity is calculated as follows:

$$OCC_{t,k,y} = \sum_{p} \left(M_{t,k,p,y} \times F_{Cp,t,p} \times PR_{de,k} \right) \quad (2)$$

Where:

$OCC_{t,k,y}$ = The organic carbon concentration (in tonnes) on a dry matter basis for biochar type *t*, applied under usage type *k* in year *y*. The classification of biochar type depends on the type of feedstock used to produce it.

$M_{t,k,p,y}$ = Dry matter mass of biochar of type *t* and application type *k* produced by production site *p* in year *y* (tonnes).

$F_{Cp,t,p}$ = On a dry weight basis, the organic carbon concentration (percent) per tonne of biochar type *t*, produced at site *p*. For high technology production facilities, this value is determined through laboratory analysis of the biochar material.

$PR_{de,k}$ = Permanence adjustment factor due to decay of biochar per application type *k* (dimensionless) $PR_{de,k}$ must be established for soil or non-soil end-use as follows:

- Soil end-use: See Table 3 which draws from IPCC (2019) and Woolf *et al*. (2021) and uses production temperatures Tprod to determine conservative defaults for $PR_{de,k}$.

Table 6：Default Values for PRde,k from Table 4 AP.2 of IPCC (2019)[26]

Temperature	Default Value
High temperature pyrolysis and gasification (> 600 °C)	$0.89 \pm 13\%$
Medium temperature pyrolysis (450 – 600°C)	$0.80 \pm 11\%$
Low temperature (350 – 450 °C)	$0.65 \pm 15\%$

- Non-soil end-use: If there is no solid scientific data on the permanence of organic carbon concentration, project proponents must apply the soil application decay factor listed in Table 3. However, they can suggest a different value for $PR_{de,k}$ instead, provided they offer at least one form of supporting evidence, as outlined under the default factor rules of the most recent SEPLS-CCRR methodology requirements. If scientific sources give different values for $PR_{de,k}$, the lowest one must be used to maintain a conservative approach. Note that materials like white papers or unpublished studies are not accepted as valid evidence.

Step 2: Estimate project emissions ($PE_{PS,p,y}$) for high technology production facilities

The emissions under the project scenario are determined by the following formula:

$$PE_{PS,p,y} = \left(P_{ED,p,y} + P_{EP,p,y} + P_{EC,p,y}\right) \times \frac{\sum_t \sum_k M_{t,k,p,y}}{M_{p,y}} \quad (3)$$

Where:

$PE_{PS,p,y}$ = Emissions generated during the production stage of biochar at site *p* in year *y*, measured in tonnes of CO_2 equivalent (tCO_2e).

$P_{ED,p,y}$ = Greenhouse gas (GHG) emissions resulting from the pre-treatment of waste biomass at production site *p* during year *y*, expressed in tonnes of CO_2 equivalent (tCO_2e).

$P_{EP,p,y}$ = Emissions associated with the conversion of waste biomass into biochar at production site *p* in year *y* (tCO_2e)

$P_{EC,p,y}$ = Emissions due to the utilization of auxiliary energy for the purpose of pyrolysis at production site *p* in year *y* (tCO_2e)

$M_{t,k,p,y}$ = Mass on a of biochar type *t* for application type *k* produced at production site *p* in year *y* (tonnes)

$M_{p,y}$ = Total mass of biochar on a dry matter basis produced in production site *p* in year *y* (tonnes)

Determining $P_{ED,p,y}$: Emissions associated with pre-treatment of feedstock at production site p in year y

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

Any energy consumed for the required pre-treatment of waste biomass must be factored into the calculation. This includes activities such as feedstock preparation (e.g., agglomeration, homogenization, or pelletizing) performed either at the production facility or in the field, as well as drying of wet waste biomass and other related processes. When the energy used is sourced from renewables, PED,p,y is set to zero; otherwise, it shall be calculated as follows:

$$P_{ED,p,y} = P_{EDE,p,y} + P_{EDF,p,y} \quad (4)$$

Where:

$P_{ED,p,y}$ = Emissions associated with pre-treatment of feedstock at production site *p* in year *y* (tCO_2e)

$P_{EDE,p,y}$ = Emissions resulting from the use of grid-connected electricity for pre-treating waste biomass at production site *p* during year *y*, measured in tonnes of CO_2 equivalent (tCO_2e). The value of $P_{EDE,p,y}$ must be calculated according to the guidelines set out in CDM Tool 05: *Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation*[27].

$P_{EDF,p,y}$ = Emissions associated with combustion of fossil fuels utilized for pre-treatment of waste biomass at production site *p* in year *y* (tCO_2e). PEDF,p,y must be calculated as per the provisions of CDM *Tool 03: Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion.* [28]

Determination of $P_{EP,p,y}$ refers to the emissions generated from the thermochemical process carried out at production site *p* during year *y*, specifically for facilities classified as high technology.

The processing of waste biomass refers to pyrolysis, a method that converts the organic carbon in biomass into stable carbon stored in biochar. The emissions released into the atmosphere during this pyrolysis process are represented by $P_{EP,p,y}$. Under the eligibility criteria for high technology production facilities, these net emissions are regarded as negligible, or de minimis. [29] Therefore,

$$P_{ED,p,y} = 0$$

Where:

$P_{EP,p,y}$ = Emissions associated with the conversion of waste biomass into biochar at production site *p* in year *y* (tCO_2e)

[27] available at https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-05-v3.0.pdf
[28] available at https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-03-v3.pdf
[29] Following condition (a) of the definition of a high technology production site, the ability to combust or recover pyrolysis gases, thereby limiting the emissions of methane to the atmosphere.

Determining $P_{EC,p,y}$: Emissions due to the utilization of auxiliary energy for the purpose of pyrolysis at production site p in year y

When external energy is needed to start and maintain the pyrolysis reactor, it must be included in the project emissions. If the auxiliary energy is renewable, $P_{EC,p,y}$ must be zero. Otherwise, it must be calculated as follows:

$$P_{EC,p,y} = P_{ECE,p,y} + P_{ECF,p,y} \quad (5)$$

Where:

$P_{EC,p,y}$ = Emissions due to the utilization of auxiliary energy for the purpose of pyrolysis at production site *p* in year *y* (tCO_2e)

$P_{ECE,p,y}$ = Emissions associated with use of grid-connected electricity utilized for starting the reactor at production site *p* in year *y* (tCO_2e). PECE,p,y must be calculated as per CDM *Tool 05: Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation.*

$P_{ECF,p,y}$ = Emissions associated with combustion of fossil fuels utilized for starting the reactor at production site *p* in year *y* (tCO_2e). PECF,p,y must be calculated as per the provisions of CDM *Tool 03: Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion.*

10.2.4 Option P.2: Low Technology Production Site

Lower-technology facilities are generally less efficient at converting organic carbon and often lack emission controls. In some cases, such as smallholder or farm settings, they still contribute to carbon removal through production and use. Any facility that does not meet the high-technology criteria is classified as low-technology.

Step 1: Estimate Organic carbon concentration ($OCC_{t,k,y}$) of biochar for low technology facilities

As in high-technology settings, low-technology settings also base GHG calculations on the total organic carbon concentration of the biochar. This value is determined by the biochar mass, its organic carbon content, and the 100-year decay rate (100-year permanence value).

For low technology production facilities, a conservative approach has been selected, related to the Organic carbon concentration of biochar (F_{Cp}), based on feedstock type and heating temperature as provided in Table 4 which draws from IPCC *Method for Estimating the Change in Mineral Soil Organic Carbon Stocks from Biochar Amendments: Basis for Future Methodological Development.*[30] In Equation 6, permanence (the fraction of carbon in the biochar remaining after 100 years) is included.

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

$$OCC_{t,k,y} = \sum_{p} (M_{t,k,p,y} \times F_{Cp,t,p} \times PR_{de,k}) \quad (6)$$

Where:

$OCC_{t,k,y}$ = Organic carbon concentration on a dry matter basis for biochar type *t* used for application type *k* in year *y* (tonnes). Biochar type is based on the feedstock used to produce the biochar.

$M_{t,k,p,y}$ = Mass on a dry matter basis of biochar type *t* for application type *k* produced at production site *p* in year *y* (tonnes)

$F_{Cp,t,p}$ = Organic carbon concentration of biochar type *t* produced in production site *p* per tonne of biochar, taken on a dry matter basis (percent). For low technology production facilities, this is determined through laboratory material analysis of biochar where possible. Otherwise, values are obtained from Table 4 per type of feedstock. Where feedstocks are mixed, the most conservative value of the relevant feedstocks must be used.

$PR_{de,k}$ = Permanence adjustment factor due to decay of biochar to be defined for application type *k* (dimensionless). Biochar is subject to natural decay rate when used in soil applications such as in agriculture, forests, croplands, or grasslands. Many low technology production facilities do not measure the temperature at biochar production. A default value of 0.56[31] must be used where pyrolysis temperature is unknown. This follows a conservative approach for carbon permanence.

Determining F_{Cp}: Values for Organic carbon concentration per tonne of biochar per production type

The organic carbon concentration must be measured in an accredited laboratory following the *IBI Biochar Testing Guidelines* or *EBC Production Guidelines*. For low-technology facilities, project proponents may instead use values from IPCC (2019) for various feedstocks and production methods (see Table 4), and may also consult other scientific sources such as Woolf et al. (2021).

[31] Value of 0.56 is used where the temperature of pyrolysis is not measured, recorded and reported. Default value taken from Figure 4Ap.1(b) in IPCC (2019) Appendix 4: Method for Estimating the Change in Mineral Soil Organic Carbon Stocks from Biochar Amendments: Basis for Future Methodological Development. Available at https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch02_Ap4_Biochar.pdf

Table 7: Values for Organic carbon concentration in Biochar from Table 4AP.1 of IPCC (2019)[32]

Feedstock	Production Process	Values for FCp
Animal manure	Pyrolysis	$0.38 \pm 49\%$
	Gasification	$0.09 \pm 53\%$
Wood	Pyrolysis	$0.77 \pm 42\%$
	Gasification	$0.52 \pm 52\%$
Herbaceous (grasses, forbs, leaves; excluding rice husks and rice straw)	Pyrolysis	$0.65 \pm 45\%$
	Gasification	$0.28 \pm 50\%$
Rice husks and rice straw	Pyrolysis	$0.49 \pm 41\%$
	Gasification	$0.13 \pm 50\%$
Nut shells, pits, and stones	Pyrolysis	$0.74 \pm 39\%$
	Gasification	$0.40 \pm 52\%$
Biosolids (paper sludge)	Pyrolysis	$0.35 \pm 40\%$
	Gasification	$0.07 \pm 50\%$

Step 2: Estimate project emissions $PE_{PS,p,y}$ for low technology production facilities.

Emissions under the project scenario are determined using the following equation:

$$PE_{PS,p,y} = (P_{ED,p,y} + P_{EP,p,y} + P_{EC,p,y}) \times \frac{\sum_t \sum_k M_{t,k,p,y}}{M_{p,y}} \quad (7)$$

Where:

$PE_{PS,p,y}$ = Project emissions at the production stage at production site *p* in year *y* (tCO_2e)

$P_{ED,p,y}$ = Emissions associated with the pre-treatment of waste biomass at production site *p* in year *y* (tCO_2e)

$P_{EP,p,y}$ = Emissions associated with the conversion of waste biomass into biochar at production site *p* in year *y* (tCO_2e)

$P_{EC,p,y}$ = Emissions due to the utilization of auxiliary energy for the purpose of pyrolysis at production site *p* in year *y* (tCO2e)

Determining $P_{ED,p,y}$: Emissions associated with the pre-treatment of feedstock at production site p in year y for low technology facilities

Energy used for required pre-treatment of waste biomass must be included. This covers feedstock preparation (e.g., agglomeration, homogenization, pelleting), drying of wet biomass, or other processes at the production site or in the field. If the energy source is renewable, PED,p,y is zero; otherwise, calculate as follows:

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

$$P_{ED,p,y} = P_{EDE,p,y} + P_{EDF,p,y} \quad (8)$$

Where:

$P_{ED,p,y}$ = Emissions associated with pre-treatment of feedstock at production site *p* in year *y* (tCO_2e)

$P_{EDE,p,y}$ = Emissions associated with grid-connected electricity utilized for pre-treatment of waste biomass at production site *p* in year *y* (tCO_2e). $P_{EDE,p,y}$ must be calculated as per the provisions of CDM *Tool 05: Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation.*

$P_{EDF,p,y}$ = Emissions associated with combustion of fossil fuels utilized for pre-treatment of waste biomass at production site *p* in year *y* (tCO_2e). $P_{EDF,p,y}$ must be calculated
as per the provisions of CDM *Tool 03: Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion*.

Determining $P_{EP,p,y}$: Emissions associated with the thermochemical process at production site p in year y for low technology facilities

If direct emission measurements are not available or cannot reliably capture project emissions, values from peer-reviewed literature must be applied in the following equation:

$$P_{EP,p,y} = \sum\sum\left(F_e \times GWP_{CH4} \times M_{t,k,p,y}\right) \quad (9)$$

Where:

PEP,p,y = Emissions associated with the conversion of waste biomass into biochar at production site p in year y (tCO_2e)

Fe = Average methane emissions from producing one tonne of biochar in year y (tCH_4/tonne). Values from Table 3 in Cornelissen et al. (2016)[33] may be used based on the corresponding kiln type (i.e., low technology production site type). Where the kiln type is not listed a default average emission factor of 0.049 t CH_4/tonne may be conservatively used based on the value for traditional kilns since simple low-cost technologies are known to emit higher levels of CH_4.[34] Project proponent may propose more appropriate values based on scientific studies, research papers or any other credible documentation and/or information related to the utilized production technology.

GWP_{CH4} = Global warming potential of methane. Use value referenced in the latest version

[33] Cornelissen, G., Pandit, N. R., Taylor, P., Pandit, B. H., Sparrevik, M., & Schmidt, H. P. (2016). Emissions and char quality of flame curtain "kon tiki" kilns for farmer-scale charcoal/biochar production. PLoS ONE, 11(5), e0154617. https://doi.org/10.1371/journal.pone.0154617

[34] Woolf, D., Lehmann, J., Ogle, S., Kishimoto-Mo, A. W., McConkey, B., & Baldock, J. (2021). Greenhouse gas inventory model for biochar additions to soil. Environmental Science & Technology, 55(21), 14795-14805.

of the *SEPLS Carbon Credit Regional Revitalization Center Standard*

$M_{t,k,p,y}$ = Mass on a dry matter basis of biochar type t and application type k produced at production site p in year y (tonnes)

Determining $P_{EC,p,y}$: Emissions due to the utilization of auxiliary energy for the purpose of pyrolysis

When external energy is needed to start up or sustain the pyrolysis reactor, it must be counted as project emissions. If this auxiliary energy comes from renewable sources, PEC,p,y is zero; otherwise, calculate as follows:

$$P_{EC,p,y} = P_{ECE,p,y} + P_{ECF,p,y} \quad (10)$$

Where:

$P_{EC,p,y}$ = Emissions due to the utilization of auxiliary energy for the purpose of pyrolysis at production site p in year y (tCO_2e)

$P_{ECE,p,y}$ = Emissions associated with use of grid-connected electricity utilized for starting the reactor at production site p in year y (tCO_2e). PECE,p,y must be calculated as per CDM *Tool 05: Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation.*

$P_{ECF,p,y}$ = Emissions associated with combustion of fossil fuels utilized for starting the reactor at production site p in year y (tCO_2e). PECF,p,y must be calculated as per the provisions of CDM *Tool 03: Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion.*

10.2.5 Application Stage

In this scenario, emissions from post-production processing of biochar can affect the overall emission-removal potential. Equation 11 is used to calculate GHG emissions during the application phase.

$$PE_{AS,y} = \sum_{k} \sum_{t} (E_{P,t,k,y} + E_{ap,t,k,y}) \quad (11)$$

Where:

$PE_{AS,y}$ = Greenhouse gas(GHG) emissions at application stage in year y (tCO_2e)

$E_{P,t,k,y}$ = Emissions from processing of biochar type t for application type k in year y (tCO_2e)

$E_{ap,t,k,y}$ = Emissions from utilization of biochar type t for application type k in year y (tCO_2e)

Determining $E_{P,k,y}$: Emissions associated with processing of biochar for application type k

If biochar is further processed (e.g., sizing, grinding, sifting) before its final soil or non-soil application, project proponents must account for energy-related emissions from grinding and other mechanical treatments. This methodology does not include emissions from producing or generating materials mixed with biochar for non-soil applications (e.g., biochar-amended concrete or asphalt).

When the energy source is renewable, $E_{P,k,y}$ is set to zero; otherwise, it must be calculated as follows:

$$E_{P,k,y} = P_{EPE,k,y} + P_{EPF,k,y} \quad (12)$$

Where:

$E_{P,k,y}$ = Emissions from processing of biochar for application type k in year y (tCO_2e)

$P_{EPE,k,y}$ = Emissions associated with grid-connected electricity utilized for processing biochar for application type k in year y (tCO_2e). PEPE,k,y must be calculated as per the provisions of CDM *Tool 05: Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation*.

$P_{EPF,k,y}$ = Emissions associated with combustion of fossil fuels utilized for processing of biochar for application type k in year y (tCO_2e). PEPF,k,y must be calculated as per the provisions of CDM *Tool 03: Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion*.

Where there is no processing of biochar, $E_{P,k,y}$ must be zero.[35]

10.3 Emission reductions due to rewetting and fire management (Fire Reduction Premium)

In agricultural landscapes, rewetting and fire management are important measures to reduce greenhouse gas (GHG) emissions from peatlands and fire-prone ecosystems. When such ecosystems are drained or poorly managed, they can release large amounts of CO_2, CH_4, and N_2O. Rewetting restores the hydrological balance, reducing peat oxidation and carbon loss, while fire management lowers emissions from biomass combustion and peat fires. These measures contribute to overall climate benefits but are not quantitatively accounted for under this methodology.

[35] As per CDM AR-ACM0003 Afforestation and reforestation of lands except wetlands. Available at https://cdm.unfccc.int/methodologies/DB/C9QS5G3CS8FW04MYYXDFOQDPXWM4OE

10.4 Leakage

This methodology requires the assessment of potential leakage emissions associated with biochar project activities. Leakage refers to any increase in GHG emissions outside the project boundary that occurs as a result of the project implementation. In the context of biochar projects, leakage may arise from activity shifting, market dynamics, or other indirect effects. The following subsections describe how leakage is identified and quantified under this methodology.

10.4.1 Activity-shifting leakage and market leakage

Emissions resulting from activity-shifting leakage or biomass diversion are considered zero, since under this methodology only waste biomass is eligible for biochar production and no alternative productive use is displaced.

In the context of biochar use, potential leakage is primarily associated with the market dynamics of transportation throughout the biochar life cycle. This includes the movement of waste biomass from its point of origin to the production site, as well as the distribution of produced biochar to end-use locations. Such transport activities are treated as part of market leakage, as they arise from logistical requirements rather than changes in land management or feedstock sourcing.

For biochar projects, leakage emissions are quantified as follows:

$$LE_y = LE_{as,y} + LE_{bd,y} + LE_{ts,y} + LE_{tap,y} \quad (13)$$

Where:

LE_y = Total leakage emissions in year y (tCO_2e)

$LE_{as,y}$ = Leakage due to activity shift in year y (tCO_2e). Leakage due to activity shift is zero as use of purposely-grown biomass for production of biochar is currently not allowed.

$LE_{bd,y}$ = Leakage due to biomass diversion in year y (tCO_2e). Leakage due to biomass (waste/residue) diversion is considered negligible since only biomass which would have been combusted or left to decay is utilized for biochar production.

$LE_{ts,y}$ = Leakage emissions from transportation of waste biomass from sourcing to biochar production site in year y (tCO_2e). As per CDM Tool 16: Project and leakage emissions from biomass,[36] GHG emissions must be accounted for only if transportation distance is more than 200 km. Project proponent must use CDM Tool 12: Project and leakage emissions from transportation of freight[37] to calculate $LE_{ts,y}$

$LE_{tap,y}$ = Leakage emissions from transportation of biochar from the production site to the site of end application in year y (tCO_2e). As per CDM Tool 16: Project and leakage emissions from biomass, GHG emissions must be accounted for only if transportation distance is

[36] available at: https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-16-v4.pdf
[37] available at: https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-12-v1.1.0.pdf

more than 200 km. Project proponent must use CDM Tool 12: Project *and leakage emissions from transportation of freight* to calculate $LE_{tap,y}$.

Determining $LE_{ts,y}$: Emissions related to leakage from transportation of waste biomass from sourcing to biochar production site

Project emissions from transportation of waste biomass from the place of origin to the biochar production site may have the following components:

Transport emissions from field to the production site

$LE_{ts,y}$ is considered zero if transportation distance (to and from—round trip) is less than 200 km. Project emissions from transportation of biochar must be calculated as per the latest version of CDM Tool 12: Project and leakage emissions from transportation of freight.

Determining $LE_{tap,y}$: Emissions related to leakage from transportation of biochar from production site to site of end-use application

Project emissions from transporting biochar to its final application site may include the following scenarios:

- Emissions from transporting biochar from the production site to a processing site; and
- Emissions from transporting it from the processing site to the end-use location;

or alternatively

- Emissions from direct transport from the biochar site to the end-use site

$LE_{tap,y}$ is considered zero if transportation distance (to and from—round trip) is less than 200 km. Project emissions from transportation of biochar must be calculated as per the latest version of CDM Tool 12: Project and leakage emissions from transportation of freight.

10.4.2 Ecological leakage

No ecological leakage is identified under this methodology. The use of waste biomass does not displace alternative productive uses or trigger indirect land-use change. All eligible feedstocks are residues that would otherwise decay or be openly burned, and the application of biochar in soil or non-soil settings does not induce additional land conversion or resource extraction.

10.5 Net GHG Emission Reductions and Removals

Greenhouse gas (GHG) emission reductions occur when:

a) Carbon stocks decrease from year t to year t + 1 in the baseline scenario and, to a lesser extent, in the project scenario. The cumulative carbon stock change in the project scenario is negative or zero (i.e., the project carbon stock at the end of the verification period is less than or equal to the carbon stock at the project start date).

b) Carbon stocks decrease from year t to year t + 1 in the baseline scenario and carbon stocks increase in the project scenario. Note that this variation may also generate carbon removals.

c) Fossil fuel use in the project is lower than typical baseline practices, but baseline emissions are conservatively set to zero in this methodology.

d) N_2O emissions from biomass burning are lower in the project than in the baseline scenario.

10.5.1 Calculation of net GHG emissions reductions

GHG emission reductions before allocation of leakage emissions are quantified as:

$$ER_y = I(\Delta CO2_{wp}) \times (\Delta CO2_{ff_y} + \Delta CH4_{bb_y} + \Delta N2O_{bb_y} + MIN(0, \Delta CO2_{wp,y}) - MIN(0, \Delta CO2_{bsl,y}) + (1 - I(\Delta CO2_{wp})) \times (\Delta CO2_{ff_y} + \Delta CH4_{bb_y} + \Delta N2O_{bb_y} + MIN(0, \Delta CO2_{wp,y}) - MIN(0, \Delta CO2_{bsl,y}) + MAX(0, \Delta CO2_{wp,y}) - MAX(0, \Delta CO2_{bsl,y})) \quad (14)$$

Where:

$I(\Delta CO_{2wp})$ = 1 if $\sum_1^t \Delta CO_{2wp,y} \geq 0$

$I(\Delta CO_{2wp})$ = 0 if $\sum_1^t \Delta CO_{2wp,y} \leq 0$

$I(\Delta CO_{2wp})$ = Switches on the first part of Equation (14) when the cumulative carbon stock change in the project scenario is positive, and the second part when the carbon stock change is negative

ER_y = Estimated reductions in year y (t CO_2e)

$\Delta CO2_{ff_y}$ = Total GHG emission reductions from fossil fuel combustion in year y (t CO_2e)

$\Delta CH4_{bb_y}$ = Total methane emission reductions from avoided or reduced biomass burning in year y (t CO_2e)

$\Delta N2O_{soil_y}$ = Total nitrous oxide emission reductions from nitrification/denitrification in year y (t CO_2e)

$UNC_{y,N2O_{soil}}$ = Uncertainty deduction in year t when using Quantification Approach 1 to model nitrous oxide emission reductions from nitrification/denitrification (fraction between 0 and 1)

$\Delta N2O_{bb_y}$ = Total nitrous oxide emission reductions from avoided or reduced biomass burning in year y (t CO_2e)

$0, \Delta CO2_{wp,y}$ = Total carbon stock change in the project scenario in year y (t CO_2e)

$\Delta CO2_{wp,y}$= Total carbon stock change in the baseline scenario in year y (t CO_2e)

Net GHG emission reductions are quantified as:

$$ER_{NET,y} = ER_y - LK_{ER,y} \quad (15)$$

Where:

$ER_{NET,y}$ = Estimated net GHG emission reductions in year y (t CO_2e)

$LK_{ER,y}$ = Leakage allocated to GHG emission reductions in year y (tCO_2e)

Leakage allocated to emission reductions ($LK_{ER,y}$) is calculated as:

$$LK_{ER,y} = (LE_{OA,y} + LE_{BR,y}) \times \frac{ER_y}{ER_y + CR_y} \quad (16)$$

Where:

$LE_{BR,y}$ = Leakage emissions from the diversion of manure or crop residues from baseline energy applications in year y (t CO_2e)

CR_y = Estimated carbon dioxide removals in year y (t CO_2e)

Carbon dioxide removals occur when the cumulative carbon stock change in the project scenario is positive (i.e., the project carbon stock is higher than at the project start date). Then, possible annual stock variation includes:

1) Carbon stocks increase from year t to year y + 1 in the baseline scenario and, to a greater extent, in the project scenario.

2) Carbon stocks decrease from year t to year y + 1 in the baseline scenario and carbon stocks increase from year t to year y + 1 in the project scenario.

Carbon dioxide removals are quantified as:

$$CR_y = I(\Delta CO2_{wp}) \times (MAX(0, \Delta CO2_{wp,y}) - MAX(0, \Delta CO2_{bsl,y})) \quad (17)$$

Where:

$I(\Delta CO2_{wp})$ = 1 if $\sum_1^t \Delta CO2_{wp,y} \geq 0$

$I(\Delta CO2_{wp})$ = 0 if $\sum_1^t \Delta CO2_{wp,y} \leq 0$

$I(\Delta CO2_{wp})$ = Switches Equation (20) on when the cumulative carbon stock change in the project scenario is positive, and off when the change is negative

Net carbon dioxide removals are quantified as:

$$CR_{NET,y} = CR_y - LK_{CR,y} \quad (18)$$

Where:

$CR_{NET,y}$ = Estimated net carbon dioxide removals in year y (t CO_2e)

$LK_{CR,y}$ = Leakage allocated to carbon dioxide removals in year y (t CO_2e)

Leakage allocated to carbon dioxide removals ($LK_{CR,y}$) is calculated as:

$$LK_{CR,y} = (LE_{OA,y} + LE_{BR,y}) \times \frac{CR_y}{ER_y + CR_y} \quad (19)$$

Net reductions and removals are quantified as:

$$ERR_{NET,y} = ER_{NET,y} + CR_{NET,y} \quad (20)$$

Where:

$ERR_{NET,y}$ = Estimated net reductions and removals in year y (t CO_2e)

Nitrous oxide emission reductions from nitrification/denitrification are quantified as:

$$\Delta N2O_soil_y = \sum_{i=1}^{y} (\overline{N2O_soil}_{bsl,i,y} - \overline{N2O_soil}_{wp,i,y}) \times A_i \quad (21)$$

Where:

$\overline{N2O_soil}_{bsl,i,y}$ = Areal mean nitrous oxide emissions from nitrogen inputs to soils in the baseline scenario for quantification unit I in year y (t CO_2e/ha)

$\overline{N2O_soil}_{wp,i,y}$ = Areal mean nitrous oxide emissions from nitrogen inputs to soils in the project scenario for quantification unit I in year y (t CO_2e/ha)

Nitrous oxide emission reductions from biomass burning are quantified as:

$$\Delta N2O_bb_y = \sum_{i=1}^{y} (\overline{N2O_bb}_{bsl,i,y} - \overline{N2O_bb}_{wp,i,y}) \times A_i \quad (22)$$

Where:

$\overline{N2O_bb}_{bsl,i,y}$ = Nitrous oxide emissions from biomass burning in the baseline scenario for quantification unit I in year y (t CO_2e/ha)

$\overline{N2O_bb}_{wp,i,y}$ = Nitrous oxide emissions from biomass burning in the project scenario for quantification unit I in year y (t CO_2e/ha)

10.5.2 Estimation of uncertainty

Once biochar has been produced, certain risks may emerge that could result in the release of carbon previously considered securely stored—this is referred to as a reversal. Before the biochar is applied to its intended use, it might be deliberately burned as a fuel, undermining its carbon sequestration value. To eliminate this risk, the methodology mandates that biochar must only be deployed in pre-approved soil or non-soil applications, with proper monitoring of its final use as outlined in the relevant criteria.

Even after its application, biochar remains exposed to potential reversal risks, stemming from both environmental factors and human activity. This methodology addresses such risks with a set of mitigation strategies, described in the following sections.

10.5.2.1 Natural Risks

Soil-applied biochar is vulnerable to a range of natural hazards linked to local weather and terrain, including fire, storm events, and erosion. The most critical concern is wildfire, which can instantaneously eliminate the carbon stored in biochar through burning. In addition, biochar can be carried away by wind or surface water runoff, potentially transporting the material beyond the intended area of application and outside the oversight of the project operator.

Natural hazards that may affect biochar applications—such as fire and erosion—can be effectively minimized by incorporating biochar beneath the soil surface, preferably at depths of 10 cm or more. In cases where biochar is applied on the soil surface instead, the exposure increases susceptibility to wind, water erosion, and combustion.

To address these concerns, biochar should be combined with organic amendments like compost or manure before surface application. This mixture reduces both the flammability and mobility of biochar particles (IBI, 2010). Accordingly, when using surface application methods, it is essential to adhere to guidance that requires such mixtures. Scientific studies have confirmed that these strategies significantly mitigate the risks of loss when biochar is used in soils.

- **Risk of Loss from Fire:**

  Soil responses to fire are strongly influenced by the temperature gradient with depth and the heat tolerance of various soil components (González-Pérez et al., 2004). As fire-induced temperatures drop sharply with increasing soil depth (Enninful & Torvi, 2008), the combustion of soil organic matter during wildfires typically affects only the surface layer (Boerner, 2009; Majder-Łopatka, 2019). In agricultural contexts, where fires are usually of lower intensity compared to forest wildfires, soil organic carbon is rarely combusted. Additionally, incorporating biochar beneath the surface has been shown to enhance soil's resistance to environmental stressors, including moisture deficiency and heat. For instance, biochar improves the soil's water-holding capacity (Głąb et al., 2016), which in turn reduces its susceptibility to combustion. When applied below the soil surface—and especially when combined with surface amendments—biochar is significantly less prone to fire-related losses (IBI, 2010).

- **Risk of Loss Beyond Project Boundaries:**

  Incorporation of biochar into soil can reduce runoff and erosion, thereby limiting the possibility of biochar particles leaving the project site (Gholami et al., 2019; Lee et al., 2015). Subsurface placement, in particular, mitigates the potential for wind-based displacement. While minor displacement through erosion may still occur, this does not equate to a loss of carbon back into the atmosphere. Rather, displaced biochar may be transported into aquatic systems and ultimately settle in sediment layers, where it can remain stable over long periods, potentially longer than in its original soil application.

When utilized in non-soil settings, biochar is generally exposed to minimal natural degradation risks. Studies by Lee et al. (2019) have demonstrated that incorporating biochar into bio-composite materials—such as those reinforced with inorganic clays—reduces thermal conductivity, effectively enhancing fire resistance. Similarly, Gupta and Kua (2019) found that biochar embedded in mineral-based building materials like gypsum, clay, or plasters remains well-protected from microbial and chemical decomposition. As a result, institutions such as the European Biochar Certificate (EBC, 2021) recognize that embedding biochar in construction materials like concrete, lime-based plasters, or gypsum renders combustion highly unlikely.

10.5.2.2 Non-Natural Risks

Non-natural risks refer to factors such as project governance, financial challenges (e.g., budget shortfalls), policy uncertainties, and stakeholder opposition.

To systematically manage these risks, project proponents must develop a Structured Risk Register. The format of this Risk Register is not prescriptive, but it must at a minimum include the following four elements for each risk item: (1) Financial; (2) Operational; (3) Socio-political; and (4) Regulatory. Each risk must be assigned a likelihood score, impact level, and proposed mitigation measure. The risk register must be maintained as a living document and reviewed at least annually.

Furthermore, a socio-political risk analysis must be conducted during the project design phase. This should identify possible sources of local resistance, land tenure disputes, or institutional fragility. Project proponents must also document how community engagement, grievance redress mechanisms, and FPIC (Free, Prior and Informed Consent)—where applicable—are incorporated into the project. Monitoring of these elements must be part of the ongoing MRV framework.

Through these measures, the project ensures that the long-term stability of carbon sequestered in soil-applied biochar is preserved and that social and institutional risks to permanence are minimized.

10.5.3 Calculation of carbon credits

To calculate the number of carbon credits or Verified Carbon Units (VCUs) that may be issued, the project proponent must consider the number of buffer credits that must be deposited in the AFOLU pooled buffer account. The number of buffer credits that must be deposited is calculated by multiplying the non-permanence risk rating by the net change in carbon stocks.

All projects are required to contribute to a centralized buffer pool or provide a recognized insurance mechanism to safeguard against unforeseen carbon reversals, such as wildfires, social conflict, or implementation failure.

The default minimum contribution to the buffer pool shall be 10% of the net GHG removals and/or carbon stock increase (measured in tCO_2e), unless a lower rate can be justified through a detailed site-specific risk assessment. Projects may submit third-party insurance coverage documents in lieu of buffer contributions, provided these instruments meet the minimum coverage value equivalent to the 10% buffer threshold and have been approved by the relevant registry or certification body.

This safeguard mechanism is essential to ensure environmental integrity, investor confidence, and long-term climate impact.

$$Bu_{ER,y} = I\left(\Delta CO_{2_{wp}}\right) \times \left(MIN\left(0, \Delta CO_{2_{wp,y}}\right) - MIN\left(0, \Delta CO_{2_{bsl,y}}\right)\right) \times NPR\% + (1 - I(\Delta CO_{2_{wp}}) \times (MIN\left(0, \Delta CO_{2_{wp,y}}\right) - MIN\left(0, \Delta CO_{2_{bsl,y}}\right) + MAX(0, CO_{2_{bsl,y}}) \times NPR\% \quad (23)$$

Where:

$I(\Delta CO_{2wp})$ = 1 if $\sum_1^y \Delta CO_{2wp,y} > 0$

$I(\Delta CO_{2wp})$ = 0 if $\sum_1^y \Delta CO_{2wp,y} \leq 0$

$Bu_{ER,y}$ = Buffer credits to be deducted from reductions in year y (t CO_2e)

$$Bu_{CR,y} = I\left(\Delta CO_{2_{wp}}\right) \times \left(MAX\left(0, \Delta CO_{2_{wp,y}}\right) - MAX\left(0, \Delta CO_{2_{bsl,y}}\right)\right) \times NPR\% \quad (24)$$

Where:

$I(\Delta CO_{2wp})$ = 1 if $\sum_1^y \Delta CO_{2wp,y} > 0$

$I(\Delta CCO_{2wp})$ = 0 if $\sum_1^y \Delta CO_{2wp,y} \leq 0$

$Bu_{CR,y}$ = Buffer credits to be deducted from removals in year y (t CO_2e)

$\Delta CO_{2_{wp,y}}$ = Total carbon stock change in the project scenario in year y (t CO_2e)

$CO_{2_{bsl,y}}$ = Total carbon stock change in the baseline scenario in year y (t CO_2e)

NPR% = Overall project non-permanence risk rating converted to a percentage

The amount of VCUs resulting from project activities leading to reductions that may be issued in year t is calculated as:

$$VCU_{ER,y} = ER_{NET,y} - Bu_{ER,y} \quad (25)$$

Where:

$VCU_{ER,y}$ = Number of VCU resulting from project activities leading to reduction in year y

$ER_{NET,y}$ = Estimated net reductions in year y (t CO_2e)

The amount of VCUs resulting from project activities leading to removals that may be issued in year t is calculated as:

$$VCU_{CR,y} = CR_{NET,y} - Bu_{CR,y} \quad (26)$$

Where:

$VCU_{CR,y}$ = Amount of VCUs resulting from project activities leading to removals in year y

$CR_{NET,y}$ = Estimated net removals in year y (t CO_2e)

The amount of VCUs that may be issued in year y is calculated as:

$$VCU_y = VCU_{ER,y} + VCU_{CR,y} \quad (27)$$

Where:

VCU_y = Amount of VCUs in year y (t CO_2e)

10.6 Cost Efficiency Analysis

To support project developers and potential investors in evaluating the cost-effectiveness of biochar-based GHG removals, this methodology recommends calculating the unit cost per tonne of CO_2e reduced or removed as follows:

$$\text{Cost per } tCO_{2e} = (LE_{OA,y} + LE_{BR,y}) \times \frac{C_{total,y}}{\text{ERRNET}_y} \quad (28)$$

Where:

Ctotal,y = Total project cost incurred in year y (USD or local currency).

This includes capital, operational, labor, transportation, and monitoring costs.

ERRNET,y = Net GHG reductions and removals in year y (tCO_2e)

The cost per tonne of CO_2e represents the project' s economic efficiency in delivering climate benefits.

Projects with lower cost per tCO_2e are generally considered more attractive to funders, buyers, and policy makers.

If ERRNET,y = 0, then no cost-efficiency value shall be reported.

11 MONITORING

This paragraph references VM0044 METHODOLOGY FOR BIOCHAR UTILIZATION IN SOIL AND NON-SOIL APPLICATIONS and Biochar Standards, and has been modified and rewritten in this article.[38][39]

11.1 Data and Parameters Available at Validation

Data / Parameter	$F_{cp,t,p}$
Description	Organic carbon concentration of biochar for each biochar type t produced in production site p per tonne of biochar, on a Dry matter basis (%)
Data unit	Percent (%)
Value applied	For high technology production facilities, value is determined from a material analysis. For low technology production facilities where FCp cannot be monitored, use values from Table 4.
Source of data	At validation stage, both types of production site may use default values provided in Table 4 and taken from IPCC (2019) Appendix 4: Method for Estimating the Change in Mineral Soil Organic Carbon Stocks from Biochar Amendments: Basis for Future Methodological Development or may provide peer-reviewed data.
Justification of choice of data or description of measurement methods and procedures applied	IPCC (2019) states global estimates of Organic carbon concentration of biochar as a function of feedstock and heating temperature, therefore the value must be calculated based on a biochar material analysis or using default values (EBC, 2022).
Equations	Equation 2, Equation 6
Purpose of data	Calculation of project emissions

Data / Parameter	$PR_{de,k}$
Description	Permanence adjustment factor due to decay of biochar (dimensionless) to be defined for application type k
Data unit	Dimensionless
Value applied	For high technology production facilities, project proponents must use Table 4 in this methodology. For low technology production facilities, project proponents must use a conservative default value of 0.56 (Figure 4Ap.1 in IPCC, 2019)[40]
Source of data	EBC (2020) Guidelines for the Certification of Biochar Based Carbon Sinks

[38] available at: https://biochar-international.org/standard-certification-training/biochar-standards/
[39] VM0044 METHODOLOGY FOR BIOCHAR UTILIZATION IN SOIL AND NON-SOIL APPLICATIONS
[40] available at https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch02_Ap4_Biochar.pdf

	IPCC (2019) Appendix 4: Method for Estimating the Change in Mineral Soil Organic Carbon Stocks from Biochar Amendments: Basis for Future Methodological Development Scientific studies, research papers, other credible documentation
Justification of choice of data or description of measurement methods and procedures applied	Biochar is a stable material that may be used for soil and non-soil applications. As a material, it has a decay rate that must be accounted for. This parameter considers how much of the original carbon will remain in the biochar and may be accounted as a carbon sink after its final application. IPCC and EBC are internationally recognized and the data provided in the guidelines are peer reviewed.
Equations	Equation 2, Equation 6
Purpose of data	Calculation of project emissions
Comments	None

Data / Parameter	GWP_{CH4}
Description	Global warming potential of methane
Data unit	tonnes CO_2e per tonne CH_4 (t CO_2e/t CH_4)
Value applied	28
Source of data	*IPCC Fifth Assessment Report*[27]
Justification of choice of data or description of measurement methods and procedures applied	The *SEPLS Carbon Credit Regional Revitalization Center Standard* requires that CH4 is converted to CO_2e using the 100-year global warming potential derived from the most recent IPCC Assessment Report.
Equations	Equation 9
Purpose of data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	GWP_{N2O}
Description	Global warming potential for N_2O
Data unit	tonnes CO_2e per tonne N_2O (t CO_2e/t N_2O)
Value applied	265
Source of data	IPCC Fifth Assessment Report (IPCC, 2013)

Justification of choice of data or description of measurement methods and procedures applied	See "Source of data." Global warming potential values must be applied as described in the most recent version of the VCS Standard and derived from IPCC Assessment Reports.
Equations	Equation 14
Purpose of data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	F_e
Description	Average methane emissions from producing one tonne of biochar in year *y* in a low technology production site
Data unit	tonnes CH4 per tonne biochar (t CH_4/t)
Value applied	0.049 tCH4/tonne of biochar produced for unknown low technology production site (i.e., kiln) type If kiln type is known and represented in Table 3, corresponding values may be used for Fe
Source of data	Table 3 in Cornelissen et al. (2016)
Justification of choice of data or description of measurement methods and procedures applied	Methane emissions must be accounted for as methane is the main gas released from low technology production facilities. The value of methane emissions per tonne of biochar produced in a low technology production site is derived from peer reviewed literature and deemed conservative.
Equations	Equation 9
Purpose of data	Calculation of project emissions
Comments	None

Data / Parameter	Biomass categories and quantities used for selection of the baseline scenario and production of biochar utilized in the project activity
Description	- Category (e.g., bagasse, rice husks, empty fruit bunches, agricultural waste); - Source (e.g., produced on-site, obtained from an identified biomass residue producer, obtained from a biomass residue market); - Documentation with sustainability criteria compliance for respective category as indicated in Table 1. Explain and document transparently in the project description which quantities of which biomass categories are used in which installation(s) under the project activity and what their baseline scenario is. Include the quantity of each category of biomass (tonnes). For selection of the baseline scenario, at validation, an ex-ante estimation of these quantities should be provided.

Description of measurement methods and procedures to be applied	Use weight meters. Adjust by moisture content in order to determine the quantity of dry biomass.
Data unit	tonnes (t) on dry basis
Source of data	On-site assessment of biomass categories and quantities
Equations	-
Purpose of data	Monitoring of eligible biomass categories and quantities used as feedstock for production of biochar
QA/QC procedures to be applied	Cross-check the measurements with an annual energy balance that is based on purchased quantities and stock changes.
Frequency of monitoring/recording	Data monitored continuously and aggregated at least monthly

11.2 Data and Parameters Monitored

Data / Parameter	$M_{p,y}$
Description	Total mass on a Dry matter basis of biochar produced in production site p in year y
Data unit	tonnes (t)
Source of data	On-site measurements
Description of measurement methods and procedures to be applied	Use weighing scales. Adjust the moisture content in order to determine quantity of dry weight biomass.
Frequency of monitoring/recording	Monitored continuously, recorded at least monthly
Equations	Equation 3
Calculation method	None
QA/QC procedures to be applied	Calibrate weighing scales as per manufacturer's specifications or at least every three years. Amount of biochar applied must be cross-checked with sales receipts and/or invoices or any other equivalent third-party evidence.
Purpose of data	Calculation of project emissions
Comments	Each biochar quantity should be weighed separately for each biochar type t and each biochar production site p. Moisture content should be monitored for each batch of biochar type t. The weighted average should be calculated for each monitoring period.

Data / Parameter	$M_{t,k,p,y}$
Description	Mass on Dry matter basis of biochar type t and application type k produced at production site p in year y

Data unit	tonnes (t)
Source of data	On-site measurements
Description of measurement methods and procedures to be applied	Use weighing scales. Adjust the moisture content in order to determine quantity of dry weight biomass.
Frequency of monitoring/recording	Monitored continuously, recorded at least monthly
Equations	Equation 2, Equation 3, Equation 6, Equation 9
Calculation method	None
QA/QC procedures to be applied	Calibrate weighing scales as per manufacturer's specifications or at least every three years. Amount of biochar applied must be cross-checked with sales receipts and/or invoices or any other equivalent third-party evidence.
Purpose of data	Calculation of project emissions
Comments	Each biochar quantity should be weighed separately for each biochar type t and each biochar production site p. Moisture content should be monitored for each batch of biochar type t. The weighted average should be calculated for each monitoring period.

Data / Parameter	$F_{cp,t,p}$
Description	Organic carbon concentration of biochar for each biochar type t produced in production site p per tonne of biochar, taken on a Dry matter basis
Data unit	Percent (%)
Source of data	Laboratory material analysis
Description of measurement methods and procedures to be applied	Laboratory material analysis following *IBI Biochar Testing Guidelines* or *EBC Production Guidelines* or other relevant guidelines on the production of biochar is required to determine FCp values on a regular basis.
Frequency of monitoring/recording	In alignment with the *IBI Biochar Testing Guidelines* testing must be performed: ● Annually; or ● After a material change in feedstock; or After a material change in thermochemical production parameters; whichever is more frequent.
Equations	Equation 2, Equation 6
Calculation method	None

QA/QC procedures to be applied	Laboratory must be accredited and/or approved by the relevant national agency to conduct required material analysis.
Purpose of data	Calculation of project emissions
Comments	For low technology production, where Organic carbon concentration of biochar cannot be sampled in alignment with the required standards, use the conservative values indicated in Table 4 as default values.

Data / Parameter	T_{prod}
Description	Average annual production temperature during pyrolysis
Data unit	degrees Celsius (°C)
Source of data	Data records of biochar production
Description of measurement methods and procedures to be applied	Use instruments with recordable electronic signal (digital or analog). Examples include thermocouple, thermoresistor or any other instrument as prescribed by relevant international or national standards.
Frequency of monitoring/recording	Continuous, aggregated to annual averages
Equations	-
Calculation method	None
QA/QC procedures to be applied	Periodic calibration against a primary device provided by an independent accredited laboratory is mandatory. Calibration and frequency of calibration is according to manufacturer's specifications.
Purpose of data	Calculation of project emissions
Comments	The average production temperature at which pyrolysis occurs will determine the stability of the biochar. It will be used to categorize the biochar in accordance with Table 3 to determine PRde. For low technology production where measuring the temperature is not feasible, or sampling of the Organic carbon concentration of the biochar according to the required standards is not possible, use the conservative values indicated in Equation 7 as default values.

Data / Parameter	*H:Corg*
Description	Ratio of hydrogen to organic carbon
Data unit	Dimensionless
Source of data	Laboratory analysis

Description of measurement methods and procedures to be applied	Laboratory analysis following *IBI Biochar Testing Guidelines* or *EBC Production Guidelines*
Frequency of monitoring/recording	Each batch of biochar produced at the production site
Equations	-
Calculation method	None
QA/QC procedures to be applied	Laboratory must be accredited and/or approved by the relevant national agency to conduct required material analysis.
Purpose of data	Used to demonstrate eligibility for use in soil applications. As per applicability condition 10, biochar used in soils must have an H:Corg of less than 0.7.
Comments	None

Data / Parameter	WS_p
Description	Fraction of total waste heat utilized at biochar production site *p*
Data unit	Percent (%)
Source of data	On-site records, estimated data from waste heat consumption in the site
Description of measurement methods and procedures to be applied	As per latest version of CDM Tool 09: *Determining the baseline efficiency of thermal or electric energy generation system.*
Frequency of monitoring/recording	Annual
Equations	-
Calculation method	-
QA/QC procedures to be applied	As per latest version of CDM Tool 09: *Determining the baseline efficiency of thermal or electric energy generation system.*
Purpose of data	To qualify and ensure that biochar is produced in a high technology production site.
Comments	See the definition of high technology production site for the conditions that must be met for the production site to qualify as high technology.

11.3 Description of the Monitoring Plan

The primary aim of monitoring is to demonstrate the carbon sequestration achieved through the end-use of biochar and to account for any greenhouse gas (GHG) emissions associated with the project activities during the crediting period and before each verification cycle.

Project developers are required to implement a structured data quality system. For every measurement stage, written protocols must clearly define roles, responsibilities, and timelines (e.g., biochar output volumes and corresponding production dates).

Under this methodology, the purpose of monitoring is to verify the carbon sequestration achieved through the final utilization of biochar and to quantify the associated GHG emissions generated throughout the project scenario during the designated crediting period and prior to any third-party verification. To ensure accurate data management, project developers must establish robust quality control systems. For each measurement point—such as biochar production quantities and corresponding dates—protocols must explicitly assign responsibilities and specify procedural schedules.

A monitoring plan must be designed and implemented in alignment with the principles of ISO 14064-2, with particular emphasis on transparency and accuracy. This plan must enable credible accounting of GHG impacts across the entire biochar lifecycle, including feedstock sourcing, production processes, and end-use applications.

Biodiversity layers (species observations, habitat classes, and update timestamps) shall be stored in the centralized database with version control to enable verifier cross-checks within the same MRV cycle.

Given the context-specific nature and complexity of tracking biochar deployment, this methodology provides a range of supporting resources; however, it does not mandate the use of any particular monitoring technology or system.

Geographic information

To ensure the integrity of carbon accounting and avoid double counting—such as recording the same carbon sink under both the soil organic carbon pool and the application of biochar—clear identification of the final location where carbon sequestration occurs is required. This requirement applies to both soil-based and non-soil-based applications.

In accordance with the rules outlined by the SEPLS Carbon Credit Regional Revitalization Center (SEPLS-CCRR), when numerous implementation sites are involved—such as multiple agricultural plots receiving biochar—project proponents must provide at least one geodetic coordinate. Additionally, adequate geographic context should be included to enable random sampling and verification by authorized auditors.

Application type

For projects involving soil application, it is essential to identify the exact locations where biochar has been incorporated. Each site must be documented with at least one geodetic coordinate to ensure traceability.

In the case of non-soil applications—such as its integration into concrete or asphalt—the verification process concludes once the biochar is embedded in the long-lasting material. Similar to soil use, each instance must be georeferenced. Moreover, statistically sound methods must be applied to confirm that the materials containing biochar remain in functional use and have not degraded into atmospheric CO_2.

Monitoring tools

To guarantee that biochar is effectively utilized in designated soil or non-soil applications, project developers must implement reliable verification mechanisms. These may include digital tracking tools such as mobile or desktop software, QR codes, blockchain-based solutions, GPS-tagged application sites, NFTs, or any system capable of recording the full chain of custody—from the source of the biomass feedstock to the final point of application.

In addition, the methodology allows for the integration of advanced monitoring technologies such as LiDAR (Light Detection and Ranging), SAR (Synthetic Aperture Radar), and AI-powered image analysis to support remote sensing accuracy and enhance the detection of land-use changes, vegetation cover, and ecosystem health metrics over time.

In cases where production monitoring equipment (such as thermal sensors) is used, developers are required to calibrate such instruments following best available practices. This includes compliance with relevant industry protocols, manufacturer guidance, or calibration standards set by device providers.

Additionally, any material characterization of biochar must be conducted in accordance with internationally recognized protocols, such as the most recent *IBI Biochar Testing Guidelines* or *EBC Production Guidelines*.

Data management

Quantitative sources of information and record-keeping procedures related to biochar sourcing, production, and application must be clearly defined and implemented. The project proponent must maintain an offsite electronic backup of all logged monitoring data.

Monitoring data shall include, at minimum: the biochar batch number, quantity, type and method of application, geographic location, and proof that the biochar will not be burned or re-pyrolyzed. The project proponent must provide access to all data platforms and ensure that all relevant evidence is available to the third-party verifier.

The centralized digital database system must be implemented. This system shall include: version control, data logs, digital timestamps, and user access history. Audit trails must be generated

automatically and retained for at least five (5) years after the final verification. The database must allow third-party verifiers to export reports in tamper-evident formats, such as digitally signed PDFs or blockchain-authenticated records.

Data governance protocols must be documented and include: defined user roles, backup frequency, and procedures for error detection and correction.

The monitoring plan must, at a minimum, include the following:

（1）A description of each monitoring task to be undertaken, along with the associated technical requirements;
（2）The type of technology used for biochar production;
（3）Documented logs of system operations and maintenance activities;
（4）Clearly defined roles, responsibilities, and qualifications of personnel involved in monitoring and management.

QA / QC

Project proponents are required to establish a quality assurance and quality control (QA/QC) plan to ensure that all measurements and calculations are conducted accurately and reliably. The QA/QC procedures may include, but are not limited to, the following actions:

（1） Securing monitoring instruments such as sealed meters and data loggers where applicable;
（2） Safeguarding monitoring data records, both in hard copy and digital formats;
（3） Conducting regular checks to verify data integrity;
（4） Comparing current estimates with historical data to identify inconsistencies;
（5） Providing adequate training for personnel involved in the sourcing, production, and application processes of biochar.

The project proponent must collect and centrally store all relevant documentation, ensuring it is accessible for verification at any time. These records must be maintained in a secure and retrievable manner for a minimum of two years following the conclusion of the project's crediting period.

Local Capacity Building and Training

To ensure high-quality data collection and robust QA/QC, the proponent shall implement a formal, auditable training program covering:

（1） Curriculum & Materials (instrument use, sampling & calibration, data logging, QA/QC documentation, GPS/RS basics, biochar characterization);
（2） Schedule & Frequency (onboarding; annual refreshers; ad-hoc retraining after non-conformances or protocol updates);
（3） Roles & Qualifications (trainers' credentials; trainee roles);
（4） Records & Evidence (attendance logs, agendas, photos, trainer names, participant

evaluations, pre/post knowledge tests);

（5） Effectiveness Monitoring (track error rates, missing-data frequency, inter-observer agreement, and data resubmission rates before/after training; document corrective actions and timelines);

（6） QA/QC Audits (periodic field/data audits with CAR/OBS closure evidence);

（7） Retention & Access (retain all training records ≥ 5 years; make available to VVB). Results and improvements shall be summarized in each Monitoring Report and stored in the centralized database.

11.4 Data, Parameters, and Description of the Monitoring Plan to Practice the Strategy and Plan of Action 2023 -2030 of the International Partnership for the Satoyama Initiative

The Data / Parameters monitored under this methodology are aligned with the following IPSI Six Ecological and Socioeconomic Perspectives:

（1）Resource use within the carrying capacity and resilience of the environment
（2）Cyclic use of natural resources
（3）Recognition of the value and importance of local and indigenous traditions and culture
（4）Multi-stakeholder participation and collaboration in sustainable and multi-functional management of natural resources and ecosystem services
（5）Contributions to sustainable socio-economies, including poverty reduction, food security, sustainable livelihoods and local community empowerment
（6）Improved community resilience to achieve multiple benefits, including ecological, social, cultural, spiritual, and economic benefits, inter alia through ecosystem-based approaches for climate change mitigation and adaptation activities

Data and Parameters:

The table below describes the Data / Parameters to be monitored and their alignment with the IPSI Six Ecological and Socioeconomic Perspectives.

Data / Parameter	$F_{cp,t,p}$
Description	Organic carbon concentration of biochar for each biochar type t produced in production site p per tonne of biochar, taken on a Dry matter basis
Data unit	Percent (%)
Source of data	Laboratory material analysis
Description of measurement methods and procedures to be applied	Laboratory material analysis following *IBI Biochar Testing Guidelines* or *EBC Production Guidelines* or other relevant guidelines on the production of biochar is required to determine $F_{cp,t,p}$ values on a regular basis.
Frequency of monitoring/recording	In alignment with the *IBI Biochar Testing Guidelines* testing must be performed:

	● Annually; or ● After a material change in feedstock; or After a material change in thermochemical production parameters; whichever is more frequent.
Equations	Equation 2, Equation 6
Calculation method	None
QA/QC procedures to be applied	Laboratory must be accredited and/or approved by the relevant national agency to conduct required material analysis.
Purpose of data	Calculation of project emissions
Perspectives	Perspective 1, Perspective 2
Comments	The data serves as a quality indicator for biogenic carbon, ensuring that biochar use remains within the environmental carrying capacity (Perspective 1) while promoting the cyclic use of biomass resources through stable long-term carbon retention (Perspective 2).

Data / Parameter	$M_{p,y}$
Description	Total mass on a Dry matter basis of biochar produced in production site p in year y
Data unit	tonnes (t)
Source of data	On-site measurements
Description of measurement methods and procedures to be applied	Use weighing scales. Adjust the moisture content in order to determine quantity of dry weight biomass.
Frequency of monitoring/recording	Monitored continuously, recorded at least monthly
Equations	Equation 3
Calculation method	None
QA/QC procedures to be applied	Calibrate weighing scales as per manufacturer's specifications or at least every three years. Amount of biochar applied must be cross-checked with sales receipts and/or invoices or any other equivalent third-party evidence.
Purpose of data	Calculation of project emissions
Perspectives	Perspective 1, Perspective 2
Comments	The data serves as a quantitative indicator for biogenic carbon, ensuring that biochar use remains within the environmental carrying capacity (Perspective 1) while promoting the cyclic use of biomass resources through stable long-term carbon retention (Perspective 2).

Data / Parameter	$ER_{NET,y}$
Description	Estimated net GHG emission reductions in year y (t CO2e)
Data unit	tonnes (t)
Source of data	Equation 15
Description of measurement methods and procedures to be applied	Follow Equation 15
Frequency of monitoring/recording	Annual
Equations	Equation 15
Calculation method	See Section 10.5.1of this paper
QA/QC procedures to be applied	-
Purpose of data	Calculation of net project GHG emission reductions
Perspectives	Perspective 6
Comments	The data on estimated net GHG emission reductions in year y helps to understand the effectiveness of community resilience efforts (Perspective 6) by showing climate-mitigation benefits that deliver long-term ecological, social, and economic gains.

Data / Parameter	$CR_{NET,y}$
Description	Estimated net carbon dioxide removals in year y (t CO2e)
Data unit	tonnes (t)
Source of data	Equation 18
Description of measurement methods and procedures to be applied	Follow Equation 18
Frequency of monitoring/recording	Annual
Equations	Equation 18
Calculation method	See Section 10.5.1 of this paper
QA/QC procedures to be applied	-
Purpose of data	Calculation of net project carbon dioxide removals
Perspectives	Perspective 6

Comments	The data on estimated net r net project carbon dioxide removals in year y helps to understand the effectiveness of community resilience efforts (Perspective 6) by showing combined mitigation and removal benefits that deliver long-term ecological, social, and economic gains.

Data / Parameter	$ERR_{NET,y}$
Description	Estimated net GHG reductions and removals in year y (t CO2e)
Data unit	tonnes (t)
Source of data	Equation 20
Description of measurement methods and procedures to be applied	Follow Equation 20
Frequency of monitoring/recording	Annual
Equations	Equation 20
Calculation method	See Section 10.5.1 of this paper
QA/QC procedures to be applied	-
Purpose of data	Calculation of net project GHG reductions and removals
Perspectives	Perspective 6
Comments	The data on estimated net reductions and removals in year y helps to understand the effectiveness of community resilience efforts (Perspective 6) by showing combined mitigation and removal benefits that deliver long-term ecological, social, and economic gains.

Data / Parameter	$VCU_{CR,y}$
Description	Amount of VCUs resulting from project activities leading to removals in year y
Data unit	token
Source of data	Equation 26
Description of measurement methods and procedures to be applied	Follow Equation 26
Frequency of monitoring/recording	Annual
Equations	Equation 26

Calculation method	See Section 10.5.3 of this paper
QA/QC procedures to be applied	-
Purpose of data	In the carbon market, transactions are measured in tonnes of CO_2 equivalent (tCO_2e), with each Verified Carbon Unit (VCU) representing one tCO_2e reduced or removed.
Perspectives	Perspective 5, Perspective 6
Comments	In the carbon market, each VCU equals one tCO_2e reduced or removed, reflecting Perspective 5 by supporting sustainable socio-economies and Perspective 6 by enhancing community resilience through climate-mitigation benefits.

11.5 Data, Parameters, and Description of the Monitoring Plan to Practice the Kunming-Montreal Global Biodiversity Framework

The Data / Parameters monitored under this methodology are aligned with the following Monitoring Plan to Practice the Kunming-Montreal Global Biodiversity Framework (GBF). The table below describes the Data / Parameters to be monitored and their alignment with the 23 action-oriented targets of GBF.

Data / Parameter	$F_{cp,t,p}$
Description	Organic carbon concentration of biochar for each biochar type t produced in production site p per tonne of biochar, taken on a Dry matter basis
Data unit	Percent (%)
Source of data	Laboratory material analysis
Description of measurement methods and procedures to be applied	Laboratory material analysis following *IBI Biochar Testing Guidelines* or *EBC Production Guidelines* or other relevant guidelines on the production of biochar is required to determine $F_{cp,t,p}$ values on a regular basis.
Frequency of monitoring/recording	In alignment with the *IBI Biochar Testing Guidelines* testing must be performed: ● Annually; or ● After a material change in feedstock; or After a material change in thermochemical production parameters; whichever is more frequent.
Equations	Equation 2, Equation 6
Calculation method	None
QA/QC procedures to be applied	Laboratory must be accredited and/or approved by the relevant national agency to conduct required material analysis.
Purpose of data	Calculation of project emissions
Target	Target 8, Target 10, Target 11

Comments	The data supports Target 8 by ensuring stable long-term carbon storage, Target 10 by promoting sustainable agricultural practices, and Target 11 by enhancing soil fertility and ecosystem services that benefit people.

Data / Parameter	$M_{p,y}$
Description	Total mass on a Dry matter basis of biochar produced in production site p in year y
Data unit	tonnes (t)
Source of data	On-site measurements
Description of measurement methods and procedures to be applied	Use weighing scales. Adjust the moisture content in order to determine quantity of dry weight biomass.
Frequency of monitoring/recording	Monitored continuously, recorded at least monthly
Equations	Equation 3
Calculation method	None
QA/QC procedures to be applied	Calibrate weighing scales as per manufacturer's specifications or at least every three years. Amount of biochar applied must be cross-checked with sales receipts and/or invoices or any other equivalent third-party evidence.
Purpose of data	Calculation of project emissions
Target	Target 10, Target 21
Comments	The data supports Target 10 by enabling sustainable agricultural practices and Target 21 by providing accessible information to guide biodiversity action.

Data / Parameter	$ER_{NET,y}$
Description	Estimated net GHG emission reductions in year y (t CO2e)
Data unit	tonnes (t)
Source of data	Equation 15
Description of measurement methods and procedures to be applied	Follow Equation 15

Frequency of monitoring/recording	Annual
Equations	Equation 15
Calculation method	See Section 10.5.1of this paper
QA/QC procedures to be applied	-
Purpose of data	Calculation of net project GHG emission reductions
Target	Target 8, Target 11, Target 21
Comments	The calculation of net project GHG emission reductions support Target 8 by demonstrating climate-mitigation outcomes, Target 11 by evidencing benefits to ecosystem services, and Target 21 by providing accessible information to guide biodiversity action.

Data / Parameter	$CR_{NET,y}$
Description	Estimated net carbon dioxide removals in year y (t CO2e)
Data unit	tonnes (t)
Source of data	Equation 18
Description of measurement methods and procedures to be applied	Follow Equation 18
Frequency of monitoring/recording	Annual
Equations	Equation 18
Calculation method	See Section 10.5.1 of this paper
QA/QC procedures to be applied	-
Purpose of data	Calculation of net project carbon dioxide removals
Target	Target 8, Target 11, Target 21
Comments	The data on the calculation of net project carbon dioxide removals supports Target 8 by demonstrating climate-mitigation outcomes, Target 11 by enhancing ecosystem services that benefit people, and Target 21 by providing accessible information to guide biodiversity action.

Data / Parameter	$ERR_{NET,y}$
Description	Estimated net GHG reductions and removals in year y (t CO2e)
Data unit	tonnes (t)
Source of data	Equation 20
Description of measurement methods and procedures to be applied	Follow Equation 20
Frequency of monitoring/recording	Annual
Equations	Equation 20
Calculation method	See Section 10.5.1 of this paper
QA/QC procedures to be applied	-
Purpose of data	Calculation of net project GHG reductions and removals
Target	Target 8, Target 11, Target 20, Target 21
Comments	The calculation of net project GHG reductions and removals supports Target 8 and Target 11, and can also contribute to Target 20 and Target 21 when the results are used for capacity building and made accessible to guide biodiversity action.

Data / Parameter	$VCU_{CR,y}$
Description	Amount of VCUs resulting from project activities leading to removals in year y
Data unit	token
Source of data	Equation 26
Description of measurement methods and procedures to be applied	Follow Equation 26
Frequency of monitoring/recording	Annual
Equations	Equation 26
Calculation method	See Section 10.5.3 of this paper
QA/QC procedures to be applied	-
Purpose of data	In the carbon market, transactions are measured in tonnes of CO_2 equivalent (tCO_2e), with each Verified Carbon Unit (VCU) representing one tCO_2e reduced or removed.

Target	Target 8, Target 10,Target 11, Target 20, Target 21
Comments	The data on the amount of VCUs resulting from removals in year y supports Target 8 by demonstrating stable carbon storage, Target 10 by promoting sustainable agricultural practices, Target 11 by enhancing ecosystem services, and Targets 20 and 21 by strengthening capacity building and ensuring information accessibility for biodiversity action.

11.6 Key Performance Indicator

The Kunming-Montreal Global Biodiversity Framework has 23 action-oriented global targets for urgent action over the decade to 2030. The actions set out in each target need to be initiated immediately and completed by 2030. Together, the results will enable the achievement of the outcome-oriented goals for 2050. Actions to reach these targets should be implemented consistently and in harmony with the Convention on Biological Diversity and its Protocols and other relevant international obligations, considering national circumstances, priorities, and socioeconomic conditions.

Table 8: Scores for landscape & seascape indicators (1)

Possible landscape & seascape -related indicators	
The annual growth rate of $ER_{NET,y}$ refers to the year-on-year percentage increase in estimated net GHG emission reductions, expressed in tonnes of CO_2 equivalent (tCO_2e), (%) The annual growth rate of $ER_{NET,y}$ supports Target 8 by tracking progress in climate-mitigation benefits, and supports Targets 20 and 21 by strengthening capacity building and ensuring information accessibility for biodiversity action.	
Setting Resource	
Global climate science indicates that to meet the goals of the Paris Agreement and the 1.5 °C limit, global GHG emissions must fall significantly each year. Annual reductions of approximately 4 %–7.5 % through 2035 are required to align with a 2 °C or 1.5 °C pathway.	
Guiding questions for target-setting (Questions for scoring)	
The indicator is positively correlated with performance—the higher the value, the better. A value below 0 indicates performance inferior to the previous year. A value of 0 indicates performance equal to the previous year. A value between 0 % and 4 % indicates improvement over the previous year. A value between 4 % and 7 % indicates alignment with the annual targets for achieving net zero by 2050. A value greater than 7 % indicates performance exceeding the 2050 net-zero annual target and serves as a benchmark for global best practice.	
Scores (point scale or number value)	Key performance indicator of Score
(5) >7% (4) 4%~7% (3) 0%~4% (2) 0% (1) <0%	> 1

Table 9: Scores for landscape & seascape indicators (2)

Possible landscape & seascape -related indicators	
$VCU_{CR,y}$ refers amount of VCUs resulting from project activities leading to removals in year y The data on the amount of VCUs resulting from removals in year y supports Target 8 by demonstrating stable carbon storage, Target 10 by promoting sustainable agricultural practices, Target 11 by enhancing ecosystem services, and Targets 20 and 21 by strengthening capacity building and ensuring information accessibility for biodiversity action.	
Setting Resource	
In the carbon market, transactions are measured in tonnes of CO_2 equivalent (tCO_2e), with each Verified Carbon Unit (VCU) representing one tCO_2e reduced or removed.	
Guiding questions for target-setting (Questions for scoring)	
A higher number of VCUs indicates greater market value of the carbon sink and delivers increased financial benefits to local communities. However, VCUs may not necessarily be sold in the same year they are issued. Accordingly, this assessment indicator is divided into two stages: whether VCUs are generated, and whether the generated VCUs are sold.	
Scores (point scale or number value)	Key performance indicator of Score
(3) $VCU_{CR,y}>0$, sold (2) $VCU_{CR,y}>0$, unsold (1) $VCU_{CR,y}=0$	> 1

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APPENDIX

None

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SATOYAMA INITIATIVE

Methodology

Me0003

Methodology for Carbon Capture and Sequestration by Crops in Agricultural Facilities

Version 1.0
Published 05 January 2026
GBF 6-8、14-16、19-23

Version 1.0 of this methodology was developed by Ph.D. Amit Kumar Sharma and **Prof.** Yen-Hsun Su (National Cheng Kung University).

Funder: National Cheng Kung University, Taiwan

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1 Source

This methodology is based on the following methodologies:

- VM0049 Carbon Capture and Storage – Version 1.0
- VMD0056 CO2 Capture from Air (Direct Air Capture) – Version 1.0
- VM0042 Improved Agricultural Land Management – Version 2.1
- VM0036 Methodology for Rewetting Drained Temperate Peatlands – Version 1.0

This methodology uses a Storage Module developed for Carbon Capture and Storage using Indoor Plants based on the following methodology:

- VMD0022 Estimation of Carbon Stocks in Living Plant Biomass
- Determination of Total, Organic, Inorganic Carbon and Total Nitrogen in Biological Cultures and Liquid Fraction Process Samples
- VMD0053 Model Calibration, Validation and Uncertainty Guidance for Biogeochemical Modeling for Agricultural Land Management Projects – Version 2.1

2 Summary Description of the Methodology

This methodology outlines the use of "Indoor Plants" as a natural carbon capture and storage (CCS) solution. This methodology leverages the carbon dioxide sequestration capabilities of Indoor Plants through photosynthesis. The approach involves cultivation of high-efficiency Indoor Plants within homes, offices, or public spaces, while ensuring the optimal growth conditions for sustained carbon uptake.

This methodology emphasizes the choice of Indoor Plant species with high photosynthetic efficiency and adaptability to indoor environments. The captured carbon dioxide is stored in the plant biomass (leaves, stems, roots) and can be preserved through processes like composting, or biochar conversion. The progress of this methodology is monitored by tracking plant growth, biomass changes and associated emissions from the maintenance activities. The methodology is aimed at promoting efficient use of water, energy, and resources, while minimizing emissions from supplemental systems like artificial lighting.

3 Relation to Strategy and Plan of Action 2023 -2030 of the International Partnership for the Satoyama Initiative

The Satoyama Initiative is a global initiative that aims to realize societies in harmony with nature through the conservation and sustainable management of Socio-Ecological Production Landscapes and Seascapes (SEPLS). The initiative promotes the sustainable use of biodiversity so that societies can enjoy a stable supply of various natural assets and ecosystem services well into the future.

SEPLS are dynamic mosaics of habitats and other land and sea use where harmonious interactions between people and nature maintain biodiversity while providing humans with goods and services needed for their livelihoods, survival, and well-being in a sustainable manner. SEPLS are found in many places in the world under different names and are deeply linked to local culture and knowledge. When well-managed, SEPLS can significantly contribute to the three objectives of the Convention on Biological Diversity (CBD) and the Sustainable Development Goals (SDGs) of conserving biological diversity, sustainable use of its components, and fair and equitable sharing of benefits arising from the utilization of the resources.

The present Strategy and Plan of Action 2023-2030 identifies five strategic objectives as described below.

- Enhance ecosystem services and biodiversity in SEPLS.
- Promoting carbon sequestration through agricultural fields and indoor facilities supports regulating ecosystem services, such as climate regulation, soil fertility, and air purification, contributing to biodiversity conservation in managed SEPLS.
- Strengthen nature-based solutions for climate change mitigation: Utilizing agricultural fields and indoor plants for CO2 capture provides a scalable, low-cost nature-based solution aligned with international climate commitments such as Kunming Montreal Global Biodiversity Framework.
- Promote sustainable use and management of natural resources: Integrating carbon capture into agroecosystems reinforces sustainable land management practices linking directly to the goals of the Satoyama Initiative of balancing productivity, sustainability, and ecological integrity.
- Support rural regeneration and community resilience: Empowering farmers and rural communities to participate in carbon farming and green indoor systems enhances livelihoods of the local communities while improving carbon balance, supporting socioeconomic revitalization of the region.
- Enable biodiversity-based carbon credit mechanism: Developing measurable carbon sequestration strategies through bio-based systems such as soil organic carbon, indoor plants, could form the basis for biodiversity-linked carbon credits.
- Promote sustainable practices, market-based mechanisms, and value chains to support sustainable production, including customary sustainable use and economies that rely on traditional knowledge and cultural values and practices, from SEPLS to contribute to the achievement of relevant targets of the Kunming-Montreal Global Biodiversity Framework.
- Knowledge Co-production and foster interdisciplinary research: This approach promotes interdisciplinary collaboration between agriculture, biodiversity, climate science, architecture, and policy to create holistic, community-informed models of sustainability.

The following principles apply to all of the strategic objectives.

i. Strengthen networking and cooperation among members at local, regional, and global scales.
ii. Promote full, effective, and equitable participation of Indigenous Peoples and Local Communities, irrespective of race, ethnic group, religion, and gender, while supporting women, youth, and people in vulnerable and marginalized situations.
iii. Comport fully with the principles of Section C of the Kunming-Montreal Global Biodiversity Framework.

The International Partnership for the Satoyama Initiative (IPSI) Secretariat will work with the Steering Committee and IPSI members, as soon as possible, to develop an actionable implementation plan for achieving strategic objectives and priority actions. This plan will include resource mobilization activities and, if possible, a conceptual diagram illustrating the relationships between the objectives and actions, as well as improvements to the functioning of IPSI, such as the IPSI Collaborative Activities mechanism, membership procedures, partner engagement, and events, as soon as possible.

4 Relation to Kunming-Montreal Global Biodiversity Framework

The vision of the Kunming-Montreal Global Biodiversity Framework is a world of living in harmony with nature where "by 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people."

4.1 Description

The Kunming-Montreal Global Biodiversity Framework has 23 action-oriented global targets for urgent action over the decade to 2030. The actions set out in each target need to be initiated immediately and completed by 2030. Together, the results will enable achievement towards the outcome-oriented goals for 2050. Actions to reach these targets should be implemented consistently and in harmony with the Convention on Biological Diversity and its Protocols, and other relevant international obligations, taking into account national circumstances, priorities and socioeconomic conditions.

4.2 Basic Information

Table 1 Basic Information

Rationale
The strategic mission of the International Partnership for the Satoyama Initiative is to: a. Promote and support the concept of SEPLS and actions towards their revitalization and sustainable management building on the knowledge and culture of Indigenous Peoples and Local Communities, within the partnership and with non-member networks and/or organizations working with socio-ecological production landscapes and seascapes (SEPLS) b. Enhance the contribution of SEPLS to achieve the objectives of the Rio Conventions and the implementation of other relevant international agreements, including, among others, the 2030 Agenda for Sustainable Development, the Kunming-Montreal Global Biodiversity Framework, and the United Nations Decade on Ecosystem Restoration; and c. c. Promote the concrete benefits of SEPLS to the environment and society, including biodiversity conservation, restoration and sustainable use, climate change mitigation and adaptation, disaster risk reduction, livelihood support, relevance to health, sustainable food systems, and human well-being.
Objectives
Reduce pollution risks and the negative impact of pollution from all sources by 2030, to levels that are not harmful to biodiversity and ecosystem functions and services, considering cumulative effects, including: (a) by reducing excess nutrients lost to the environment by at least half, by way of including efficient nutrient cycling and use; (b) by reducing the overall risk from pesticides and highly hazardous chemicals by at least half, including through integrated pest management, based on science, taking into account food security and livelihoods; and (c) by preventing, reducing, and working towards eliminating plastic pollution.
Activities and/or practices employed
1. Collect, publish, and share knowledge on the conservation, sustainable use, and restoration of SEPLS through the IPSI online portal of case studies, among others.

2. Support IPSI members, in particular those working with Indigenous Peoples and Local Communities, to produce case studies and relevant knowledge materials to enhance knowledge of community-led and traditional systems of SEPLS management.
3. Encourage synergies between modern science and traditional knowledge systems on the benefits of landscape and seascape approaches for conservation and sustainable use of biodiversity including through tools such as geospatial data, scenarios, and modelling.
4. Develop and promote IPSI collaborative activities that contribute to integrated research and capacity development action on the conservation and restoration of SEPLS, including recommendations to enable socio-ecological resilience.
5. Implement outreach activities to transfer knowledge and build further recognition and visibility of the Satoyama Initiative, IPSI, and SEPLS concept taking advantage of social media channels, international meetings, and other relevant events.
6. Review and synthesize information from case studies submitted by IPSI members, including through the publication of the Satoyama Initiative Thematic Review (SITR), promotion of further cooperation between IPSI and International Platform on Biodiversity and Ecosystem Services (IPBES), and facilitation of the transfer and uptake of this knowledge by relevant science and policy processes, capacity building, and education initiatives.
7. Support efforts to explore the concept of "biocultural diversity" and its relevance to SEPLS.

Monitoring methodology

IPSI will develop and implement a system for monitoring progress in the implementation of the strategic objectives and priority actions and assess their overall policy impact. Two main mechanisms will be used to report progress: annual reports of IPSI activities and program implementation reports. Annual reports will track activities from the previous fiscal year and present major achievements related to strategic objectives, including, among others, updates on the partnership, major events, collaborative activities, knowledge products, and Steering Committee decisions every three months. The minutes of the meeting will be recorded and used as a guiding tool for monitoring the progress of the project. A mid-term implementation report covering from 2023 to 2026 will be developed to provide a systematic and impartial assessment of the IPSI program and strategy to determine its relevance, efficiency, effectiveness, impact, and sustainability to support the vision of societies in harmony with nature. In addition to the progress made through the IPSI program, the mid-term report will specifically address failures of the project and the associated causes, this will enable an efficient implementation in the future. The report will seek to strengthen the IPSI program, share learning lessons and identify gaps. Based on the outcomes and recommendations of the mid-term report, the IPSI Steering Committee will have the opportunity to update and make the necessary adjustments to its Strategy and Plan of Action, as needed. The mid-term report could provide relevant information to related IPBES reports, Global Biodiversity Outlooks, and Local Biodiversity Outlooks. A final implementation report covering 2023-2030 will be developed to evaluate the achievements and the overall impact of IPSI on the goals and targets of the Kunming-Montreal Global Biodiversity Framework, SDGs, and other relevant initiatives, and including a survey of IPSI members on their individual contributions. The report will seek to highlight lessons learned and create the groundwork for the development of the next IPSI Strategy and Plan of Action, as appropriate.

4.3 Landscape & Seascape Approaches

Table 2 Specifically, biochar contributes to the following targets

1. Reducing threats to biodiversity
TARGET 6: Reduce the Introduction of Invasive Alien Species by 50% and Minimize Their Impact
Possible landscape & seascape -related indicators
• Percentage of land and seas covered by biodiversity-inclusive spatial plans • Percentage of the population in traditional occupations • Proportion of agricultural area under productive and sustainable agriculture • Progress towards sustainable forest management • Progress towards sustainable water management • Proportion of agricultural area managed with climate, water and biodiversity-friendly practices • National policy support for integrated landscape management • National policy support for integrated basin management
TARGET 7: Reduce Pollution to Levels That Are Not Harmful to Biodiversity
Possible landscape & seascape -related indicators
• Percentage of the population in traditional occupations • Proportion of agricultural area under productive and sustainable agriculture • Progress towards sustainable forest management • Progress towards sustainable water management • Proportion of agricultural area managed with climate, water and biodiversity-friendly practices • Percentage improvement in income and food security of human well-being of households within a landscape
TARGET 8: Minimize the Impacts of Climate Change on Biodiversity and Build Resilience
Possible landscape & seascape -related indicators
• Level of cross-sector involvement in compiling an NBSAP • Number of local authorities applying landscape approaches in a country • Percentage of land and seas covered by biodiversity-inclusive spatial plans • Number of integrated landscape initiatives • Proportion of soil and groundwater managed with climate, water and biodiversity-friendly practices
2. Tools and solutions for implementation and mainstreaming
TARGET 14: Integrate Biodiversity in Decision-Making at Every Level
Possible landscape & seascape -related indicators
• Level of cross-sector involvement in compiling an NBSAP • Number of companies reporting on disclosures of risks, dependencies and impacts biodiversity • Number of integrated landscape initiatives • National policy support for integrated landscape management • National policy support for integrated basin management

• Capacity building among local communities and relevant stakeholders • Ensure zoning land and water use for agriculture, restoration, and conservation of biodiversity • Incentives and infrastructure development to drive decision making related to conservation of biodiversity
TARGET 15: Businesses Assess, Disclose and Reduce Biodiversity-Related Risks and Negative Impacts
Possible landscape & seascape -related indicators
• Level of cross-sector involvement in compiling an NBSAP • Percentage of land and seas covered by biodiversity-inclusive spatial plans • Number of companies reporting on disclosures of risks, dependencies and impacts biodiversity • Number of integrated landscape initiatives • National policy support for integrated landscape management • National policy support for integrated basin management
TARGET 16: Enable Sustainable Consumption Choices To Reduce Waste and Overconsumption
Possible landscape & seascape -related indicators
• develop and enforce regulatory framework for harmful waste • Provide waste incentives to promote durable repairable and reusable options • Promote source separation, composting, and recycling systems that minimize landfill use • Raise awareness of the environmental and biodiversity impacts of overconsumption to motivate behavior change.
TARGET 19: Mobilize $200 Billion per Year for Biodiversity From all Sources, Including $30 Billion Through International Finance
Possible landscape & seascape -related indicators
• Involve public and private capital towards maximizing the co-benefits between mitigation, adaptation and sustainable development • Invest in advanced agricultural biotechnology methods, practices and novel technologies • Identify flexible grants, concessional debts, guarantees or equity instruments to leverage private investments into climate action
TARGET 20: Strengthen Capacity-Building, Technology Transfer, and Scientific and Technical Cooperation for Biodiversity
Possible landscape & seascape -related indicators
• Level of cross-sector involvement in compiling an NBSAP • Percentage of the population in traditional occupations • Number of companies reporting on disclosures of risks, dependencies and impacts biodiversity • National policy support for integrated landscape management • National policy support for integrated basin management • Percentage improvement in the multiple dimensions of human well-being of households within a landscape
TARGET 21: Ensure That Knowledge Is Available and Accessible To Guide Biodiversity Action
Possible landscape & seascape -related indicators

• Ensure that knowledge is available and accessible to guide biodiversity action through online, manuals, local language material • Organize stakeholder meetings for SEPLS knowledge sharing, at least once a year • Conduct a minimum of two training sessions per year for policy makers and community leaders for decision making • At least 3 community-level biodiversity knowledge and capacity-building sessions per year A minimum of 60 participants annually, with at least 40% women and youth • National policy support for integrated basin management • Percentage improvement in the multiple dimensions of human well-being of households within a landscape
TARGET 22: Ensure Participation in Decision-Making and Access to Justice and Information Related to Biodiversity for all
Possible landscape & seascape -related indicators
• Number of local authorities applying landscape approaches in a country • Percentage of land and seas covered by biodiversity-inclusive spatial plans • Percentage of the population in traditional occupations • National policy support for integrated landscape management • National policy support for integrated basin management • Percentage improvement in the multiple dimensions of human well-being of households within a landscape • Proportion of IPLC groups involved in landscape and seascape planning. • Proportion of the adult population with secure tenure rights to land, across genders .
TARGET 23: Ensure Gender Equality and a Gender-Responsive Approach for Biodiversity Action
Possible landscape & seascape -related indicators
• Percentage of the population, across genders, in traditional occupations • Extent to which education for sustainable development, including gender equality and human rights, are mainstreamed at all levels in national education policies, curricula, teacher education and student assessments • Percentage improvement in the multiple dimensions of human well-being of households within a SEPLS region • Proportion of countries where the legal framework (including customary law) guarantees women's equal rights to land • ownership and/or control • Degree of application of a legal/regulatory/policy/institutional framework which recognizes and protects access rights for small-scale fisheries

5 DEFINITIONS

In addition to the definitions detailed in the VCS Program Definitions and VM0049, the following definitions applies to this methodology.

Ambient Air

Ambient air refers to the outdoor air in the surrounding environment, outside of buildings and industrial stacks that people and ecosystems are exposed to.

Baseline Scenario

In the absence of the proposed project activity and interventions, the on-site carbon dioxide emissions would continue to rise under conventional operations

Biomass Expansion Factor

The ratio of the total above ground biomass (stem, leaves, branches) to total living biomass of the plant

Biomass sources

Carbon/carbon dioxide sequestered would be stored in the plant biomass. The biomass in this methodology refers to the total mass of the living plant material that captures and stores carbon. These include stem, leaves, flowers and other plant parts visible above soil or planting medium

Carbon dioxide

A naturally occurring gas and a by-product of burning fossil fuels and biomass, as well as of land-use changes and other industrial processes. It is the principal anthropogenic greenhouse gas that affects the Earth's radiative balance

Carbon sources

Indoor carbon dioxide sources refer to the processes, activities or systems within enclosed spaces that release carbon dioxide into the indoor air. These processes include carbon emissions from combustion-based cooking methods such as gas stoves or ovens, fuel-burning appliances such as heaters, furnaces, or fireplaces that emit carbon dioxide during operations, activities like cigarettes smoking or burning candles and incense, and spaces with poor ventilation

Carbon capture

It refers to the process of separating and capturing carbon dioxide from large emission sources before it is released to the atmosphere for subsequent transport and long term storage

Direct air capture (DAC)

A process to capture and concentrate carbon dioxide from the enclosed environment or atmosphere

Dissolved Organic Carbon (DOC)

Organic carbon that remains in the sample after filtration of the solution

Dynamic baseline scenario

A dynamic change in the on-site carbon dioxide levels as a result of the project interventions, that are measured every two years and used as a new baseline scenario. The interventions include the adoption of new agricultural land management practices, such as crop rotation, low tillage, and changes in biomass accumulation, or use of plants to capture carbon dioxide from the atmosphere and project area

Indoor Air Quality

Indoor air quality refers to the quality of the air inside buildings and enclosed spaces, especially in terms of how it affects the health and comfort of occupants

Indoor Plants

Indoor Plants are the plant species that are specifically cultivated and maintained indoors to enhance the aesthetic appeal, improve air quality, and create a calming environment within indoor spaces like homes, offices, or public buildings

Indoor Plant Selection

It refers to the process of choosing plant species that are optimal for indoor environments, with emphasis on high photosynthetic rate, adaptability to low-light conditions, and resilience in confined spaces

Living Biomass

The mass of the living plant material, including above ground biomass (stem, leaves, branches) and below ground biomass (roots)

Model validation

The process of evaluating model performance relative to measured values, with a validated model having demonstrated satisfactory performance in terms of goodness of fit and characterization of model prediction error. Model validation must use datasets independent of those used in model calibration, unless a statistical approach like k-folding is applied (e.g., in a data-limited situation).

Model Validation Report

A document which must demonstrate that model calibration and validation are specific to the model being proposed for use in the project and appropriate for the land management system and biophysical conditions occurring in the project, and that requirements related to the assessment of

model bias and fit have been met. Data sources for calibration and validation datasets must be specified in the MVR, which is prepared by the project proponent.

Photosynthetic rate

The photosynthetic rate in indoor plants refers to the rate at which the plants convert carbon dioxide into biomass through light and water. This process, called photosynthesis, is typically measured in micromoles of carbon dioxide fixed per square meter of leaf area per second

Project Area

The area of the land on which the project proponent will undertake the project activities

Total Carbon

The sum of the organic and inorganic carbon including elemental carbon

Total Inorganic Carbon (TIC)

The measure of the carbon that is not covalently bound in the organic molecules, such as carbonate, bicarbonate and dissolved carbon dioxide

Total Organic Carbon (TOC)

The measure of the carbon stored in the organic material of the plants, derived from dry biomass after water removal

Woody Biomass

The mass of organic material in stems and branches, primarily in the form of lignified tissues

Wood Density

The mass per unit volume of the dry wood of a given species

Volatile Organic Carbon (VOC)

The sum of organic carbon that is not converted to carbon dioxide

6 APPLICABILITY CONDITIONS

This methodology is globally applicable to project activities that capture CO2 emissions from the ambient air. This module applies to project activities that capture CO2 from ambient air using the VM0049 and VM0056. This methodology is applicable under the following conditions:

1. Project activities include carbon sequestration through enhanced photosynthesis of "Indoor Plants"

2. The project involves the cultivation and maintenance of "Indoor Plants" to enhance carbon sequestration through photosynthesis

3. The "Indoor Plants" would be placed in residences, offices, educational institutions, or public buildings to contribute to the indoor air quality and carbon reduction.

4. The selected plants would demonstrate high photosynthetic efficiency and ability to grow in low-light or artificial light conditions. Peace Lily is one example of such plants.

5. Project must include provisions for maintaining optimal conditions for plant growth, including light sources (natural or artificial), humidity, and soil health.

6. Carbon captured must be stored in plant biomass, i.e. leaves, stems, and roots, or utilized in durable products.

7. The plants must be maintained for a significant period of time to ensure sustained carbon capture. Regular monitoring is required to replace dead or unhealthy plants.

8. Care should be taken to limit or avoid excessive emissions while performing maintenance activities, such as watering, fertilizing, reshaping, or pruning of the plants.

9. The buildings where plants are installed should have sufficient ventilation and space to accommodate plant growth without interfering in daily activities.

10. The project must avoid overuse of resources like water, synthetic fertilizers or pesticides that could offset carbon sequestration benefits.

11. Ensure that plant growth does not contribute to issues like mold or poor indoor air quality.

12. The project should not displace agricultural activities or negatively impact existing land-use practices. For example, plants should not come from regions where their extraction might harm biodiversity or ecosystems.

13. The project should involve stakeholders, such as building occupants or facility managers to ensure proper care and alignment with local needs.

14. In addition to carbon capture, the project must demonstrate added benefits, such as improving indoor air quality, reducing stress among occupants or enhancing aesthetics.

This methodology is not applicable under the following conditions:

1. In regions with limited access to water or high cost of maintaining optimal growth conditions, such as artificial lighting humidity control.

2. Indoor spaces in areas with poor air quality might accumulate dust or pollutants that negatively affect plant health and reduce their efficiency in carbon sequestration.

3. The project would not be applicable to conditions where artificial light conditions are powered by non-renewable energy sources.

4. Indoor Plants with relatively slow growth rates, limiting their overall capacity for carbon sequestration.

5. Maintenance cost of large number of Indoor Plants can be resource-intensive, requiring skilled personnel, time, and financial resources to meet sustainability goals.

6. Care should be taken against pests that are attracted toward Indoor plants, potentially offsetting environmental benefits.

7. Urban environments with limited indoor space may not exhibit significant applicability.

8. Temporary installations, such as seasonal plants, lack the longevity needed for measurable carbon capture.

7 PROJECT BOUNDARY

The project boundary encompasses all the plant cultivation areas, processing facilities and storage location. The project boundary defines all the physical, geographic, and operational aspects that influence carbon capture, emissions, and storage. The project boundary covers indoor spaces where the plants are cultivated for carbon capture, equipment supporting their growth and maintenance and process for biomass management or disposal.

- Indoor spaces: Buildings or rooms where plants are placed, such as residences, offices, commercial buildings, or public spaces. This also includes dedicated growing areas, with appropriate natural lighting, like green walls, planters, windows, ceilings or hydroponic systems.
- Supplementary equipment: These include tools or devices that support plant growth and maintenance, such as artificial lighting, humidifiers, fans, and irrigation systems.
- Carbon storage areas: These are the locations where the plant biomass or processed materials are stored or utilized.
- Carbon dioxide capture efficiency: Within the defined project boundary, improved air quality is demonstrated by a 15–20% reduction in indoor CO_2 concentration relative to the baseline, as quantified using the measurement methods and tools specified in this methodology.

Figure 1 A general overview of Carbon dioxide source included in the project boundary. The specific carbon dioxide capture and storage modules are depicted.

7.1 Temporal Boundaries

The temporal boundary is defined as the timeframe within which project activities, assessments, or impacts are measured. It establishes the start date, duration, and end date of a project, ensuring consistency in evaluating historical baselines and future projections. Temporal boundaries will determine the changes CO_2 emissions, agricultural field crop productivity over defined intervals for maintaining comparability, reliability, and adherence to this framework.

7.2 Geographic Boundaries

The geographic boundary 455000 hectare land area in the Yanshui District of Tainan City, Taiwan, defines the spatial extent within which activities, land management and environmental assessments occur. Located in southwestern Taiwan (23°16'00.8"N 120°14'29.0"E), the region is characterized by urban development, historic sites, and proximity to agricultural regions. The project area of 870.8 hectare serves the local ethnicities of Pingpu and Hokkien people of the region. The geographic boundary ensures consistency in monitoring soil health, air quality, and land use change for sustainability initiatives.

7.3 Carbon Pools

Carbon Pools including aboveground biomass, belowground biomass, soil organic carbon, and harvested products in the project boundary are included in the baseline and project scenarios. The aboveground biomass consists of crops, grasses, and vegetation that store carbon, while belowground biomass includes root systems that contribute to soil carbon through organic matter decomposition. Soil organic carbon is a critical long-term carbon reservoir, significantly affected by land use and management practices. The harvested agricultural products temporarily store carbon before consumption, use, or decay.

7.4 Sources of Greenhouse Gases (GHGs)

CO_2 sources such as electricity consumption, fossil fuel consumption on agricultural fields, liming, indoor venting emissions, indoor consumption of natural gas, and biomass burning are included in this project boundary in the baseline and project scenarios. If the impact of greenhouse gas sources, whether reducing carbon stocks or increasing greenhouse gas emissions, exceed 5% of the project's total greenhouse gas benefit, they cannot be omitted and must be included in calculations.

8 BASELINE SCENARIOS

Project proponents must accurately determine the activities and indoor carbon dioxide emissions that would have occurred in the absence of the project activity. This methodology framework aims at accurately determining the baseline scenario.

- Indoor carbon dioxide accumulation

  In the absence of the project, indoor carbon dioxide levels would continue to accumulate from common sources such as household appliances, gas appliances, indoor combustion from heaters, fireplace, or cigarettes, emissions from poorly ventilated spaces. The project proponent must demonstrate:

  1. Prior to implementation of the project, indoor spaces rely solely on natural or mechanical ventilation to manage carbon dioxide levels, resulting in no active carbon capture mechanisms.
  2. Provide evidence of typical indoor carbon dioxide sources, such as cooking activities, or combustion-based appliances.

- No active carbon capture

  Without indoor plants, there would be no natural process for actively removing carbon dioxide from indoor air. This results in a static or rising concentration of carbon dioxide over time. Project proponents must confirm:

  1. The baseline scenario does not include any indoor plants or other biological systems actively capturing carbon dioxide within the project area.
  2. The rise in the carbon dioxide concentration within an appropriate duration before the start of the project.

- Ventilation dependent emissions

  Project proponents must document and quantify reliance on Heating, Ventilation and Air Conditioning (HVAC) systems for managing indoor air quality. The baseline must show that this results in indoor carbon dioxide being displaced to outdoor air without reducing atmospheric carbon concentrations.

- Absence of vegetative carbon storage

  Project proponents must verify that the baseline scenario involves no plant biomass or other vegetative carbon storage medium within the project boundary.

Dynamic baseline scenario

The dynamic baseline scenario represents a scenario in which CO2 fluxes from the same agricultural fields evolve based on regional agronomic trends, climate conditions and updates to the land management practices that may be adopted without project intervention. This includes increased adoption of low-tillage practices, crop rotation policies for food security, changes in regional precipitation or temperature patterns affecting plant biomass accumulation, or voluntary shifts toward regenerative agriculture due to national policy incentives. The dynamic baseline is updated periodically (e.g., every 2 years) based on monitored reference plots or spatial datasets (e.g., remote sensing of normalized difference vegetation index (NDVI), soil carbon maps, or national GHG inventory updates) and reflects the expected carbon stock changes under a realistic, non-project intervention scenario. It serves as a moving benchmark to assess the additionality of project-induced carbon removals through improved crop selection, intercropping, agroforestry, or the integration of high-biomass cover crops.

In the absence of project activity, indoor environments (e.g., offices, residential buildings, commercial spaces) would continue to use ornamental plants primarily for aesthetic purposes. The plant selection would favor low-maintenance species with minimal carbon sequestration potential. Additionally, suboptimal placement, limited lighting, and irregular care would result in low photosynthetic efficiency, contributing negligibly to indoor CO2 capture. As a result, the indoor air quality improvements and measurable carbon removals would remain insignificant and unaccounted for, with no monitoring system in place to quantify any environmental service provided by indoor flora.

9 ADDITIONALITY

This methodology uses the project method to assess additionality using the following steps.

Step 1: Regulatory Surplus

Project proponents shall demonstrate regulatory surplus per the rules and requirements set out in the most recent version of the VCS Methodology Requirements.

Project proponents shall comply with the laws, statutes, regulatory frameworks, and policies applicable in the jurisdiction of the capture site(s).

Step 2: Implementation Barrier

Project proponents must demonstrate that they face an investment barrier (i.e., capital or investment return constraints) that would prevent the project from being implemented without carbon credit revenues.

To analyze the investment barrier, project proponents must conduct an investment analysis per Step 2 in the most recent version of CDM TOOL01 Tool for the Demonstration and Assessment of Additionality following Option III "Apply the benchmark analysis" and using CDM TOOL27 Investment Analysis.

The following also applies to the investment analysis:

1) The assessment must be from the perspective of the capture activity. Transport and storage activities must be treated as costs to the capture activity. This applies to both:
   a) Projects with diverse operatorships where costs may be incurred as real fees from transport and storage site operators; and
   b) Vertically integrated projects, where the project proponent must internally account for capital and operating costs of the transport and storage site(s).
2) Revenues (e.g., from subsidies paid by governments) from capture, transport (where applicable), and storage activities must be incorporated into the investment analysis (e.g., a fee per ton of CO_2 transported and/or stored), regardless of the owner/operator of the transport facilities and storage site(s). This does not apply to revenues arising from payments between capture, transport, and storage services as part of the project activities.
3) Where shared infrastructure is relevant to the economics of a project, costs or revenues must reflect the estimated (or contracted, where available) usage rate of transport and storage by each capture activity (e.g., where a capture activity uses 10% of the transport and storage capacity, the costs must be prorated and not reflect the cost of the entire transport and storage capacity).
4) Where multiple capture activities exist, the investment analysis must consider all capture activities in the project when demonstrating the existence of an investment barrier.
5) Where a project has undersubscribed transportation and/or storage usage at the time of the investment analysis, the expected usage rate, fee structure, and return on investment must be used

as inputs.

6) Revenue and indirect financial benefits (e.g., savings) for the CO_2 source facilities must be accounted for, regardless of whether the operators of source facilities and capture facilities are the same entity. Examples include:
   a) Savings from avoiding or reducing the payment of carbon tax or other fines/levies.
   b) Revenue generation based on the forecasted value of emissions allowances granted to the project activity for periods when Verified Carbon Units (VCUs) are not issued (VCUs are not issued for the reductions and removals benefit where emissions allowances are also granted); and
   c) Savings from avoiding or reducing costs for (flue) gas cleaning.
7) Payments from the capture facilities to the source facilities for the CO_2 captured are not considered costs in the investment analysis.
8) Funding from governments or other institutions in the form of grants, tax credits, concessional loans, guarantees, contracts for difference, negative emission payments, or other subsidies (all herein referred to as public support mechanisms) must be reflected as revenues, savings, or in the determination of the benchmark as applicable, regardless of whether the project is vertically integrated or has diverse ownership. However, public support mechanisms should not be considered in the financial additionality analysis where:
   a) The funder requires the project proponent to try to generate and sell carbon credits as a condition for the public support mechanism; and
   b) The carbon credit revenue (in whole or part) displaces funds from the public support mechanism that would have otherwise been provided to the project.

Contingencies for Operating and Maintenance Costs

Contingency costs account for costs that cannot be anticipated/forecasted when applying the investment analysis tool. Estimated contingency costs are expressed as a percentage of the operating and maintenance costs used in the investment analysis completed for a comparable prior activity. One of the following options must be used to determine contingency costs in the context of operating and maintenance costs of the project activity:

Option 1: Reference previously estimated contingency costs from other activities undertaken by the project proponent, with a comparable level of technological maturity and risk to the project activity at the time of the final investment decision.

Option 2: Reference actual historical contingency costs incurred when the project proponent implemented other activities using technologies with similar levels of maturity and risk to the project activity. The contingency costs are calculated by subtracting the actual operating and maintenance costs incurred over a given period from the estimated operating and maintenance costs for the same period. The estimated operating and maintenance costs must be obtained from background work such as feasibility studies to inform investment decisions.

Option 3: Use other approaches that have been applied in a relevant industrial sector (i.e., related to the applicable source facilities) to determine contingency costs, with a maximum value of 15% for this option.

Step 3: Common Practice

The project activity must not be common practice, determined for each capture activity included or added to the project as follows:

1) The project type must not be common practice in the respective sector and country.
   - Common practice is defined as the project activity implemented in more than 20% of comparable source facilities in the sector and country.
   - Similar project activities under validation, submitted for registration, or registered under any GHG crediting program may be excluded from the common practice analysis.
   - The "sector" refers to the source facility sector (e.g., fossil fuel or geothermal-based power and heat generation, industrial processes, oil and gas production and processing, bioethanol production, biomass power and heat).
   - Where a project includes multiple source facilities representing different sectors, each source facility requires a separate common practice assessment.
   - Where different types of capture facilities are included in the project, a common practice assessment is required for each.
   - DAC is not considered common practice by default, as there is no source facility.
2) Where similar activities exist, the project proponent must identify barriers faced compared with existing projects to underpin the risks, costs, and/or limitations to regular advancement of the project activity, to demonstrate that this is not common practice for the project activity.

Projects that demonstrate regulatory surplus, an investment barrier, and are not common practice are deemed additional.

Evidence must be provided in the form of publicly available information contained in:

a) Agricultural census or other government (e.g., survey) data;
b) Peer-reviewed scientific literature;
c) Independent research data; or
d) Reports or assessments compiled by industry associations.

To demonstrate common practice, the project area must be stratified to the state or provincial level (or equivalent second-order jurisdiction) in the countries where the project is being developed. Where supporting evidence is unavailable at the state/provincial level (e.g., in developing countries), aggregated data or evidence at a subnational, national, or regional level may be used with justification. Where stratification based on geopolitical boundaries is impractical (e.g., due to lack of data), other forms of stratification, such as major soil types or cropping zones, may be used with justification. The same stratification approach and data sources must be applied across the entire project to maintain the integrity of the common practice demonstration. Where a common practice assessment data source is unavailable for a subset of the project region, justification must be provided to use a different data source.

Where evidence for a single proposed project activity in the region is not available from any of these sources, the project proponent may obtain a signed and dated attestation statement from a qualified

independent local expert (e.g., agricultural extension agent, accredited agronomist) estimating the adoption rate for the weighted mean calculation. Where evidence on the suite of proposed activities is unavailable, a qualified independent local expert may provide a signed and dated attestation statement stating whether the proposed suite of project activities is common practice in the region and providing estimated values for the regional existing adoption rate of proposed project activities (EA_{ay}; see Equation (1)). All projects using independent local expert attestation must provide the qualifications of the expert and the methods used to inform their analysis.

Equation (1) must be applied to calculate the weighted mean adoption rate in each region included in the project area. In case the project involves only one activity, and the project proponent demonstrates that the adoption rate of that activity is below 20% in the region where the project area is located, Equation (1) is not required.

$$AR = (EA_{a1} \times PA_{a1}) + (EA_{a2} \times PA_{a2}) + \cdots + (EA_{ay} \times PA_{ay}) \quad (1)$$

Where:

$$PA_{a1} = \frac{Area_{a1}}{(Area_{a1} + Area_{a2} + \cdots + Area_{ay})}$$

$$PA_{a2} = \frac{Area_{a2}}{(Area_{a1} + Area_{a2} + \cdots + Area_{ay})}$$

$$PA_{ay} = \frac{Area_{ay}}{(Area_{a1} + Area_{a2} + \cdots + Area_{ay})}$$

and:

AR	= Weighted mean adoption rate in each region included in the project area (%)
EA_{ay}	= Existing adoption rate of proposed project activity ay in the region (%)
PA_{ay}	= Ratio of proposed project-level adoption of activity ay relative to sum of proposed project-level adoption of all activities in the project area
$Area_{ay}$	= Area of proposed project-level adoption of activity ay in the project area (hectares)
ay	= 1, …, ay proposed project activities

A project proponent may include areas where more than one project activity will be implemented on the same land (e.g., reduced tillage plus cover crops). Evidence of existing adoption rates for the combined (two or more) activities should be used to calculate the weighted mean adoption rate of the proposed combined activities (i.e., parameter EA_{ay} would represent the adoption rate of a combined activity as the two are implemented on the same land or field). Where evidence on existing adoption rates for the combined activities is not available, the project proponent may multiply the existing adoption rates (i.e., pre-project) of the individual activities to estimate the combined activity adoption rate. In practice, this encourages "stacking" of new activities to enhance reductions and/or removals compared to implementing only one new activity on a given area or farm. For example, with a statewide existing adoption rate of 40% for reduced tillage and 10% for cover-cropping, the adoption rate to be applied in Equation (1) for land combining (stacking) these two activities would be 4% (i.e., $EA_{ay} = 0.4 \times 0.1 = 0.04$).

Where Steps 1–3 are satisfied, the proposed project activity is additional.

10 QUANTIFICATION OF GREENHOUSE GAS EMISSION REDUCTIONS AND REMOVALS

This section establishes overarching quantification approaches for carbon dioxide reductions and removals.

10.1 Baseline Emissions

Baseline emissions refer to GHGs that would have occurred from the continued production of fossil-based hydrogen (e.g., SMR or ATR).

$$BE_{year,y} = H_y \times EF_{fossil\ H_2}$$

Where:

$BE_{year,y}$ = Baseline emissions in year y (tCO_2e)

H_y = Amount of hydrogen (in kg) displaced by the project in year y

$EF_{fossil\ H2}$ = Emission factor for fossil hydrogen production (kg CO_2e/kg H_2)

Emission factors shall be based on IPCC defaults, national databases, or validated life-cycle models (e.g., GREET, ecoinvent).

Baseline emissions are calculated for tons of carbon dioxide equivalent (t CO_2e), using Equation (2):

$$BE_y = \sum_i Q_{CO2,\text{appliances},y} + \sum_i Q_{CO2,\ \text{combustion sources},y} + \sum_i Q_{CO2,\text{HVAC systems},y} \quad (2)$$

Where:

BE_y = Baseline emissions of carbon in year, (t CO_2e) (y)

$Q_{CO2,appliances,y}$ = Mass of carbon dioxide measured from appliances at the injection point (i) in year (y) at the project boundary (t CO2e)

$Q_{CO2,combustion\ sources,y}$ = Mass of carbon dioxide measured from combustion sources such as gas stove and fireplace at the injection point (i) in year (y) at the project boundary (t CO_2e)

$Q_{CO2,HVAC\ systems,y}$ = Mass of carbon dioxide measured from HVAC systems at the injection point (i) in year (y) at the project boundary (t CO_2e)

10.2 Project Emissions

This subsection provides methods and guidance for measuring the amount of CO_2 for safe and permanent storage. The same methods apply for measuring the amount of CO_2 captured, transported, received, and leaving the project boundary as applicable.

To determine the quantity of carbon dioxide sequestered using Indoor plants, the project proponent must use the diameter (D) of the stem, height (H) of the plant, and using Equations (3–9):

$$\text{Above-Ground biomass} = 0.25 \times D^2 \times H \quad (3)$$

$$\text{Below-Ground biomass} = 0.2 \times \text{Above-Ground biomass} \quad (4)$$

$$\text{Total Biomass} = \text{Total Ground biomass} \times 1.2 \quad (6)$$

$$\text{Total Dry weight} = \text{Total Biomass} \times 0.725 \quad (7)$$

$$\text{Total Carbon weight} = \text{Total Dry weight} \times 0.5 \quad (8)$$

$$\text{Total Carbon dioxide sequestered (t } CO_2\text{e)} = \text{Total Carbon weight} \times 3.667 \quad (9)$$

The above ground biomass and below ground biomass in each plant can be estimated either using Allometric equations method.

The following steps can be followed:

a. Measure the diameter of the height (H) of the plant and the diameter (D) of the largest stem at its widest point. The variation in H and D may depend on the plant species and the weather conditions in the vicinity of the project area.
b. Establishing and applying appropriate allometric equations

Above-Ground Biomass calculations:

$$\text{Above-Ground Biomass (AGB) (kg)} = D \times H \quad (10)$$

Verification must be undertaken by destructively harvesting 5 branches or stems of the species or species group to which the equation is to be applied within the project area. The biomass of these plants must be measured and compared to the results derived from the equation. If the biomass measured from the harvested plant is not more than 10% less than that predicted by the Allometric equation, it can be assumed the selected equation is suitable for the project.

If this is not the case, it is recommended to develop local allometric equations for the project. In order to develop the equations, a sample of indoor plants, representing different size classes, is destructively harvested, and the total dry biomass of each plant is determined. The number of plants to be destructively harvested and measured depends on the range of size classes and number of species—the greater the heterogeneity the more plants are required. Finally, allometric equations are constructed relating the biomass with values from easily measured variables, such as the D and H.

Below-Ground Biomass calculations:

$$\text{Below-Ground Biomass (BGB) (kg)} = AGB \times R \quad (11)$$

where, R is root-to-shoot ratio.

$$\text{Total Ground biomass} = \text{Above-Ground biomass} + \text{Below-Ground biomass} \quad (12)$$

10.2.1 Calculation of the Total Biomass

Total Biomass comprises of smaller woody and non-woody vegetation, for which a destructive sampling method must be used. The steps in sampling and calculating biomass for smaller woody and non woody biomass are:

Step 1. Stratification and determination of distribution

Additionally, stratification of the project area, where more than one variety of indoor plants are available within the leakage belt or reference region, must be undertaken using the methods specified in VMD0018 Methods to Determine Stratification. During stratification, necessary attention must be given to the species and spatial distribution and ecological and management dynamics of the indoor plant and woody species.

Step 2. Sampling

Destructive sampling entails the collection of all aboveground material within the plant pot. As such, plant pots are typically relatively small, to avoid the necessity of collecting large amounts of material. Square pots of 1 m × 1 m are acceptable where the material is relatively evenly distributed at the individual plant level. Where more heterogeneous distributions are found, larger plant pots may be considered.

Step 3. Measurement of Biomass

Within the project area, all biomass is weighed, oven dried, and weighed again, to give both green and dry weights. Ideally the biomass is oven dried, to achieve “bone dry” conditions. However, drying in direct sun may also be used. In case biomass samples are weighed after sun drying, small representative subsamples need to be taken from the larger sample, weighed, oven dried as described above, and weighed again to determine the level of residual moisture in the weighed sample. The dry weights of the samples must then be adjusted accordingly, to provide an estimated oven dry weight of the biomass.

Step 4. Testing Statistical Confidence

Calculations to test the statistical confidence of the mean must be carried out on the total above ground biomass per plant. The error of the mean must not be greater than 10%, at a 90% confidence level.

Step 5. Calculation of Total Biomass

Total Biomass small woody and non-woody biomass per stratum is then calculated using the following equation:

$$B_s = \sum_s^w b_s \times 10^2 \times A_s^{-1} \times A \times (1 + R) \quad (13)$$

where,

B_s	= Total biomass including small woody and non-woody biomass living vegetation per stratum
s	= small biomass plants
w	= number of small biomass plants
b_s	= biomass of the collected small woody and non-woody vegetation in each plant (kg)
A_s	= Area of small biomass plant (m^2)
A	= Area of the stratum (m^2)
R	= Root-to-shoot ratio for small woody and non-woody biomass

10.2.2 Calculations for Total Organic Carbon (TOC)

TOC in the whole suspended plant biomass and in cell free supernatant can be determined by calculating the Total Carbon (TC) and subtracting the Total Inorganic Carbon (TIC), to avoid negative or inaccurate results and establishing a baseline. High concentrations of TIC can interfere with the absolute concentrations of TOC owing to the buffering capacity of carbonate and bicarbonate ions. Care should be taken to dry the living biomass by heat treatment. The amount of volatile organic carbon (VOC) must be determined accurately and removed from the solution by purging with VOC free gas to avoid interference with the absolute carbon dioxide stored in the living biomass.

Step 1. Sampling

The living biomass such as must be collected precisely in unused glass. The biomass may be heat-treated to ensure the removal of water. Post-heat treatment, the biomass must lose structural integrity and fall into pieces upon evaluation with a spatula. The weight of the sample must be recorded accurately, and mark as Dry Biomass.

Step 2. Calculation of TOC

TOC can be calculated using the following methods:

1. Samples with moisture or unknown Total Biomass:

$$TOC = \text{Total Biomass (kg)} \times (1 - \text{Moisture Content}) \quad (14)$$

where,
Moisture content in living biomass is typically 70%.

Additionally, the project proponents must evaluate the moisture content of living biomass in case Total Biomass calculations could not be employed.

2. Sample with known Total Biomass (calculated as per equation 12)

$$TOC = Total\ Biomass \times 0.5 \quad (15)$$

where,
0.5 is the most widely employed carbon content in plants
This equation can also be employed for samples prepared as per Step 3 of Section 4.3, replacing Total Biomass with the calculated Dry Biomass.

10.2.3 Calculations for the amount of Carbon Dioxide Stored in the plant

TOC determined from equation 11 can be used to calculate the amount of carbon dioxide stored in the plant, consequently determining the amount of carbon sequestered through the indoor plant. The ratio of the molecular weight of carbon dioxide to carbon can be multiplied with the calculated TOC to determine the accurate carbon sequestered using the plant.

$$Mass\ of\ CO_2\ sequestered\ (kg) = TOC\ (kg) \times \frac{Molecular\ weight\ of\ CO_2}{Mass\ of\ Carbon} \quad (16)$$

10.3 Project Emissions

Not applicable to this methodology. This subsection is intentionally left blank as no rewetting or fire-related activity is included in the green hydrogen project boundary.

The overarching equation for project emissions, tons of carbon dioxide equivalent (t CO_2e), is Equation (17):

$$PE_y = \sum_c PE_{Cap,c,y} + \sum_t PE_{Tra,t,y} + \sum_s PE_{Sto,s,y} \quad (17)$$

Where:

PE_y	= Project emissions in year y (t CO_2e)
$PE_{Cap,c,}$	= Project emissions from CO_2 capture activity (c) in year (y) (t CO_2e)
$PE_{Tra,t,y}$	= Project emissions from CO_2 transport activity (t) in year (y) (t CO_2e)
$PE_{Sto,s,y}$	= Project emissions from CO_2 storage activity (s) in year (y) (t CO_2e)

10.4 Leakage

The leakage emissions refer to the unintended carbon dioxide emissions that occur outside the project boundaries as direct or indirect result of the project activities. The overarching equation for leakage emissions is Equation (18):

$$LE_y = \sum_c LE_{Cap,c,y} + \sum_t LE_{Tra,t,y} + \sum_s LE_{Sto,s,y} \quad (18)$$

Where:

LE_y = Leakage emissions in year y (t CO_2e)
$LE_{Cap,c,y}$ = Leakage emissions from CO_2 capture activity (c) in year (y) (t CO_2e)
$LE_{Tra,t,y}$ = Leakage emissions from CO_2 transport activity (t) in year (y) (t CO_2e)
$LE_{Sto,s,y}$ = Leakage emissions from CO_2 storage activity (s) in year (y) (t CO_2e)

10.4.1 Market Leakage

Where manure or crop residue management is a component of the project activity, and the manure or crop residues are diverted from energy applications (e.g., fuel for cookstoves or biomass power generation) in the baseline scenario there is a risk of leakage. Implementation of the project activity may force these competing energy applications to use inputs which are not carbon neutral. Leakage emissions $LE_{BR,Div,t}$ must be determined following procedures in the CDM's TOOL16: Project and leakage emissions from biomass.

10.5Net GHG Emission Reductions and Removals

GHG emission reductions occur when:

1. Carbon stocks decrease from year t to year t + 1 in the baseline scenario and, to a lesser extent, in the project scenario. The cumulative carbon stock change in the project scenario is negative or zero (i.e., the project carbon stock at the end of the verification period is less than or equal to the carbon stock at the project start date).
2. Carbon stocks decrease from year t to year t + 1 in the baseline scenario and carbon stocks increase in the project scenario. Note that this variation may also generate carbon removals.
3. CO_2 emissions from fossil fuel combustion and liming are lower in the project than in the baseline scenario.
4. CH_4 emissions from the SOC pool (i.e., through soil methanogenesis), livestock enteric fermentation, manure deposition, and biomass burning are lower in the project than in the baseline scenario.
5. N_2O emissions from nitrogen fertilizers and nitrogen-fixing species, manure deposition, and biomass burning are lower in the project than in the baseline scenario.

10.5.1 Calculation of net CO_2 emissions reductions

Net CO_2 emission reductions are quantified as:

$$ER_{NET,t} = ER_t - LK_{ER,t} \qquad (19)$$

Where:

$ER_{NET,t}$ = Estimated net CO_2 emission reductions in year t (t CO_2e)
$LK_{ER,t}$ = Leakage allocated to CO_2 emission reductions in year t (tCO_2e)

Leakage allocated to emission reductions ($LK_{ER,t}$) is calculated as:

$$LK_{ER,t} = (LE_{OA,t} + LE_{BR,t}) \times \frac{ER_t}{ER_t + CR_t} \quad (20)$$

Where:

$LE_{BR,t}$ = Leakage emissions from the diversion of manure or crop residues from baseline energy applications in year t (t CO2e)

CR_t = Estimated carbon dioxide removals in year t (t CO2e)

Carbon dioxide removals occur when the cumulative carbon stock change in the project scenario is positive (i.e., the project carbon stock is higher than at the start date). Then, possible annual stock variation includes:

1. Carbon stocks increase from year t to year t + 1 in the baseline scenario and, to a greater extent, in the project scenario.

2. Carbon stocks decrease from year t to year t + 1 in the baseline scenario and carbon stocks increase from year t to year t + 1 in the project scenario.

Carbon dioxide removals are quantified as:

$$CR_t = I(\Delta CO2_{wp}) \times (MAX(0, \Delta CO2_{wp,t}) - MAX(0, \Delta CO2_{bsl,t})) \quad (21)$$

Where:

$I(\Delta CO2_{wp})$ = 1 if $\sum_1^t \Delta CO2_{wp,t} \geq 0$

$I(\Delta CO2_{wp})$ = 0 if $\sum_1^t \Delta CO2_{wp,t} \leq 0$

$I(\Delta CO2_{wp})$ = Switches Equation (21) on when the cumulative carbon stock change in the project scenario is positive, and off when the change is negative

Net carbon dioxide removals are quantified as:

$$CR_{NET,t} = CR_t - LK_{CR,t} \quad (22)$$

Where:

$CR_{NET,t}$ = Estimated net carbon dioxide removals in year t (t CO2e)

$LK_{CR,t}$ = Leakage allocated to carbon dioxide removals in year t (t CO2e)

Leakage allocated to carbon dioxide removals ($LK_{CR,t}$) is calculated as:

$$LK_{CR,t} = (LE_{OA,t} + LE_{BR,t}) \times \frac{CR_t}{ER_t + CR_t} \quad (23)$$

Net reductions and removals are quantified as:

$$ERR_{NET,t} = ER_{NET,t} + CR_{NET,t} \quad (24)$$

Where:
$ERR_{NET,t}$ = Estimated net reductions and removals in year t (t CO2e)

10.5.2 Calculation of net GHG emissions removals

Carbon dioxide removals can be calculated as per Equation (25):

$$ER_y = (BE_y - PE_y - LE_y) \times (1 - DF) \quad (25)$$

Where:
ER_y = Total net reductions or removals in year y (t CO_2e)
BE_y = Baseline emissions in year (y) as calculated in Equation (1) (t CO_2e)
PE_y = Project emissions in year (y) as calculated in Equation (9) (t CO_2e)
LE_y = Leakage emissions in year (y) as calculated in Equation (10) (t CO_2e)
DF = Discount factor for uncertainty calculated in Equation (12) (%)

10.5.3 Estimation of uncertainty

Uncertainty deductions are estimated within a project. Deductions are based on an estimate of the total error of the project's calculated reductions and removals for that source over a given verification period. Key sources of uncertainty that contribute to this error differ for each quantification approach. This section details these sources of error and methods to estimate such errors for use in an uncertainty assessment and calculation of the required uncertainty deduction.

Uncertainty guidance provided here assumes that all soil sampling/analysis and modeling occur on a point basis. In other words, the model is run in a manner to represent a single point in space at which initial soil data and management data have been collected, and uncertainty is calculated by combining estimates of sampling, modeling, and measurement error based on the design chosen to select the points. Alternative approaches (e.g., modeling on an areal basis) are considered a deviation and project proponents must demonstrate that such approaches will not negatively impact the conservativeness of reduction and removal estimates per the most recent version of the VCS Standard.

Across quantification approaches, a key source of error is sampling error, which emerges from only being able to measure/model a portion of the total project area. Appropriate estimates of this source of error are specific to the sample design employed. This methodology requires that stratified random sampling is used. Strata should be based on physical and management factors that minimize within-strata variability. Individual sample points are allocated randomly within those strata on a proportional basis by area.

The remainder of this section is based on a simplified example of a stratified random sampling design in which the entire project is divided into strata and points within those strata are placed

using simple random sampling with replacement. Where a project proponent elects to use an alternative design via a methodology deviation, they must provide a similar demonstration of uncertainty calculations that consider the same sources of error identified here and that are appropriate to the chosen design.

Uncertainty of measurement error from leakage emissions from the production of capture materials is considered de minimis where the magnitude of the leakage emissions from the production of capture materials is less than 2% of the net emission reduction or removal benefit of the project. Uncertainty of measurement or estimation error from venting emissions from project fuel consumption is considered de minimis where the magnitude of the emissions from venting is less than 2% of the net emission reduction or removal benefit of the project. Proponents whose projects do not meet the above conditions for a source of uncertainty must include that source of uncertainty in their uncertainty assessment described in section 8.5 of VM0049

This methodology involves the process for determining the uncertainty associated with the project activity. The uncertainty is defined by the variability in photosynthetic rate, variability in plant growth and plant health, carbon dioxide concentration fluctuations, variability in availability of natural or artificial light, ventilation and airflow, plant lifespan and replacement, and maintenance activities.

Identification and Assessment of Uncertainties

Step 1: Identify Potential Sources of Uncertainty

Examine all steps in the carbon dioxide calculation process to identify potential sources of uncertainty, including measurement errors, model assumptions, and data quality issues.

Step 2: Calculation of Overall Uncertainty ($U_{overall}$)

The project proponent must calculate the overall uncertainty in the volume of net reductions and removals using one of the following approaches.

- Error Propagation: Use error propagation equations to combine uncertainties from various data sources and measurement errors. Project proponents may follow Volume 1, Chapter 3, Section 3.2.3.1 in IPCC (2006) to estimate overall uncertainty.
- Monte Carlo Simulations: Employ Monte Carlo simulations for more complex or interdependent data sources to model the probability distributions of inputs and calculate the resulting distribution of the emission estimates. This technique is beneficial when dealing with non-linear relationships or when input variables are not independent.

Step 3: Calculation of Discount Factor (DF)

The project proponent must apply a discount factor to the calculated net reductions and removals. The discount factor is identified as follows:

1) Where the overall uncertainty calculated in Step 2 is unlikely to exceed 10%, the discount factor may be estimated to be zero.
2) Where the overall uncertainty calculated in Step 2 is likely to exceed 10%, the discount factor must be calculated with the following equation.

$$DF = \frac{U_{Overall}}{t_{\alpha=10\%}} \times xt_{\alpha} = 66.6\% \quad (26)$$

Where:

DF	= Discount factor for conservativeness (%)
$U_{overall}$	= Overall uncertainty (%)
$t_{\alpha=10\%}$	= t-value for a two-sided 90% confidence interval, equal to (1.6449)
$t_{\alpha=66.690\%}$	= t-value for a one-sided 66.67% confidence interval, equal to (0.4307)

10.5.4 Calculation of carbon credits

The calculations for carbon credits involve quantifying the amount of carbon dioxide emissions reduced or sequestered by the project. Each carbon credit typically represents one metric ton of carbon dioxide emissions mitigated. The project proponents can use the Equation (27) for determining carbon credits through this methodology:

Carbon credits (t CO_2e) = Total net reductions in year (t CO_2e) – Leakage emissions in year (t CO_2e) (27)

To calculate the number of carbon credits or Verified Carbon Units (VCUs) that may be issued, the project proponent must consider the number of buffer credits that must be deposited in the AFOLU pooled buffer account. The number of buffer credits that must be deposited is calculated by multiplying the non-permanence risk rating by the net change in carbon stocks. The buffer credits are quantified as:

$$Bu_{ER,t} = I(\Delta CO2_{wp}) \times \left(MIN(0, \Delta CO2_{wp,t}) - MIN(0, \Delta CO2_{bsl,t})\right) \times NPR\% + (1 - I(\Delta CO2_{wp}) \times (MIN(0, \Delta CO2_{wp,t}) - MIN(0, \Delta CO2_{bsl,t}) + MAX(0, CO2_{bsl,t}) \times NPR\% \quad (28)$$

Where:

$I(\Delta CO2_{wp})$	= 1 if $\sum_1^t \Delta CO2_{wp,t} > 0$
$I(\Delta CO2_{wp})$	= 0 if $\sum_1^t \Delta CO2_{wp,t} \leq 0$
$Bu_{ER,t}$	= Buffer credits to be deducted from reductions in year t (t CO2e)

$$Bu_{CR,t} = I(\Delta CO2_{wp}) \times \left(MAX(0, \Delta CO2_{wp,t}) - MAX(0, \Delta CO2_{bsl,t})\right) \times NPR\% \quad (29)$$

Where:

$I(\Delta CO2_{wp})$	= 1 if $\sum_1^t \Delta CO2_{wp,t} > 0$

$I(\Delta CO2_{wp})$ = 0 if $\sum_1^t \Delta CO2_{wp,t} \leq 0$
$Bu_{CR,t}$ = Buffer credits to be deducted from removals in year t (t CO2e)
$\Delta CO2_{wp,t}$ = Total carbon stock change in the project scenario in year t (t CO2e)
$\Delta CO2_{bsl,t}$ = Total carbon stock change in the baseline scenario in year t (t CO2e)
NPR% = Overall project non-permanence risk rating converted to a percentage

The number of VCUs resulting from project activities leading to reductions that may be issued in year t is calculated as:

$$VCU_{ER,t} = ER_{NET,t} - Bu_{ER,t} \quad (30)$$

Where:
$VCU_{ER,t}$ = Number of VCU resulting from project activities leading to reduction in year t
$ER_{NET,t}$ = Estimated net reductions in year t (t CO2e)

The number of VCUs resulting from project activities leading to removals that may be issued in year t is calculated as:

$$VCU_{CR,t} = CR_{NET,t} - Bu_{CR,t} \quad (31)$$

Where:
$VCU_{CR,t}$ = Number of VCUs resulting from project activities leading to removals in year t
$CR_{NET,t}$ = Estimated net removals in year t (t CO2e)

The number of VCUs that may be issued in year t is calculated as:

$$VCU_t = VCU_{ER,t} + VCU_{CR,t} \quad (32)$$

Where:
VCU_t = Number of VCUs in year t (t CO2e)

11 MONITORING

11.1 Data and Parameters Available at Validation

Data/Parameter	M_{CO2}
Data unit	g/mol
Description	Molar mass of CO_2
Source of data	The most recent version of the CDM TOOL06 Methodological Tool:

	Project Emissions From Flaring
Value applied	44.0095
Justification of choice of data or description of measurement methods and procedures applied	A physical constant
Purpose of data	Calculation of baseline and project emissions
Comments	N/A

Data/Parameter	STP
Data unit	K and Pa
Description	Standard temperature and pressure
Source of data	Industry practice
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Standard temperature and pressure must be defined to allow the conversion of volumetric flow from operating to standard conditions.
Purpose of data	Determining CO_2 density
Comments	The project description must clearly identify the standard temperature and pressure used as a reference.

Data/Parameter	$\rho CO_{2x(STP)}$
Data unit	t CO_2/m^3
Description	Density of CO_2 at flow meter x at standard temperature and pressure
Equations	(4), (6)
Source of data	Internationally accepted datasets following equation of states as applicable (e.g., Span and Wagner, 1996)
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Density depends on temperature and pressure as defined under standard temperature and pressure conditions.

Purpose of data	Calculation of baseline and project emissions
Comments	The project description must clearly identify the standard temperature and pressure used as a reference.

11.2 Data and Parameters Monitored

Data/Parameter	$FR_{mass,x}$
Data unit	tonnes
Description	Mass flow measured by mass flow meter x
Equations	(2)
Source of data	Mass flow meters
Description of measurement methods and procedures to be applied	Mass flow rates must be determined by commercially available devices that measure the mass flow rate of a fluid flowing through a measurement channel (e.g., Coriolis meters, thermal meters, impeller meters, twin turbine meters).
Frequency of monitoring/recording	Monitored continuously (i.e., one measurement at least every 15 minutes)
QA/QC procedures to be applied	The metering equipment must be installed and calibrated in accordance with the specifications of either local/national standards or the manufacturer. Where local/national standards and manufacturer specifications are unavailable, international standards (e.g., IEC, ISO) must be followed.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Direct measurement (preferred) or the accumulated mass for each sampling interval of mole fractions (composition analysis)
Comments	For further guidance see US EPA (2010). General Technical Support Document for Injection and Geologic Sequestration of Carbon Dioxide: Subparts RR and UU GHG Reporting Program.

Data/Parameter	M_k
Data unit	g/mol
Description	Molar mass of component k
Equations	(3)
Source of data	Physical property tables

Description of measurement methods and procedures to be applied	N/A
Frequency of monitoring/recording	To be updated based on components k found in the CO_2 stream
QA/QC procedures to be applied	N/A
Purpose of data	Calculation of baseline and project emissions
Calculation method	N/A
Comments	N/A

Data/Parameter	X_{CO2}
Data unit	% mole
Description	Mole fraction of CO_2 in flow at flow meter x
Equations	(3), (5)
Source of data	Composition analysis
Description of measurement methods and procedures to be applied	Mole fractions must be determined by commercially available devices. **Option A**: gas chromatography **Option B**: gas chromatography with IR spectroscopy
Frequency of monitoring/recording	**Option A**: Monitored every 15 minutes and aggregated weekly **Option B**: Monitored every 15 minutes and aggregated monthly
QA/QC procedures to be applied	The metering equipment must be installed and calibrated in accordance with the specifications of either local/national standards or the manufacturer. Where local/national standards and manufacturer specifications are unavailable, international standards (e.g., IEC, ISO) must be followed.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Direct measurement **Option A**: Use the lower value of two consecutive composition analyses to calculate continuous (i.e., at least every 15 minutes) values between the two composition measurements. **Option B**: Use values from IR spectroscopy measurements
Comments	For further guidance see US EPA (2010).

Data/Parameter	X_k
Data unit	% mole
Description	Mole fraction of component k in flow at flow meter x
Equations	(3), (5)
Source of data	Composition analysis
Description of measurement methods and procedures to be applied	Mole fractions must be determined by commercially available devices. **Option A**: gas chromatography **Option B**: gas chromatography with IR spectroscopy
Frequency of monitoring/recording	**Option A**: Monitored every 15 minutes and aggregated weekly **Option B**: Monitored every 15 minutes and aggregated monthly
QA/QC procedures to be applied	The metering equipment must be installed and calibrated in accordance with the specifications of either local/national standards or the manufacturer. Where local/national standards and manufacturer specifications are not available, international standards (e.g., IEC, ISO) must be followed.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Direct measurement **Option A**: Use the lower value of two consecutive composition analyses to calculate continuous (i.e., at least every 15 minutes) values between the two composition measurements. **Option B**: Use values from IR spectroscopy measurements.
Comments	For further guidance see US EPA (2010).

Data/Parameter	x(P,T)
Data unit	Pa and K
Description	Pressure and temperature at operating conditions in flow at flow meter x
Equations	(6)
Source of data	Pressure and temperature meters
Description of measurement methods and procedures to be applied	Instruments with recordable electronic signals (analog or digital) are required (e.g., pressure transducers, thermocouples, thermistors).
Frequency of monitoring/recording	Monitored continuously (i.e., same time interval as flow rate measurement)

QA/QC procedures to be applied	The metering equipment must be installed and calibrated in accordance with the specifications of either local/national standards or the manufacturer. Where local/national standards and manufacturer specifications are unavailable, international standards (e.g., IEC, ISO) must be followed.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Average value over the same time interval as the flow rate measurement
Comments	N/A

Data/Parameter	$FR_{vol,x(P,T)}$
Data unit	m^3
Description	Total volume measured by flow meter x at actual conditions during the monitoring period
Equations	(6)
Source of data	Volumetric flow meters
Description of measurement methods and procedures to be applied	Volumetric flow must be determined by commercially available devices that measure the flow of a fluid through a measurement channel (e.g., rotameters, turbine meters, orifice meters, wedge meters, ultra-sonic flow meters, vortex flow meters).
Frequency of monitoring/recording	Monitored continuously (i.e., one measurement at least every 15 minutes)
QA/QC procedures to be applied	The metering equipment must be installed and calibrated in accordance with the specifications of either local/national standards or the manufacturer. Where local/national standards and manufacturer specifications are not available, international standards (e.g., IEC, ISO) must be followed.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Flow is measured directly and aggregated for reporting period to calculate total volume.
Comments	For further guidance see US EPA (2010).

Data/Parameter	$\rho CO2_{x(P,T)}$
Data unit	t CO_2/m^3
Description	Density of CO_2 at actual conditions at flow meter x

Equations	(6)
Source of data	Internationally accepted datasets following equation of states as applicable
Description of measurement methods and procedures to be applied	Density is derived from the measurement of temperature and pressure at actual conditions.
Frequency of monitoring/recording	Aligned to the measurement of $FR_{vol,x(P,T)}$
QA/QC procedures to be applied	N/A
Purpose of data	Calculation of baseline and project emissions
Calculation method	Density of CO_2 at actual conditions
Comments	For further guidance see US EPA (2010).

11.3 Description of the Monitoring Plan

The monitoring plan includes:

The project proponent must establish, maintain, and apply a monitoring plan and carbon dioxide information system that includes criteria and procedures for obtaining, recording, compiling, and analyzing data, parameters, and other information important for quantifying and reporting carbon dioxide emissions relevant to the project and baseline scenarios. The monitoring procedures must address the following:

1. Types of data and information to be reported.
2. Units of measurement.
3. Origin of the data.
4. Monitoring methodologies (e.g., estimation, modeling, measurement, and calculation).
5. Type of equipment used.
6. Monitoring times and frequencies.
7. QA/QC procedures.
8. Monitoring roles and responsibilities, including experience and training requirements.
9. Carbon dioxide information management systems, including the location, backup, and retention of stored data.

Where measurement and monitoring equipment is used, the project proponent must ensure the equipment is calibrated according to current good practice (e.g., relevant industry standards).

Quality assurance/quality control (QA/QC) procedures must include, but are not limited to:

a) Data gathering, input, and handling measures.
b) Checking input data for typical errors, including inconsistent physical units and unit conversion

errors.

c) Checking for typographical errors caused by data transcription from one document to another and missing data for specific time periods or physical units.
d) Checking input time series data for unexpected variations (e.g., orders of magnitude) that may indicate input errors.
e) Use of version control for all electronic files to ensure consistency.
f) Physical protection of monitoring equipment.
g) Physical protection of records of monitored data (e.g., hard copy and electronic records).
h) Checking and documenting data units.
i) Documenting all sources of data, assumptions, and emission factors.

Additional criteria and procedures for monitoring are established in respective capture, transport, and storage modules and related VCS and CDM tools.

11.4 Data, Parameters, and Description of the Monitoring Plan to Practice the Strategy and Plan of Action 2023 -2030 of the International Partnership for the Satoyama Initiative

The monitoring system aligns with the Satoyama Initiative's goal of integrating socio-ecological

The following indicators will be taken into account to measure the progress of implementing the strategic objectives during the process of developing mid-term and final implementation reports. These indicators may be revised and updated in line with the finalization of the monitoring framework for the Kunming Montreal Global Biodiversity Framework expected to take place at Sixteenth meeting of the Conference of the Parties (COP-16) to the Convention on Biological Diversity (CBD).

Key indicator

Number of IPSI members, Number of case studies, Number of publications on SEPLS produced by IPSI and its members, including academic papers, SITR, books, and reports, Number of IPSI newsletters published, Number of academic papers and publications which refer to IPSI-related work, Number of MEA decisions and NBSAPs referring to IPSI-related work, Number of IPSI-related conferences and meeting, Number of people trained by relevant capacity development activities, Increased capacities of IPSI members and related stakeholders in knowledge documentation and transfer, research, and educational activities concerning SEPLS management, Number and area of SEPLS reported as PAs and/or OECMs, Better management effectiveness of PAs and/or OECMs through SEPLS management, Number of IPSI member organizations engaged in restoration activities, Number and area or volume of SEPLS under ecosystem restoration, Number of IPSI members able to take advantage of sustainable trade initiatives, Number of case studies documenting best practices and success stories of economic, market, and financial mechanisms, Increase in uptake of products from SEPLS and the SEPLS concept in activities of actors outside the SEPLS (e.g. consumers, planners outside SEPLS, private sector), Number of initiatives implemented for each strategic objective, Number of SDGs targets to which IPSI made a contribution, Number of targets of the Kunming-Montreal GBF to which IPSI made a contribution.

11.5 Data, Parameters, and Description of the Monitoring Plan to Practice the Kunming-Montreal Global Biodiversity Framework

Montreal Global Biodiversity Framework

To effectively implement the Kunming-Montreal Globa Biodiversity Framework (KMGBF), this methodology integrates multi-scale data, measurable indicators, and robust technologies that support real-time tracking, validation, and adaptive biodiversity governance. The integration of multiple independently functioning subsystems (e.g., satellite imaging, drone monitoring, field data, community-based sensing) produce synergistic monitoring capabilities.

The monitoring framework is anchored on a hybrid data architecture combining:

- Satellite-based remote sensing: Utilize long-term satellite imagery to assess land use and vegetation dynamics over time. For example, FORMOSAT-5 (3m resolution) and FORMOSAT-8 (1m resolution) provide frequent observations ideal for seasonal monitoring of agricultural lands and conservation corridors.
- Drone mapping: Drone imagery for localized, high-resolution monitoring (≤10 cm per pixel), particularly in smallholder agricultural landscapes, SEPLS, and forest-agriculture interface zones. Drone imagery will support canopy analysis, erosion detection, and tree health assessment.
- Conduct field validation of remotely sensed data via GPS-tagged ecological surveys. Plot-level data such as tree DBH, species composition, and soil carbon content will serve as ground-truth reference points.
- Incorporate indigenous and local community observations into the MRV system, especially for areas beyond technological coverage. This supports inclusivity and validates satellite/drone interpretations with cultural landscape knowledge.
- Socio-economic datasets such as land tenure, resource dependency, and biodiversity-dependent livelihoods.

Table 3 Data Parameters Monitored for KMGBF

Subsystem	Function	Technology/Equipment
Satellite-based Monitoring	Macro-scale land use, vegetation trends	FORMOSAT-5, FORMOSAT-8
Drone-based UAVs	High-res mapping, microhabitat monitoring	RGB/multi-spectral drones
Field Ecological Surveys	Species-level data, validation	GPS-tracked biodiversity and carbon plots
IoT & Smart Sensors	Real-time environmental sensing	Soil moisture, CO_2, humidity sensors
Indoor CO_2 Plant Systems	Carbon removal tracking in closed systems	AI + sensor integration
Community-based Monitoring	Local and indigenous knowledge	Mobile apps, participatory mapping

Carbon Credit Platforms	Climate finance verification	Verra, Gold Standard, ISO 14064
AI/ML Analytics Systems	Data harmonization, pattern detection	LLMs, time-series remote sensing analytics

11.6 Key Performance Indicator

The Kunming-Montreal Global Biodiversity Framework has 23 action-oriented global targets for urgent action over the decade to 2030. The actions set out in each target need to be initiated immediately and completed by 2030. Together, the results will enable the achievement of the outcome-oriented goals for 2050. Actions to reach these targets should be implemented consistently and in harmony with the Convention on Biological Diversity and its Protocols and other relevant international obligations, considering national circumstances, priorities, and socioeconomic conditions.

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APPENDIX

BACKGROUND INFORMATION

A1.1 Justification for the Use of the Project Method to Demonstrate

Additionality

The selection of the project method for assessing additionality is based on the following considerations pertinent to CCS projects:

- Complex regulatory and operational environments: CCS projects are subject to a diverse array of legal, technological, and market conditions that vary significantly across jurisdictions. The project method allows for an in-depth and conservative examination of these factors on a project-by-project basis, ensuring that assessments of regulatory surplus and specific implementation barriers are accurately discussed.
- Investment barriers: Given the high capital requirements, technological uncertainties, and potential for variable financial returns associated with CCS projects, demonstrating investment barriers is a central component of establishing additionality. The project method effectively addresses this by incorporating detailed investment analysis tools, enabling a nuanced evaluation of the financial viability and specific economic challenges faced by CCS projects.
- Technology-specific considerations: The range of technologies involved in CCS, each with a different level of maturity and implementation challenges, necessitates a method that can accommodate such variability. The project method allows for the consideration of technology specific factors, including performance, integration complexity, and scalability, which are vital for assessing the additionality of CCS projects.
- Sectoral and geographic variability: CCS encompasses a broad spectrum of activities across various sectors and regions, each with distinct attributes and challenges. The flexibility of the project method in evaluating additionality for different capture activities, sectors, and geographic contexts ensures that the unique aspects of various CCS applications are adequately considered.
- Dynamic market conditions: The evolving nature of policies, technologies, and market dynamics impacting the CCS sector requires an additionality assessment approach that can adapt to changing conditions. The project method provides a structured, flexible framework that facilitates incorporation of the most recent and relevant data, reflecting the dynamic environment in which CCS projects operate.

A1.2 Materiality Threshold

The materiality threshold determines which leakage emissions are material and are either included in the GHG quantification or excluded. A leakage source has been included in the quantification where it is estimated to equal more than 2% of the net project reductions and removals over the anticipated typical project lifetime. Total excluded leakage emissions must not exceed this 2% threshold in total.

The following leakage sources are excluded.

1) Production and transport of equipment and materials used for construction of project facilities;

2) Research and development activities;

3) Staff commuting; and

4) Direct and indirect land use change due to construction and operation of project facilities and equipment.

A1.3 Model Validation Report

Model validation involves assessing the model's performance against observed data, ensuring it meets standards for fit quality and prediction error characterization. This section details the necessary procedures for conducting validation. It is important to note that once a model has been validated, its parameters cannot be altered when applying it to simulate baseline scenarios and practices. Every parameter set must undergo validation in accordance with the guidelines provided. If the minimum requirements fail to validate all parameter sets and no further validation steps are taken, those unvalidated sets are deemed ineligible for project implementation.

Each monitoring report must be accompanied by a Model Validation Report (MVR) that adheres to the specified requirements and guidance. Model validation—including the approval of MVRs—must be completed and confirmed no later than the conclusion of project verification activities. Although not mandatory, it is strongly recommended that MVRs be submitted for Initial Methodological Evaluation (IME) during the project validation phase. Project proponents must use VMD0053v2.1 for detailed procedures for IME assessment.

MVR must be tailored to the specific project, clearly demonstrating model validation within the defined project domain. MVRs must either:

- Undergo independent evaluation by an IME, appointed by the Validation/Verification Body (VVB), who satisfies the minimum qualifications established by Verra; or
- **Be accepted for publication in one of the peer-reviewed journals listed in VMD0053v2.1, with subsequent review by an IME meeting Verra's qualification criterion. In the case of peer-reviewed publications, the following conditions apply:**
    - **If the manuscript has passed peer review and is accepted for publication—with revisions that do not alter model validation as defined in this guidance—it may serve as an MVR prior to formal publication. The project proponent must submit both the manuscript and documented responses to all reviewer comments, confirming that revisions do not affect model validation procedures.**
    - **Alternative validation approaches may be permitted, provided the publication includes clearly separated datasets for model calibration and validation, and peer reviewers deemed the model suitable for the specified biophysical domain and practices.**
    - **The publication must fully align with domain criteria outlined in Sections 5.2.2 and 5.2.3 of and must cover the PCs and CFGs described in Section 5.2.1 of VMD0053v2.1.**
    - The same datasets used in the peer-reviewed model validation must be used to calculate model prediction error in the project and evaluate model uncertainty.
    - The same model version and model parameter values/parameter set values must be used in the paper as are used in the project.
    - As a means of enhancing transparency with peer reviewers, the authors must clearly state the purpose of the paper as being to validate the model for use in generating verifiable carbon credits and therefore the ISO 14064 principles for GHG accounting should be kept in mind.
    - The project proponent must submit a sub-report outlining how the above requirements have been met and clarifying any aspects of the peer-reviewed paper as it pertains to the overall requirements of the MVR.

For subsequent monitoring reports, the MVR remains valid as long as the project area is unchanged or only expanded to include new fields that fall within the previously validated domain. Model recalibration or revision is allowed based on updated data, or a new model may be introduced, provided

that the same model version with identical parameters/parameter sets is consistently applied to both baseline and project scenarios.

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DOCUMENT HISTORY

Version	Date	Changes & Comment
v1.0	21 July 2025	Initial version

SATOYAMA INITIATIVE

Methodology

Me0004

Methodology for Crop Rotation in Integrated Agricultural Land-use Systems

Version 1.0
Published 05 January 2026
GBF 1、3、7、8、11、13、17

Version 1.0 of this methodology was developed by Ph.D. Amit Kumar Sharma (National Cheng Kung University) and Ph.D. Chen-Piao Yen.

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1 Source

This methodology is based on the following methodologies:

- VM0042 Improved Agricultural Land Management – Version 2.1
- VM0051 Improved Agricultural Land Management in Rice Production Systems – Version 1.0
- VM0036 Methodology for Rewetting Drained Temperate Peatlands – Version 1.0
- VMD0056 CO2 Capture from Air (Direct Air Capture) – Version 1.0
- VM0049 Carbon Capture and Storage – Version 1.0
- Geologic Carbon Storage (GCS) Non-Permanence Risk Tool

This methodology uses a Storage Module developed for Carbon Capture and Storage using Indoor Plants based on the following methodology:

- VMD0022 Estimation of Carbon Stocks in Living Plant Biomass
- CDM TOOL09 Determining the baseline efficiency of thermal or electric energy generation systems
- CDM TOOL10 Tool to determine the remaining lifetime of equipment
- CDM Tool for Testing Significance of GHG Emissions in A/R CDM Project Activities
- CDM TOOL16 Project and Leakage Emissions from Biomass

2 Summary Description of the Methodology

This methodology provides procedures to estimate the greenhouse gas (GHG) emission reductions (CO_2, CH_4, and N_2O) and carbon dioxide removals (reductions and removals) resulting from the adoption of advanced agricultural land management (ALM) practices.

This methodology considers new agricultural biotechnology methods to assist in improving the soil organic carbon storage while increasing the agricultural yield in the region. The baseline scenario considers the ongoing ALM practices before the implementation of the project in year 0. These practices are established by reviewing a minimum of three years of historical data to develop an annual activity schedule. Key operations such as tillage, planting, harvesting, and fertilization are applied throughout the baseline period. The baseline emissions are modeled to establish reference conditions, that are periodically reevaluated in accordance with the latest version of the VM0042 and updated as necessary to reflect current agricultural production trends in the region. A dynamic baseline is considered that focuses on the timely impact of climate change on the ALM practices by comparing the reductions or removals of GHG emissions to the baseline emissions. This periodical update in the baseline reflects the improvements accurately for long-term projects.

Additionality is evaluated based on the adoption of one or more new practice, discontinuation of pre-existing practice, adjustment to a pre-existing practice, or a combination of the above. The adjustments are valid in conditions which demonstrate more than 5% of the pre-existing practices, for example, conserving tillage, frequency of crop rotation, and quantity of fertilizers.

3 Relation to Strategy and Plan of Action 2023 -2030 of the International Partnership for the Satoyama Initiative

The present Strategy and Plan of Action 2023-2030 of the International Partnership for the Satoyama Initiative (IPSI) identifies five strategic objectives as described below.

- Knowledge Co-Production, Management, and Uptake: Conduct research and knowledge management related to landscape and seascape approaches to address direct and underlying causes responsible for the loss of biological and cultural diversity as well as ecological and socio-economic services from SEPLS.

- Institutional Frameworks and Capacity Development: Strengthen institutional frameworks and develop capacity to integrate landscape and seascape approaches into policies and cross sectoral strategies related to biodiversity, climate change, sustainable land and sea management, health, agri-food systems, and disaster risk reduction to maintain or enhance the benefits of SEPLS to the environment and society.

- Area-Based Conservation Measures: Promote effective conservation and management through protected areas and other effective area-based conservation measures (OECMs), recognizing indigenous and traditional territories where applicable, and facilitate their integration into the wider landscape and seascape to contribute to the relevant targets of the Kunming-Montreal Global Biodiversity Framework.

- Ecosystem Restoration: Promote the restoration of SEPLS and contribute to the goals of the United Nations Decade on Ecosystem Restoration and relevant targets of the Kunming-Montreal Global Biodiversity Framework.

- Sustainable Value Chain Development: Promote sustainable practices, market-based mechanisms, and value chains to support sustainable production, including customary sustainable use and economies that rely on traditional knowledge and cultural values and practices, from SEPLS to contribute to the achievement of relevant targets of the Kunming-Montreal Global Biodiversity Framework.

The IPSI Secretariat will work with the Steering Committee and IPSI members, as soon as possible, to develop an actionable implementation plan for achieving the strategic objectives and priority actions below. This plan will include resource mobilization activities and, if possible, a conceptual diagram illustrating the relationships between the objectives and actions, as well as improvements to the functioning of IPSI, such as the IPSI Collaborative Activities mechanism, membership procedures, partner engagement, and events, as soon as possible.

4 Relation to Kunming-Montreal Global Biodiversity Framework

The vision of the Kunming-Montreal Global Biodiversity Framework is a world of living in harmony with nature where "by 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people."

4.1 Description

The Kunming-Montreal Global Biodiversity Framework outlines 23 action-driven global targets aimed at addressing biodiversity challenges over the decade leading up to 2030. Each target requires immediate initiation and completion by 2030 to collectively advance progress toward the broader outcome-oriented goals set for 2050. The implementation of these actions should align with the Convention on Biological Diversity and its Protocols, as well as other relevant international commitments, while considering national contexts, priorities, and socioeconomic factors.

4.2 Basic Information

Table 1 Basic Information

Rationale
The initiative aims to promote and revitalize socio-ecological production landscapes and seascapes (SEPLS) by leveraging Indigenous Peoples' and Local Communities' knowledge and culture. It supports collaboration within partnerships and non-member organizations focused on SEPLS sustainability. Additionally, it enhances SEPLS' role in achieving global environmental commitments, including the Rio Conventions, the 2030 Agenda, and the Kunming-Montreal Global Biodiversity Framework. SEPLS contribute significantly to biodiversity conservation, climate action, disaster resilience, livelihood security, health, food systems, and human well-being. Through sustainable management, SEPLS foster ecological restoration and long-term environmental and social benefits.
Objectives
The Kunming-Montreal Global Biodiversity Framework outlines four long-term goals for 2050: (A) restoring ecosystems, halting species extinction, and preserving genetic diversity; (B) sustainably managing biodiversity and ecosystem services; (C) ensuring fair benefits from genetic resources, especially for Indigenous communities; and (D) securing financial, technical, and scientific resources for global biodiversity efforts while bridging the $700 billion annual finance gap. These goals collectively align biodiversity conservation with sustainable development, supporting resilient ecosystems and equitable access to resources for all nations.
Activities and/or practices employed
Enhance the recognition of the IPSI and SEPLS through outreach via social media, global meetings, and events. Foster peer learning on OECMs and SEPLS interconnections to support their recognition. Advance IPSI research to bridge gaps in science and traditional knowledge for SEPLS restoration, while promoting collaboration under UN Ecosystem Restoration Task Forces.
Monitoring methodology

IPSI will establish a system to monitor progress in implementing strategic objectives and priority actions while evaluating their overall policy impact. Two primary reporting mechanisms will be used: annual IPSI activity reports and program implementation reports. Annual reports will document key activities from the previous fiscal year, including partnership updates, major events, collaborative initiatives, knowledge outputs, and Steering Committee decisions. A final implementation report for 2023–2030 will assess IPSI's overall impact on the Kunming-Montreal Global Biodiversity Framework, SDGs, and other relevant initiatives. It will incorporate a survey of IPSI members' contributions, highlight lessons learned, and lay the foundation for the next IPSI Strategy and Plan of Action.

4.3 Landscape & Seascape Approaches

Table 2 Specifically, biochar contributes to the following targets

1. Reducing threats to biodiversity
TARGET 1: Plan and Manage all Areas To Reduce Biodiversity Loss
Possible landscape & seascape -related indicators
• Local authorities implement spatial planning at community level to map biodiversity-rich zones and agricultural landscape • Develop integrated land management plans with farmers for biodiversity inclusive cropping • Establish proportion of agricultural areas under productive and sustainable agriculture • Establish proportion of agricultural areas managed with climate-, water- and biodiversity-friendly practices • Creating community level decision support dashboard combining land capability, biodiversity sensitivity and farmer preferences for scalable planning adoption
TARGET 3: Conserve 30% of Land, Waters and Seas
Possible landscape & seascape -related indicators
• Identify and designate 30% of district agricultural lands as biodiversity conservation zones through participatory mapping with farmers • Monitor conservation area coverage using annual satellite imagery and ground-truthing, reporting progress against 30% target with standardized KMGBF indicators
TARGET 7: Reduce Pollution to Levels That Are Not Harmful to Biodiversity
Possible landscape & seascape -related indicators
• Establish district pollution monitoring network (soil, water, air) with open data platform for real-time tracking and adaptive management. • Implement advanced agricultural biotechnology approach for modifying plant species to enhance carbon dioxide capture • Map fertilizer and pesticide hotspots using farm-level application records and soil testing, targeting 50% reduction through precision nutrient management
TARGET 8: Minimize the Impacts of Climate Change on Biodiversity and Build Resilience
Possible landscape & seascape -related indicators
• Conduct climate risk assessments overlaying projected temperature/rainfall changes with biodiversity-sensitive agricultural zones, prioritizing resilient crop varieties and practices

• Implement climate-smart agriculture (e.g., conservation agriculture, drought-tolerant cultivars) on 40% of vulnerable farmlands, enhancing ecosystem resilience • Integrate nature-based solutions through high carbon capturing plants and subsequently soil carbon sampling sequestering atmospheric carbon while maintaining biodiversity
2. Meeting people's needs through sustainable use and benefit-sharing
TARGET 11: Restore, Maintain and Enhance Nature's Contributions to People
Possible landscape & seascape -related indicators
• Restore degraded farmlands through biodiversity-friendly practices enhancing nature's contributions • Establish farmer-managed rewarding biodiversity stewardship that sustains eco-friendly services • Percentage improvement in the multiple dimensions of human well-being of households within a landscape
TARGET 13: Increase the Sharing of Benefits From Genetic Resources, Digital Sequence Information and Traditional Knowledge
Possible landscape & seascape -related indicators
• Document traditional knowledge through farmer participatory inventories, establishing community seed banks for equitable access • Ensure implementation of traditional knowledge for cropping and plantation while preserving biodiversity • Formalize farmer cooperatives with capacity building for digital sequence information management • Develop district-level protocols for commercial crop varieties, ensuring benefit sharing royalties for the local community
3. Tools and solutions for implementation and mainstreaming
TARGET 17: Strengthen Biosafety and Distribute the Benefits of Biotechnology
Possible landscape & seascape -related indicators
• Proportion of agricultural area under productive and sustainable agriculture • Conduct risk assessments for all crops and new biological inputs proposed for district adoption, following national biosafety protocols • Establish farmer training on coexistence measures preventing GM/non-GM contamination in seed systems • Ensure companies reporting on disclosures of risks, dependencies and impacts biodiversity • Monitor biodiversity impacts of new inputs through sentinel plots adjacent to demonstration farms

5 DEFINITIONS

Annual

A plant species that complete their life cycle—from germination to seed production—within a single growing season before dying

Artificial Intelligence Enhanced Monitoring and Verification

The application of artificial intelligence (AI), including machine learning and pattern recognition algorithms, to process, interpret, and validate land management data, reduce uncertainty, enable transparent reporting

Baseline control site

A designated area managed under pre-project (baseline) practices, as outlined in the schedule of activities, for direct measurement of Greenhouse Gas emissions. It serves as a reference, representing the land in one or more quantification units. Baseline control sites can be located within or beyond the project area

Baseline evaluation period

The period preceding the project's start date, spanning at least three years and one full crop rotation. This retrospective timeframe serves as the basis for developing the schedule of activities

Continuous flooding

A method of growing irrigated crops in which fields remain submerged during most of the growing season, with drainage occurring only shortly before the crop matures and again at harvest time

Controlled irrigation

A form of water management in which irrigation infrastructure enables project farmers to regulate the water regime, including control overflow rates, flooding durations, and timing

Crop management structure

The collection of farming practices and machinery operations employed for crop cultivation within the project area. This encompasses both quantitative and qualitative descriptions of project implementation and management strategies, including the timing, duration, rate, and frequency of flooded and non-flooded conditions, use of machinery, fertilization methods, and weed and pest control practices

Cultivation timeline

The timeframe spanning from initial field preparations prior to planting through to the crop harvest

Dynamic Baseline Scenario

The dynamic baseline represents the counterfactual scenario to estimate the consequences in the absence of management interventions. A dynamic baseline accounts for the fact that certain conditions, like drought, can impact outcomes on both the baseline and management actions which might, with only a historical baseline, be falsely attributed as part of the intervention. A dynamic baseline can be updated every two years, considering tillage, frequency of crop rotation, and quantity of fertilizers, environmental factors influencing project activities, etc.

Geospatial Validation

The process of cross-referencing satellite-derived observations with ground-truth data, control sites, or historical baselines to ensure accuracy and consistency in monitoring outputs

Handling of Biomass

A residue management system that monitors and prevents the burning of biomass after harvesting

Integrated data driven monitoring, reporting, and verification tools

Technologies that support digital collection, analysis, monitoring, and communication of information to enable effective tracking, reporting, and verification processes

Intelligent Data Modeling Systems

Data-driven analytical frameworks that apply machine learning techniques such as Genetic Algorithm Neural Network to generate predictive insights and automate the land use classification, estimating changes in soil organic carbon (SOC) storage, verifying reported activities, and enabling dynamic baseline revisions

Monitoring Period

The defined timeframe during which satellite observations are collected and analyzed to assess project activities and outcomes. This may align with seasonal cycles, annual reporting intervals, or dynamic baseline reassessment schedules

New ALM Practices

An enhanced ALM approach that boosts crop production by optimizing fertilizer or soil amendment application, water management, tillage, residue management, planting and harvesting techniques, crop rotation, or grazing practices. Projects may adopt a single improvement or integrate multiple practices (stacked approach) across their fields or designated land areas

Perennial

A plant species that persists for multiple years, completing its life cycle, reproduction, and eventual decline over an extended period rather than within a single growing season

Project domain

Set of conditions (including crop type, soil texture, and climate) in which model application has been validated

Quantification unit

A designated project area where greenhouse gas emission reductions and carbon dioxide removals are quantified using the chosen methodology

Remote Sensing Data

Data acquired from Earth-observing satellites equipped with optical, multispectral, hyperspectral, or radar sensors. This data is used to derive indicators such as Normalized Difference Vegetation Index (NDVI), land surface temperature, soil moisture, and crop classification

Sample point

Sample location of undefined area

Schedule of activities

A structured annual record of historical management practices implemented during the baseline scenario and updated as per dynamic baseline scenario across the baseline evaluation period, including activities such as tillage, planting, harvesting, and fertilization

Satellite-based monitoring system

A remote sensing framework that utilizes satellite imagery and geospatial analytics to observe, quantify, and verify land use, vegetation cover, soil conditions, and agricultural practices over time. These systems enable consistent, scalable, and non-intrusive data collection across large geographic areas

Stratification

The act of dividing the project area into relatively homogeneous strata. Stratification can occur at the project level and within a quantification unit

Stratum

A discrete area in which biophysical factors are more homogeneous than they are across the project area as a whole

6 APPLICABILITY CONDITIONS

This methodology applies to a broad range of project activities that reduce emissions of greenhouse gases from ALM operations compared to the baseline scenario. A dynamic baseline scenario has to be considered for timely intervention. The methodology is globally applicable.

This methodology is applicable under the following conditions:

1) Projects implementing one or more enhancements to existing ALM practices, including:

    a) Optimizing fertilizer application
    b) Enhancing water management and irrigation efficiency
    c) Reducing tillage and improving residue management
    d) Refining crop planting, crop rotation and harvesting
    e) Advancing sustainable grazing practices.

2) Projects introduce quantitative adjustments—such as decreasing fertilizer application rates—that surpass 5% of the pre-existing values. These modifications are calculated using the average value from the historical look-back period and integrated into the baseline and dynamic baseline activity schedule.

3) Project activities must be conducted on land classified as cropland or grassland at the project start date. This designation must be maintained for the project's duration, except in specific scenarios that allow for land-use transitions under predefined conditions:

    a) Temporary grassland may be introduced into cropland if, prior to the project start date and before adding new project activities, it is demonstrated that integrating forage crops (e.g., annual/perennial grasses, legumes) into annual cropping systems is part of a planned, long-term ALM strategy, such as an integrated crop-livestock system. Project proponents must provide documentation outlining long-term management plans for the project's duration, detailing proposed practices, crop selection, expected benefits, and anticipated outcomes of the integrated grassland-cropland approach; or
    b) A one-time land conversion between grassland and cropland may be implemented if, prior to project validation, it is demonstrated that baseline lands are degraded and that improved land-use practices would substantially enhance soil health. Project proponents must provide evidence showing the initial state of degradation and that it would persist under baseline conditions due to ongoing degradation of drivers or pressures.

4) Designated models for estimating stock change/emissions. Three quantification approaches to quantify reductions and CO_2 removals are shown in this methodology.

    Quantification Approach 1 includes:

    a) The model must be publicly accessible, though not necessarily free of charge, from a reputable source such as the model developer's website, IPCC, or a government agency. Conceptual documentation detailing inputs, outputs, and SOC dynamics representation must be available. Project proponents must cite the model source in the project description, but providing source code or an API for independent replication is not required.
    b) Shown in peer-reviewed scientific studies to successfully simulate changes in SOC and trace

gas emissions resulting from the changes in ALM practices included in the project description.

c) Able to support repetition of the project model simulations. This includes clear versioning of the model used in the project and stable software support, as well as fully reported sources and values for all parameters used with the project version of the model. Where multiple sets of parameter values are used in the project, they clearly identify the sources of varying parameter sets and how they were applied to estimate stock change/emissions in the project. Acceptable sources include peer-reviewed literature and statements from appropriate expert groups that demonstrate evidence of expertise with the model via authorship of peer reviewed model publications or authorship of reports for entities supporting climate-smart agriculture. These sources must describe the datasets and statistical processes used to set parameter values.

d) Validated per datasets and procedures detailed in Section 5.2 of VCS Module VMD0053 Model Calibration, Validation, and Uncertainty Guidance for Improved ALM. Model prediction errors must be calculated using datasets as described in Section 5.2.5 of VMD0053 and must use the same parameters or sets of parameters applied to estimate stock change/emissions in the project; and

e) Using the same model version in the baseline and project scenarios. Further, the same parameters/parameter sets must be used in the baseline and project scenarios. Model input data must be derived following guidance as per Baseline Emissions Quantification Approach. Model uncertainty must be quantified following guidance in Section 10.5.2 of this methodology.

This methodology is not applicable under the following conditions:

5) The project site has undergone clearance of native ecosystems within the ten years preceding the official project start date.

6) The proposed activity is anticipated to lead to a sustained decline in productivity exceeding 5%, based on evidence from peer-reviewed or publicly available studies relevant to the region or a comparable context.

7) The activity involves the application of biochar. While biochar may be used as a soil amendment within the project boundary, its total organic carbon content must be deducted from the estimated increase in soil organic carbon stocks in the project scenario at each verification.

The project activity is implemented on wetland areas. However, this condition does not apply to crops cultivated under managed flooding systems—provided it is demonstrated that such cultivation does not alter the hydrological function of adjacent wetlands.

7 PROJECT BOUNDARY

The project boundary will encompass the spatial, temporal, geographical boundaries along with carbon pools and sources of greenhouse gas emission. The spatial boundary is the geographic area where the project activities are implemented, including designated crops, grasslands and vegetation zones. The specific ALM practices are enforced in this region.

7.1 Temporal Boundaries

The temporal boundary is defined as the timeframe within which project activities, assessments, or impacts are measured. It establishes the start date, duration, and end date of a project, ensuring consistency in evaluating historical baselines and future projections. Temporal boundaries will determine the changes in soil health, emissions, or crop productivity over defined intervals for maintaining comparability, reliability, and adherence to this framework.

7.2 Geographic Boundaries

The geographic boundary defines the spatial extent within which project activities, land management and environmental assessments occur. The geographic boundary includes feedstock sourcing area where eligible biomass is collected, biochar production facilities where thermochemical conversion of biological waste into biochar takes place, and application sites where biochar is applied to soil or in non-soil applications. The geographic boundary is the area over which greenhouse gas emissions, removals, and leakage are assessed and monitored throughout the project lifecycle. This region is characterized by the local indigenous population with their agricultural and non-agricultural practices, ensuring consistency in monitoring soil health, air quality, and land use change for sustainability initiatives.

7.3 Carbon Pools

Carbon Pools including aboveground biomass, belowground biomass, SOC, and harvested products in the project boundary are included in the baseline and project scenarios. The aboveground biomass consists of crops, grasses, and vegetation that store carbon, while belowground biomass includes root systems that contribute to soil carbon through organic matter decomposition. SOC is a critical long-term carbon reservoir, significantly affected by land use and management practices. The harvested agricultural products temporarily store carbon before consumption, use, or decay.

Improving land management strategies—such as optimized fertilizer application, enhanced irrigation, reduced tillage, and diversified cropping systems, crop rotation—can support long-term carbon retention while mitigating greenhouse gas emissions.

7.4 Sources of Greenhouse Gases

Greenhouse Gas (GHG) sources such as SOC, fossil fuel, liming, soil methanogenesis, Enteric fermentation, manure deposition, nitrogen fertilizers and nitrogen fixing species, and biomass burning are included in this project boundary in the baseline, dynamic and project scenarios. If the impact of

greenhouse gas sources, whether reducing carbon stocks or increasing GHG emissions, exceeds 5% of the project's total GHG benefit, they cannot be omitted and must be included in calculations.

8 BASELINE SCENARIOS

The continuation of pre-project ALM practices is the most credible and well-supported baseline scenario. For each defined quantification unit—whether a field or another designated land area—baseline practices mirror those observed during the baseline evaluation period, forming a structured annual schedule of activities. This schedule is applied consistently throughout the initial baseline period to ensure methodological integrity. The quantification of baseline emissions and stock changes are modeled directly to measure the SOC at baseline control sites subjected to the prescribed activity schedule. Within the quantification methods, an initial SOC stock estimate at the start of the project is required as a fundamental input for model calibration and initialization. Furthermore, crops and management practices assumed within the baseline scenario must undergo systematic re-evaluation aligned with the latest VM0042 requirements. Revisions must reflect prevailing agricultural production trends in the region, ensuring methodological accuracy and relevance.

8.1 Determination of the Most Plausible Baseline Scenario

For each quantification approach, the schedule of activities in the baseline scenario is established by analyzing pre-project ALM practices. The assessment period, x years, must span a minimum of three years and include at least one full rotation where applicable. If crop rotation is absent in the baseline, then $x \geq 3$ years applies. For each year preceding the project start ($t = -1$ to $t = -x$), ALM practice data must be determined per the criteria outlined in the table below.

Typically, the quantitative data aligns with corresponding qualitative assessments determined through direct consultation with the farmer or landowner of the sample field and validated with a signed attestation. In cases where the farmer or landowner is unable to provide qualitative information, such as when a field is newly leased, the project proponent must adhere to the following prescribed quantitative information hierarchy.

1. Historical management records from the $t = -1$ to $t = -3$ period serve as primary sources, including farm logs, invoices, equipment specifications, and sensor-generated data. Remote sensing technologies, such as satellite imagery and drone footage, further validate key land use parameters like tillage, crop types, and irrigation.
2. Where direct management records are unavailable, historical management plans supported by agronomist recommendations can provide structured baseline estimates. If multiple values exist within these records (e.g., varying prescribed fertilizer rates), the most conservative value—leading to the lowest expected emissions or highest stock change—must be applied.
3. A signed attestation from the farmer or landowner offers additional verification, provided the declared values align with other evidence-supported benchmarks for similar fields, adjacent years, or government agricultural data.
4. If attestations fail to meet validation standards, regional agricultural census data spanning up to 20 years or 10 most recent dataset iterations must be referenced. Disaggregated estimates, where available, should be prioritized for accuracy.

This hierarchy applies to any additional quantitative input required by the model quantification approaches or default factor selected. The principle of conservativeness must be applied in all cases.

Negative qualitative data indicates the absence of relevant quantitative data for a given practice, whereas a positive qualitative response necessitates its inclusion. The established schedule, starting at t = –x years, is systematically applied to the baseline scenario from t = 1 onward, repeating at x-year intervals through the duration of the first baseline period.

Table 3 Minimum specifications for ALM practices in the baseline scenario

ALM Practice	Qualitative	Quantitative
Crop Planting and Harvesting	• Crop type(s)	• Approximate date(s) planted (where applicable) • Approximate date(s) harvested/terminated (where applicable) • Crop yield (where applicable)
Nitrogen Fertilizer Application	• Manure (Y/N) • Compost (Y/N) • Synthetic N fertilizer (Y/N)	• Manure type application rate (where applicable) • Compost type application rate (where applicable) • N application rate in synthetic fertilizer (where applicable)
Tillage and/or Residue Management	• Tillage (Y/N) • Crop residue removal (Y/N)	• Depth of tillage (where applicable) • Frequency of tillage (where applicable) • Percent of soil area disturbed (where applicable) • Percent of crop residue removed (where applicable)
Water Management/Irrigation	• Irrigation (Y/N) • Flooding (Y/N)	• Irrigation rate (where applicable)
Grazing Practices	• Grazing (Y/N) • Animal type (where applicable) • Harvesting/mowing (Y/N)	• Animal stocking rate (i.e., number of animals and length of time grazing in each area annually, where applicable) • Frequency of harvest
Liming	• Application of calcitic limestone or dolomite (Y/N)	• Calcitic limestone or dolomite application rate (where applicable)

*Y/N: Yes/No

8.2 Reassessment of the Baseline Scenario

The baseline scenario's activity schedule remains valid until a re-assessment is required under the latest version of VM0042. At the conclusion of each baseline period, the commercial crop production defined within the baseline scenario must undergo re-evaluation. This process necessitates consultation of published regional (sub-national) agricultural production data spanning the five years immediately preceding the current baseline period's end, ensuring alignment with evolving agricultural trends and conditions.

- If there is documented evidence of continued production of the relevant commercial crop(s) using the same ALM practices in the region, the baseline scenario remains unchanged, carrying forward the established schedule of activities.
- If such evidence is lacking, a revised schedule of ALM activities, aligned with regional agricultural practices, must be developed. This revision should be based on written recommendations from independent experts, including agronomists, soil scientists, husbandry specialists, or representatives of government agricultural bodies, such as agricultural extension agents. These recommendations must provide sufficient detail to meet the minimum ALM practice specifications outlined in Table 1.
- If multiple values are documented in the recommendations (e.g., varying application rates), the principle of conservativeness applies, selecting the value that results in the lowest expected emissions or the highest rate of stock change for the baseline scenario.
- If field-specific evidence is unavailable, derived values must be supported by a documented methodology justifying their appropriateness.

8.3 Integration of Satellite measurements

Satellite-based remote monitoring shall be used as a primary supporting data source to inform the development and periodic reassessment of the baseline scenario. Specifically, satellite imagery and derived geospatial indicators, such as NDVI, surface reflectance, water indices, maybe used to:

- Verify historical land use and management practices during the baseline evaluation period, including irrigation regimes, residue management, and crop phenology
- Establish or validate the schedule of activities for each quantification unit, particularly where field-level records are incomplete or unavailable
- Support stratification and quantification unit delineation by identifying homogeneous zones based on vegetation, hydrology, or soil characteristics
- Cross-check farmer attestations or regional datasets to ensure consistency and conservativeness in baseline assumptions.
- Determine the land use area and quantify the amount of GHG between soil and atmosphere

All satellite-derived data must be processed using documented methodologies and validated against ground-truth data or control sites where feasible. The use of satellite data must follow the data sourcing hierarchy outlined in Box 1 of this methodology and adhere to the principle of conservativeness.

8.4 Dynamic Baseline Scenario

At the end of each crediting period, typically the first three years of the baseline evaluation period, satellite measurements may be used to reassess the baseline scenario by:

- Detecting shifts in regional crop cultivation practices, such as changes in flooding duration, plantation period, tillage intensity, SOC, etc.
- Quantifying trends in vegetation cover, water management, and residue retention using time dependent analysis for a supervised and un-supervised classification
- Validating the representativeness of updated regional datasets used to revise the baseline schedule of activities
- Compare the images of the classification and create a database of change to be used in Machine learning model to determine the choice of crops for rotation
- Supporting the selection of new baseline control sites where applicable

Where satellite data is used to justify a dynamic update to the baseline, the project proponent must demonstrate that the imagery is of sufficient spatial and temporal resolution, replicable, and conservative.

9 ADDITIONALITY

This methodology employs a project-based approach to demonstrate additionality. For grouped projects, additionality must be established based on the initial project activity instances, following the requirements outlined in the latest version of VM0042.

Project proponents utilizing this methodology must:

1. Demonstrate a regulatory surplus, ensuring the proposed activities exceed existing legal or policy requirements
2. Identify institutional barriers that would hinder the adoption of modifications to pre-existing ALM practices
3. Verify that the proposed suite of project activities does not represent common practice within the region or sector

Detailed guidance on each requirement is provided below:

Step 1: Regulatory surplus

The project proponent must demonstrate regulatory surplus in accordance with the rules and requirements set out in the most recent version of VM0042.

Step 2: Identify institutional barriers that would prevent implementation of a change in pre-existing ALM practices

The project proponent must determine whether there are cultural and/or social barriers (e.g., cultural practices and social norms, attitudes, and beliefs) to the proposed change(s) in ALM expected that prevent implementation of the change without the project proponent's intervention and the resulting revenue from the sale of Verified Carbon Units (VCUs). The project proponent must list and describe barriers to the implementation of proposed changes to pre-project ALM practices to establish that the change would not occur if the project was not undertaken by the project proponent and registered as a VCS project.

Demonstration of cultural and/or social barriers must be supported by peer-reviewed and/or published studies specific to the project region. Where evidence is not available for the project region, evidence from other regions may be used where it is demonstrated how those cultural and/or social barriers also apply to the project region.

Such barriers may include traditional knowledge or lack thereof, laws and customs, market conditions, and lack of motivating incentives to change practices, including, but not limited to:

- Traditional equipment and technology
- Grower risk tolerance and beliefs about the feasibility of adopting new practices, and implications of their decisions
- Growing openness to new ideas and perceptions of the magnitude of the change

- Barriers associated with grower identity

Step 3: Demonstrate that adoption of the suite of proposed project activities is not common practice

The project proponent must determine whether the proposed project activity or suite of activities (activities implemented across the aggregated project and not on individual farm) are common practice in each region (or 'geographic area' as defined for grouped projects in the VM0042) included within the project area. As per Section 18 of the CDM Methodological Tool: Common Practice, common practice is defined as greater than 20% adoption (Further information is available at: https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-24-v1.pdf). Where the project is implementing only one activity, the adoption rate of that practice must be lower than 20 percent in each region within the project spatial boundary.

Project proponents must justify the timing of the intervention to accelerate emission reductions or sustainable practices that would otherwise occur later or not considered. Satellite time-series data can be used to demonstrate the observed shifts in land management. Digital monitoring, reporting, and verification (DMRV) systems and machine learning tools are used to automate monitoring and analysis. The remote sensing and time-series analytics is considered as part of the dynamic baseline framework.

To establish that a proposed project activity or set of activities does not constitute common practice, the project proponent must demonstrate that the area-weighted mean adoption rate of the principal project activities across each region within the project boundary is below 20%, as calculated using Equation (1). In cases where one activity (e.g., reduced tillage) exceeds this threshold in a given region, the inclusion of additional activities with lower regional adoption rates (e.g., cover cropping, fertilizer management) in appropriate proportions is required to ensure that the overall weighted average remains below 20%.

An individual activity with a documented adoption rate at or below 20% in the applicable region is automatically considered additional. However, if the adoption rate of an individual activity exceeds 20%, it may only be deemed additional when the area-weighted mean across all project activities in that region, considering their respective extents, remains below the 20% common practice threshold

Evidence must be provided in the form of publicly available information contained in:

a) Agricultural census or other government (e.g., survey) data
b) Peer-reviewed scientific literature
c) Independent research data, or
d) Reports or assessments compiled by industry associations
e) Data compiled using remote sensing datasets

To demonstrate common practice, the project area must be stratified at the state, provincial, or equivalent second-order administrative level within the host country. In situations where data at this resolution are not available—particularly in the context of developing country—aggregated information at the subnational, national, or regional level may be utilized, provided the selection is

clearly justified. Where geopolitical stratification is infeasible due to data limitations, alternative stratification criteria such as dominant soil types, agroecological zones, or cropping systems may be adopted, with supporting rationale.

The chosen stratification framework and corresponding data sources must be applied consistently across the entire project area to ensure methodological coherence. In cases where an appropriate data source for common practice analysis is lacking for a portion of the project region, a reasoned justification is required to support the use of a different data source for that subset.

Where evidence for a single proposed project activity in the region is not available from any of these sources, the project proponent may obtain a signed and dated attestation statement from a qualified independent local expert (e.g., agricultural extension agent, accredited agronomist) estimating the adoption rate for the weighted mean calculation. Where evidence on the suite of proposed activities is unavailable, a qualified independent local expert may provide a signed and dated attestation statement stating whether the proposed suite of project activities is common practice in the region and providing estimated values for the regional existing adoption rate of proposed project activities (EA_{ay}; see Equation (1)). All projects using independent local expert attestation must provide the qualifications of the expert and the methods used to inform their analysis.

Equation (1) shall be used to determine the weighted average adoption rate across all regions within the project boundary. However, if the project includes only a single activity and the proponent can substantiate that its adoption rate is below 20% in the applicable region, the use of Equation (1) is not necessary.

$$AR = (EA_{a1} \times PA_{a1}) + (EA_{a2} \times PA_{a2}) + \cdots + (EA_{ay} \times PA_{ay}) \quad (1)$$

Where:

$$PA_{a1} = \frac{Area_{a1}}{(Area_{a1} + Area_{a2} + \cdots + Area_{ay})}$$

$$PA_{a2} = \frac{Area_{a2}}{(Area_{a1} + Area_{a2} + \cdots + Area_{ay})}$$

$$PA_{ay} = \frac{Area_{ay}}{(Area_{a1} + Area_{a2} + \cdots + Area_{ay})}$$

and:

AR	= Weighted *mean* adoption rate in each region included in the project area (%)
EA_{ay}	= Existing adoption rate of proposed project activity ay in the region (%)
PA_{ay}	= Ratio of proposed project-level adoption of activity ay relative to sum of proposed project-level adoption of all activities in the project area
$Area_{ay}$	= Area of proposed project-level adoption of activity ay in the project area (hectares)
ay	= 1, …, ay proposed project activities

A project proponent may include areas where more than one project activity will be implemented on the same land (e.g., reduced tillage plus cover crops). Evidence of existing adoption rates for the

combined (two or more) activities should be used to calculate the weighted mean adoption rate of the proposed combined activities (i.e., parameter EA_{ay} would represent the adoption rate of a combined activity as the two are implemented on the same land or field). Where evidence on existing adoption rates for the combined activities is not available, the project proponent may multiply the existing adoption rates (i.e., pre-project) of the individual activities to estimate the combined activity adoption rate. In practice, this encourages "stacking" of new activities to enhance reductions and/or removals compared to implementing only one new activity on a given area or farm. For example, with a statewide existing adoption rate of 40% for reduced tillage and 10% for cover-cropping, the adoption rate to be applied in Equation (1) for land combining (stacking) these two activities would be 4% (i.e., $EA_{ay} = 0.4 \times 0.1 = 0.04$).

Where Steps 1–3 are satisfied, the proposed project activity is additional.

10 QUANTIFICATION OF GREENHOUSE GAS EMISSION REDUCTIONS AND REMOVALS

This methodology provides a structured framework for quantifying greenhouse gas emission reductions and removals resulting from the adoption of improved Agricultural Land Management (ALM) practices relative to the baseline scenario. Emissions under both baseline and project conditions are quantified in terms of methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) fluxes, expressed as metric tons of CO_2 equivalent (tCO_2e) per hectare per verification period. Each quantification unit employs a standardized accounting approach to estimate stock changes and emissions across relevant carbon pools and GHG fluxes on a per-unit-area basis. For verification periods that span multiple calendar years, reductions and removals are disaggregated and reported annually to distinguish separate vintage periods.

The project area is divided into multiple quantification units that must exhibit higher internal consistency than the surrounding landscape. These units are delineated based on shared characteristics such as land use practices, soil properties, and prevailing climatic conditions, in order to improve the accuracy of emission reduction and removal (ERR) estimates. In justified cases, the entire project area may be designated as a single quantification unit. ERRs are quantified at the unit level and subsequently aggregated to yield the total emission reductions or removals for the project as a whole.

Table 4 details the methodologies for quantifying CO_2, CH_4, and N_2O emissions. If multiple quantification approaches are permitted for a given gas and source, concurrent methodologies may be employed, provided the same approach is consistently applied to the corresponding quantification unit in both the baseline and project scenarios.

Table 4 Summary of allowable quantification approaches

GHG/ Pool	Source	Quantification Approach 1: Measure and Model*	Quantification Approach 2: Measure and Remeasure	Quantification Approach 3: Default Factors
CO_2	SOC	X	X	
	Fossil fuel			X
	Liming			X
	Woody biomass**			
CH_4	Soil methanogenesis***	X		
	Enteric fermentation			X
	Manure deposition			X
	Manure deposition			X
N_2O	Use of nitrogen fertilizers***	X		X

	Use of nitrogen-fixing species***	X		X
	Manure deposition***	X		X
	Biomass burning			X

* Approach 1 may only be used where a valid model is available
**If included in the project boundary, woody biomass is calculated using the CDM A/R tools Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities and Simplified baseline and monitoring methodology for small scale CDM afforestation and reforestation project activities implemented on lands other than wetlands. Where woody biomass is harvested, project proponents must calculate the long-term average GHG benefit following guidance in the most recent versions of the VCS Methodology Requirements, and the VM0042.
***Measured data on CH_4 and N_2O fluxes as described in VMD0053, v2.0 are required for model calibration and validation when following Quantification Approach 1. Periodic measurements of CH_4 and N_2O fluxes as part of project monitoring are not required.

For each pool/source, subdivisions of the project area using different quantification approaches must be stratified and accounted separately. A project may switch between allowable quantification approaches for a given source during the project lifetime, provided that the same approach is used for both the project and baseline scenarios. The quantification approaches are as follows.

Quantification Approach 1: Measure and Model

A validated model is employed to estimate greenhouse gas flux by integrating soil characteristics, implementing ALM practices, measured initial soil organic carbon stocks, and climatic conditions within designated quantification units. SOC stock measurements are required at intervals of five years or more frequent reassessments, as outlined in Table 3. The resulting remeasurement data informs model recalibration and refines prediction error estimates. Initial and periodic measurements of methane (CH_4) and nitrous oxide (N_2O) fluxes are not mandated for project monitoring. Instead, model calibration necessitates high-quality experimental data on soil CH_4 and N_2O emissions, sourced from controlled research trials or approved datasets defined in VMD0053. Experimental datasets must originate from peer-reviewed and published research, ideally featuring control plots to assess changes in practice. Additionally, benchmark datasets curated by third-party institutions or within-project boundary measurements, which are subject to approval by an independent modeling expert, may be utilized for validation.

Quantification Approach 2: Measure and Remeasure

Direct measurement serves as a key methodology for quantifying soil organic carbon stock changes, particularly in cases where validated or parameterized models are unavailable or where project proponents opt for empirical assessment over model-based estimation. This approach ensures baseline conditions are accurately established through direct sampling and periodic reassessment at designated control sites corresponding to one or more quantification units.

Under Quantification Approach 2, soil organic carbon stock changes are exclusively measured rather than modeled, providing a high level of precision in tracking carbon dynamics over time. The validity

of this approach relies on rigorous sampling protocols, ensuring that baseline remeasurements reflect actual field conditions.

Quantification Approach 3: Default Factors

Greenhouse gas (GHG) flux is quantified in accordance with the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, utilizing equations specific to this methodology. If a particular activity is absent in either the baseline or project scenario—resulting in an effective input of zero—the corresponding equation element is excluded from calculations. Baseline and project emissions are determined for each sample field based on applicable default values and monitored parameters, ensuring consistency and accuracy.

To select the most appropriate emission factor for project conditions, the following hierarchical approach is applied:

1) Peer-reviewed scientific publications—Where available, a project-specific emission factor derived from peer-reviewed literature must be used.
2) Alternative sources—If no relevant peer-reviewed studies exist, project proponents may utilize alternative sources (e.g., government databases, industry publications) but must provide verification of their credibility through independent expert attestation.
3) Tier 2 emission factors—Where alternative sources are unavailable, projects may derive emission factors based on activity data collected during implementation, following Tier 2 methodologies outlined in the IPCC guidelines.
4) Tier 1 and Tier 1a emission factors—If sufficient activity data or project-specific sources are not accessible, default Tier 1 and Tier 1a emission factors from the IPCC guidelines may be used.

10.1 Baseline Emissions

Quantification Approach 1

The baseline is modeled for each quantification unit. The model serves to project future stock change/emissions resulting from the schedule of ALM activities taking place in the baseline scenario. Further guidance on biophysical model inputs is elaborated in Table 5.

Table 5 Guidance on collection of biophysical model inputs for the baseline scenario, where required by the model selected

Model Input Category	Timing	Approach
SOC content to calculate SOC stocks (initial)	Determined prior to project intervention via direct measurements at t = 0 or (back-) modeled to t = 0 from measurements collected within ±5 years of t = 0	Directly measured via conventional analytical laboratory methods (e.g., dry combustion) or proximal sensing techniques with known uncertainty following the criteria in Appendix 4 at t = 0 or (back-) modeled to t = 0 following VMD0053 guidance. See parameter table for $SOC_{bsl,i,t}$.
Bulk density to calculate SOC stocks (initial)	Determined prior to project intervention via direct measurements at t = 0 or	See Section 10.2.1.5

	from measurements collected within ±5 years of t = 0	
Soil properties (other than bulk density and SOC)	Determined prior to project intervention	Directly measured or determined from published soil maps with known uncertainty. Estimates from direct measurements must: • Be derived from representative (unbiased) sampling; and • Ensure accuracy of measurements through adherence to best practices.
Climate variables (e.g., precipitation, temperature)	Continuously monitored ex post	Measured for each model-specific meteorological input variable at its required temporal frequency (e.g., daily) for the model prediction interval. Measurements are taken at the closest continuously monitored weather station not exceeding 50 km from the sample field, or from a synthetic weather station (e.g., PRISM*).

*Available at: https://climatedataguide.ucar.edu/climate-data/prism-high-resolution-spatial-climate-data-united-states-maxmin-temp-dewpoint

Quantification Approach 2

Baseline soil organic carbon (SOC) stocks are systematically measured and periodically measured at designated baseline control sites associated with quantification units and assigned as Dynamic baseline. These control sites operate under the activity schedules established in the baseline scenario and must meet the similarity criteria outlined in Table 6 while remaining within 250 km of their linked quantification units. A single control site may serve multiple quantification units, provided it meets the requisite similarity criteria for each. Management responsibilities may rest with project proponents, implementing partners, or external entities, including experimental research stations beyond the project area. While management structures may evolve throughout the project, the physical location of control sites must remain unchanged for the project's duration to ensure consistent baseline measurements. Control sites must be sufficiently large to eliminate edge effects and facilitate uninterrupted baseline management practices—allowing standard agricultural operations such as tractors and combines to function as they would under normal conditions. In the event of extreme weather, pest outbreaks, or other adverse conditions, control site managers may deviate from planned activities to mitigate potential negative impacts, ensuring the site reflects real-world agricultural responses rather than artificial constraints imposed by carbon project parameters. At least three control sites are required across the project area, though additional sites reduce uncertainty—especially when fewer than ten are used. Given the natural variability and heterogeneity within agricultural landscapes, larger projects necessitate an increased number of control sites to uphold methodological rigor. Stratified random sampling requires a minimum of one control site per stratum, or alternatively, each control site must be partitioned to match the stratification of its corresponding quantification unit. Baseline SOC stocks must be reported both for the control sites and within each stratum of the project area.

Table 6 Similarity criteria for linking baseline control sites to quantification units under Quantification Approach 2

Control Site Similarity Criterion	Threshold[a]
Topography	Most frequent slope class must be the same in the quantification units and control sites (to be determined from a slope map or via a GIS slope analysis). For control sites classified as hilly, steep, or very steep, the aspect must be within 30° of the cardinal direction of the linked quantification unit.
Soil texture to depth of project boundary (minimum 30 cm)	Average soil texture must be in the same FAO[25] soil textural class as the average soil texture of the linked quantification unit. Note that where significant textural differences are evident within 0-30 cm depth, texture should be determined separately for the different soil horizons within that depth range.
Soil group	Soil groups must be within the same reference soil group, according to the FAO World Reference Base for Soil Resources, as the linked quantification unit.
Average SOC percent by dry weight to depth of project boundary (minimum 30 cm)	The percentage must not be significantly different from the mean percentage SOC of the linked quantification unit at a 90% confidence level.
Historical ALM activities	Historical ALM activities must be the same as in the linked quantification unit for at least five years prior to project start date: • Tillage (Y/N[d]) and type of tillage practice (no tillage, conservation tillage, or conventional (full) tillage) • Crop residue removal (Y/N) • Crop planting and harvesting (crop type[e]) • Manure application (Y/N) • Compost application (Y/N) • Irrigation (Y/N) Note that not all of these activities will be universally relevant to all agricultural systems. Therefore, the project proponent must provide evidence supporting the selected historical ALM activities used to link control sites with quantification units.
Historical land cover[b]	For lands converted up to 50 years prior to the project start date, the site must be converted from the same major land cover type (e.g., forestland, grassland, savanna) as the linked quantification unit within ±10 years.
Native vegetation	The site must be within the same terrestrial ecoregion as the linked quantification unit.
Climate zone	The site must be within the same IPCC-defined climate zone as the linked quantification unit.
Precipitation[c]	The site must have mean annual precipitation within ±100 mm of the linked quantification unit.

[a]Estimates of these quantitative thresholds must be derived from unbiased, representative sampling of the control site. Accuracy must be ensured through adherence to best practices (as per VM0042).
[b]Estimated based on historical satellite or aerial imagery or, where imagery is unavailable, confirmed via local expert attestation
[c]Estimated based on measurements taken at the closest continuously monitored weather station not exceeding 50 km from the control site or from a synthetic weather station (e.g., PRISM)
[d]Y/N: Yes/No

[e]Where crop type in the quantification unit of the project area cannot be matched in the baseline control site, a different crop from the same crop functional group may be selected. Crop functional group is defined in VMD0053 as "Broad category of crop species with similar characteristics (e.g., grasses, legumes, non-legume broadleaf species).

Quantification Approach 3

Baseline calculations for each sample field follow the equations prescribed within this methodology, ensuring consistency in estimating emissions. The emissions associated with ALM activities under the baseline scenario are quantified using default emission factors. Validation requires that relevant data be determined at the sample-field level, ensuring accuracy in baseline estimations.

10.1.1 Soil Organic Carbon (SOC) Stocks

Direct measurements of SOC stocks are required under Quantification Approach 1 as model inputs for baseline setting and at a minimum every five years after for model true-up. Direct measurements of SOC stocks are also required under Quantification Approach 2 to determine the baseline and project SOC stocks at the project start date and at each verification event. The initially measured SOC stocks (at t = 0 determined through direct measurements or (back-) modeled to t = 0 from measurements collected within ±5 years of t = 0) are the same in both the baseline and project scenarios at the outset of the project (i.e., $SOC_{wp,i,0} = SOC_{bsl,i,0}$) when following Quantification Approach 1.

Soil sampling and modeling should occur on a point or small plot (i.e., composite sample) basis to allow for accurate estimation of sampling error and its contribution to the uncertainty of credit estimates. Points should be allocated within the lowest level quantification units using an acceptable approach. Where small plots or composite samples are used, the distance between points in such a sample should be minimized to improve estimates of spatial variability.

SOC stock estimates generated must:

1) Be demonstrated to be unbiased and derived from representative sampling; and
2) Ensure the accuracy of measurements and procedures through the employment of quality assurance/quality control (QA/QC) procedures (to be determined by the project proponent and outlined in the monitoring plan).

Measurement procedures for SOC and bulk density must be thoroughly described, including all sample handling, analysis preparation, and analysis techniques. Further details on each of these procedures are provided in the following sections.

10.1.1.1 General Requirements for Soil Sampling

Standard QA/QC procedures for soil inventory including field data collection and data management must be applied. Use or adaptation of QA/QC procedures available from published handbooks is recommended, such as those produced by FAO and available on the FAO Soils Portal, the ISO

standards on soil sampling (including ISO 18400-104 Soil quality — Sampling — Part 104: Strategies), or the IPCC Good Practice Guidance LULUCF 2003.

For all directly sampled parameters, the project monitoring plan must clearly spatially delineate the sample population and specify sampling intensities, selection of quantification units, and sampling stages (where applicable). The statistical analysis measurements plan must be submitted as part of the sampling plan for project validation. The detailed sample design must be specified in the monitoring plan, and unbiased estimators of population parameters identified for application in calculations.

- For re-sampling purposes, sample locations must be georeferenced (depending on the available GPS precision) and seasonal variability considered.
- Sampling and re-sampling campaigns must be conducted during the same season over time.
- Where organic amendments are applied, projects should delay sampling or re-sampling to the latest time possible after the previous application and the shortest time possible before the next application.

10.1.1.2 Sampling Design: Stratified Random Sampling

Soil sampling must adhere to a stratified random sampling strategy, ensuring that each quantification unit within the project area is divided into homogeneous strata based on factors that influence soil organic carbon (SOC) stock distribution. The stratification process enhances methodological precision by creating sub-units that exhibit greater uniformity than the broader project area.

In a hierarchical (nested) design, strata must be established at the lowest level of quantification units. If a project incorporates primary and secondary quantification units, strata should be generated within each secondary quantification unit, ensuring that SOC stock variability is captured with greater accuracy. The scale and layout of agricultural fields or paddocks dictate stratification. Strata may span multiple fields or, conversely, a single field or paddock may be divided into several strata, depending on the variability of SOC stock distribution within the project area.

Project-specific strata, their corresponding areas, and designated sampling points within each stratum must be documented in a spreadsheet and submitted as an annex to the project documentation for every verification cycle.

In a multi-stage sampling framework, stratified random sampling may function as a nested component, but it must be applied at the stage immediately preceding the final sample point selection to maintain methodological consistency and ensure representativeness across quantification units.

Projects proposing alternative sampling strategies must submit a methodology deviation, supported by a scientific rationale and project-specific justification. These deviations must uphold statistical integrity and demonstrate alignment with the objectives of quantification and verification.

Random sampling schemes that lack stratification tend to introduce higher uncertainties when estimating SOC stock changes. Similarly, grid and linear sampling patterns, while requiring numerous sample points, often lead to biased results, as linear site features may be over- or underrepresented in the dataset. For these reasons, grid and linear sampling patterns are not recommended for this methodology.

To determine strata, the best available data on factors expected to affect the response of SOC stocks to the project activities must be used.

Projects must report the factors used in stratification and how strata were developed.

Numerous factors determine SOC heterogeneity in field (10 - 100 ha) and landscape (100 - 1000 ha) scales, including climate, topography, historical land use and vegetation, parent material, soil texture, and soil type. Stratifying the project area (or quantification units) into strata that are more homogenous than the project area in its entirety, defined by factors that influence SOC stocks (as listed in VM0042) is expected to improve sampling efficiency and reduce errors associated with project scale estimates of SOC stocks.

The sampling design must capture variability within the project area. An unbiased spatially stratified approach is important to capture variations in SOC across the project area. The larger a stratum's area and the greater the expected or known variability within a stratum, the higher the number of samples that must be taken within the stratum. In addition, soil texture is easily estimated in the field. Since land use and management history frequently aligns with existing fields, field boundaries should be considered when delineating strata, though potential changes in field boundaries over time must be considered. Defined strata should remain stable over time.

The number of homogeneous sites (i.e., the number of strata) and soil composite samples should be maximized. The number of years required to detect SOC stock changes decreases with increasing sample number. Compositing or bulking soil samples may better represent spatial variability but may reduce the ability to detect SOC stock changes over time. Therefore at least 3–5 composite samples should be taken within each stratum for model true-up or when using Quantification Approach 2.

10.1.1.3 Collection and Processing of Soil Samples

The following are guidelines for collection and processing of soil samples and reporting.

1) Soil sampling must follow established best practices, such as those found in FAO (2019, 2020), De Gruijter et al. (2006), Smith et al. (2020), and Soil Science Division Staff (2017).
2) Where possible, SOC content and soil mass should be obtained from the same sample, or alternatively from adjacent samples taken during the same sampling event. Where multiple cores are composited to create a single sample, these cores must be from the same depth and fully homogenized prior to subsampling.
3) All organic material (e.g., living plants, crop residue) must be cleared from the soil surface before soil sampling.
4) Soil mass must not include particles greater than 2 mm in diameter (i.e., gravel/stones) nor plant material. Any coarse material must be prevented from passing through a 2 mm sieve. Drying and

sieving procedures must follow laboratory-specific standard operating procedures (SOPs) and be consistent for all samples collected as part of the project, and during the entire project lifetime.

5) Soil samples must be shipped within five days of the completion of a sampling campaign. Until then, samples may be temporarily stored on-site in a location protected from sunlight, humidity, and precipitation, avoiding mixing of the different soil materials. Once shipped and before analysis, samples may be stored under environmentally controlled conditions that minimize biological activity (e.g., as dried or refrigerated samples, but not frozen). The duration of refrigerated storage before analysis should not exceed 3 months.
6) Sample processing procedures must be reported in detail, explicitly describing sieving and grinding procedures. These must remain consistent throughout the entire project lifetime even if there is a change in analytical laboratory.
7) Reporting SOC stock changes from direct measurements under Quantification Approaches 1 and 2 must occur on an equivalent soil mass (ESM) basis.
    a) The mass of soil in each depth layer depends on the bulk density of the respective layers. Therefore, it is important to differentiate between soil mass layers and soil depth layers to enable a consistent comparison of SOC changes and differences between two points in time and between baseline and project areas.
    b) SOC stocks and stock changes must be reported to a minimum depth of 30 cm (or down to bedrock/hardpan where soils are shallower than 30 cm). To eliminate the need for extrapolation outside of the measured range, soils must be sampled deeper than the minimum 30 cm required for reporting SOC stock changes.
    c) To enable the ESM approach, soil samples at re-sampling must be divided into at least two increments. Soil mass may be derived from bulk density measurements using soil corers.
    d) The project proponent may select the depth increments sampled according to expected loosening or compaction effects throughout the project lifetime, because bulk density changes as a result of improved ALM will depend largely on land use in the project area and the ALM practices implemented as part of the project.
    e) Where possible, soils should be sampled to 50 cm depth (i.e., in two depth increments 0–30 cm and 30–50 cm), following the recommendation in Wendt and Hauser (2013) to ensure sub-soil depth layers are sufficient to permit adjustments. From these measurements, the ESM layers and the depths to reference mass (see columns K and L in Figure 2) are determined (see Section 10.2.1.6). Note that only the soil mass is required from the two separate depth increments. SOC content analysis may be performed on only one sample after mixing the two depth increments.
    8) Soils less than 30 cm deep (e.g., due to shallow bedrock or a formed hardpan) must be sampled to the depth of the impeding layer. Quantification units with these characteristics must be documented and SOC stocks must only be reported to the sampled depth.
9) Geographic locations of intended sampling points must be established prior to sampling. The location of both the intended sampling point and the actual sampling point must be recorded.
10) The number of samples to be taken within each stratum should be determined based on the expected variance, to reduce overall uncertainty. A pre-sampling of 5 to 10 soil samples per stratum may provide an estimate of SOC variance where up-to-date soil data are unavailable.
11) Power analysis may be conducted to calculate the number of samples needed to enable accounting of a minimum detectable difference, following Equations (2) and (3) (FAO, 2019). However, projects are not required to take this number of samples.

$$MDD \geq \frac{S}{\sqrt{n}} \times (t_{\alpha,\upsilon} + t_{\beta,\upsilon}) \quad (2)$$

$$n \geq \left(\frac{S \times (t_{\alpha} + t_{\beta})}{MDD}\right)^2 \quad (3)$$

Where:

MDD	= Minimum detectable difference
S	= Standard deviation of the difference in SOC stocks between t_0 and t_1
N	= Number of samples
t_α	= Two-sided critical value of the t-distribution at a given significance level (α) frequently taken as 0.05 (5%)
t_β	= One-sided quartile of the t-distribution corresponding to a probability of type II error β (e.g., 90%)

10.1.1.4 Measurements of SOC Content

SOC content with known uncertainty should be measured using dry combustion (Dumas method). In addition, the following proximal sensing techniques are allowed: infrared spectroscopy, including near infrared (NIR), visible near infrared (Vis-NIR), and mid-infrared spectroscopy (MIR); laser-induced breakdown spectroscopy (LIBS); and inelastic neutron scattering (INS, also known as neutron-stimulated gamma ray analysis or spectroscopy).

The selection of an analytical laboratory should be based on its listing as an approved analytical service provider of SOC measurements according to national and/or international standards/accreditation. Where possible, the selected analytical laboratory should be ISO/IEC 17025 accredited. All samples throughout the entire project lifetime should be analyzed in the same laboratory. A change of analytical laboratory requires justification. The project proponent must ensure that soil analysis methods and procedures remain consistent even if there is a change of laboratory.

The selected analytical laboratory should quantify and report analytical error statistics (determined by repeated analyses of the same sample) to project proponents on a regular basis. The selected laboratory should provide information on their internal quality control program, for example inclusion of soil reference material with known results, testing documentation according to quality cards (monitoring of variation in analysis, set of error thresholds). Further evidence of analytical quality performance evaluation should be provided by participation in round-robin testing (e.g., through participation in the North American Proficiency Testing program, https://www.naptprogram.org/) or registration as a member of the Global Soil Laboratory Network (GLOSOLAN, https://www.fao.org/global-soil-partnership/glosolan/en/).

10.1.1.5 Measurements of Bulk Density

Bulk density must be determined by applying the core, excavation, or clod methods in the field, and subsequently processing the samples in the laboratory. Best practice guidance and established standards for these methods, such as ISO 11272:2017 Soil quality — Determination of dry bulk density, must be used. Bulk density as soil mass per volume of sampling cores must not include particles greater than 2 mm in diameter (i.e., gravel/stones/rocks/coarse fraction) nor plant material. The coarse fraction may be estimated by sieving and weighing stones/rocks/gravel and multiplying them by the average density of the coarse material. Beem-Miller et al. (2016) provide a useful approach to ensuring high-quality sampling in rocky agricultural soils. Samples for bulk density, dry soil mass, and SOC content should be taken at the same time and from sampling locations within a few meters of the previous sampling point location, avoiding edge effects and disturbed areas.

10.1.1.6 Calculation of SOC Stocks

To ensure that changes in SOC stocks do not arise solely from a temporal change in bulk density (related to ALM practices), SOC stock changes based on measurements (including for baseline and true-up measurements under Quantification Approach 1) must be calculated on an Emission Sources and Mitigation (ESM) basis following the procedures explained in Ellert and Bettany (1995), Wendt and Hauser (2013), or von Haden et al. (2020). The SOC mass of each depth layer or increment per unit area is calculated as the product of soil mass and organic carbon concentration, where soil mass is obtained by dividing the dry sample mass in each depth layer by the area sampled by the probe or auger (Wendt & Hauser, 2013):

$$M_{n,dl,SOC} = \left(\frac{M_{n,dl,sample}}{\pi\left(\frac{D}{2}\right)^2 \times N} \times 10000\right) \times OC_{n,dl} \quad (4)$$

Where:

$M_{n,dl,SOC}$	= SOC mass in soil sample n in depth layer dl (kg/ha)
$M_{n,dl,sample}$	= Soil mass of sample n in depth layer dl (g)
D	= Inside diameter of probe or auger (mm)
N	= Number of cores sampled (unitless)
$OC_{n,dl}$	= Organic carbon content in sample n in depth layer dl (g/kg)
10 000	= Conversion factor from g/mm^2 to kg/ha

The cumulative SOC mass per unit area is then calculated by summing all sampled depth increments. Project proponents may use spreadsheet provided in Wendt and Hauser (2013) to calculate reference ESMs and adjustments independently from sampled depth increments by using a cubic spline function. Alternatively, the R script provided in von Haden et al. (2020) may be applied. Where one of these templates is used, a copy showing the calculation procedures must be submitted as part of the documentation to be validated by the validation/verification body (VVB). When re-sampling and comparing SOC stocks at two different points in time, the same principle must be applied to ensure that results are reported for an ESM that covers the measured sample with the highest density (i.e., highest determined soil mass).

Under Quantification Approach 1, SOC stocks for model initialization may be calculated using Equation (5) where models use SOC stocks as an input rather than ingesting SOC content and bulk density values separately.

$$SOC_{model} = 100 \times BD_{corr} \times d \times OC_{n,dl} \quad (5)$$

Where:

SOC_{model}	= SOC stock as model input data (t/ha)
BD_{corr}	= Corrected bulk density of the fine soil fraction, after subtracting the mass proportion of the coarse fragments (g/cm^3)
d	= Soil depth (cm)
100	= Conversion factor from g/cm^2 to t/ha

Finally, modeled SOC stocks under Quantification Approach 1 must be calculated using Equation (6) and following the guidance in VMD0053:

$$SOC_{bsl,i,t} = ƒ(SOC_{bsl,i,t}) \quad (6)$$

Where:

$SOC_{bsl,i,t}$ = Estimated carbon stocks in the SOC pool in the baseline scenario for quantification unit i at the end of year t (t CO^2e/ha)

$ƒ(SOC_{bsl,i,t})$ = Modeled SOC stocks in the baseline scenario for quantification unit i in year t, calculated by modeling SOC stock changes over the course of the preceding year (t CO^2e/ha)

i = Quantification unit

10.1.2 Change in Carbon Stocks in Aboveground and Belowground Woody Biomass

Where carbon stocks in aboveground and belowground woody biomass are included in the project boundary, the change in carbon stocks in trees ($\Delta C_{TREE,bsl,i,t}$) and shrubs ($\Delta C_{SHRUB,bsl,i,t}$) in the baseline for quantification unit i in year t are calculated using the CDM A/R tools Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities and Simplified baseline and monitoring methodology for small scale CDM afforestation and reforestation project activities implemented on lands other than wetlands.

10.1.3 Carbon Dioxide Emissions from Liming

Application of calcitic limestone ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$) releases bicarbonate ($2HCO_3^-$), which evolves into CO_2 and water (H_2O) as carbonate limes dissolve. Where one of the ALM practices is liming and resulting carbon dioxide emissions are not deemed de minimis, they are quantified in the baseline scenario under Quantification Approach 3 using Equations (7) and (8).

Parameter $CO_2_lime_{bsl,i,t}$ is estimated using the following equation:

$$CO_2_lime_{bsl,i,t} = EL_{bsl,i,t}/A_i \quad (7)$$

Where:

$CO_2_lime_{bsl,i,t}$ = Areal mean carbon dioxide emissions from liming in the baseline scenario for quantification unit i in year t (t CO_2e/ha)

$EL_{bsl,i,t}$ = Carbon dioxide emissions from liming in the baseline scenario for quantification unit i in year t (t CO_2e)

$$EL_{bsl,i,t} = ((M_{Limestone,bsl,i} \times EF_{Limestone}) + (M_{Dolomite,,bsl,i} \times EF_{Dolomite})) \times 44/12 \quad (8)$$

Where:

$M_{Limestone,bsl,i}$ = Amount of calcitic limestone ($CaCO_3$) applied to quantification unit i in year t (tonnes)

$EF_{Limestone}$ = Emission factor for calcitic limestone (0.12) (t C/t of limestone)

$M_{Dolomite,bsl,i}$ = Amount of dolomite ($CaMg(CO_3)_2$) applied to quantification unit i in year t (tonnes)

$EF_{Dolomite}$ = Emission factor for dolomite (0.13) (t C/t of dolomite)

44/12 = Molar mass ratio of CO_2 to C applied to convert CO_2-C emissions to CO_2 emissions

10.1.4 Methane Emissions from the SOC Pool

Where methane emissions from soil methanogenesis are included in the project boundary per Table 3, they are quantified in the baseline scenario under Quantification Approach 1 using Equation (9).

$$CH4_soil_{bsl,i,t} = GWP_{CH4} \times \int(CH4_soil_{bsl,i,t}) \quad (9)$$

Where:

$CH4_soil_{bsl,i,t}$ = Areal mean methane emissions from SOC pool in the baseline scenario for quantification unit i in year t (t CO_2e/ha)

$\int(CH4_soil_{bsl,i,t})$ = Modeled methane emissions from soil in the baseline scenario for quantification unit i in year t, calculated by modeling soil methane fluxes over the course of the preceding year (t CO_2e/ha)

GWP_{CH4} = Global warming potential for CH_4 (t CO_2e/t CH_4)

10.1.5 Methane Emissions from Livestock Enteric Fermentation

Where methane emissions from livestock enteric fermentation are included per Table 3, they are quantified in the baseline scenario under Quantification Approach 3 using Equation (10). Following the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, quantification must be differentiated by livestock type, manure management system, and productivity system.

$$CH_4_ent_{bsl,i,t} = \left(\frac{GWP_{CH4} \times \sum_{l=1}^{L} Pop_{bsl,l,i,t,P} \times EF_{ent,l,P}}{1000}\right)/A_i \quad (10)$$

Where:

$CH_4_ent_{bsl,i,t}$ = Areal mean methane emissions from livestock enteric fermentation in the baseline scenario for quantification unit i in year t (t CO_2e/ha)

$Pop_{bsl,l,i,t,P}$ = Population of grazing livestock of type l in quantification unit i for productivity system P in year t in the baseline scenario (head numbers)

$EF_{ent,l,P}$ = Enteric fermentation emission factor for livestock type l in productivity system P (kg CH_4/(head × year))

L = Type of livestock

P = Productivity system

1000 = Conversion factor from kg to t

10.1.6 Methane Emissions from Manure Deposition

Where methane emissions from manure deposition are included in the project boundary per Table 3, they are quantified in the baseline scenario under Quantification Approach 3 using Equations (11) and (12).

$$CH_4_md_{bsl,i,t} = \frac{GWP_{CH4} \times \sum_{l=1}^{L}(Pop_{bsl,l,i,t,P} \times VS_{l,i,t,P} \times AWMS_{l,i,t,P,S} \times EF_{CH4,md,l,P,S})}{10^6 \times A_i} \quad (11)$$

Where:

$CH_4_md_{bsl,i,t}$ = Baseline areal mean CH4 emissions from manure deposition in the baseline scenario for quantification unit i in year t (t CO_2e/ha)

$VS_{l,i,t,P}$ = Average volatile solids excretion per head for livestock type l in quantification unit i for productivity system P in year t (kg volatile solids/(head × day)

$AWMS_{l,i,t,P,S}$ = Fraction of total annual volatile solids for each livestock type l in quantification unit i, that is managed in manure management system S in the project area, for productivity system P (dimensionless)

$EF_{CH4,md,l,P,S}$ = Emission factor for methane emissions from manure deposition for livestock type l for productivity system P in manure management system S (g CH_4/kg volatile solids)

S = Manure management system

10^6 = Conversion factor from grams to tonnes

$$VS_{l,i,t,P} = (VS_{rate,l,P} \times \frac{W_{bsl,l,i,t,P}}{1000}) \times 365 \quad (12)$$

Where:

$VS_{rate,l,P}$ = Default volatile solids excretion rate for livestock type l for productivity system P (kg volatile solids/(1000 kg animal mass × day))

$Wb_{sl,l,i,t,P}$ = Average weight in the baseline scenario of livestock type l for quantification unit i in productivity system P in year t (kg animal mass/head)

1000 = Conversion factor kg per tonne

365 = Days per year

10.1.7 Methane Emissions from Biomass Burning

Where methane emissions from biomass burning are included in the project boundary per Table 3, they are quantified in the baseline scenario under Quantification Approach 3 using Equation (13).

$$CH_4_bb_{sl,i,t} = \frac{GWP_{CH4} \times \sum_{c=1}^{C} (MB_{bsl,c,i,t,} \times CF_c \times EF_{c,CH4})}{10^6} / A_i \quad (13)$$

Where:

$CH_4_bb_{sl,i,t}$ = Methane emissions in the baseline scenario from biomass burning for quantification unit i in year t (t CO_2e/ha)

$MB_{bsl,c,i,t}$ = Mass of agricultural residues of type c burned in the baseline scenario for quantification unit i in year t (kg)

CF_c = Combustion factor for agricultural residue type c (proportion of pre fire fuel biomass consumed)

$EF_{c,CH4}$ =Methane emission factor for the burning of agricultural residue type c (g CH_4/kg dry matter burned)

c = Type of agricultural residue

10^6 = Conversion factor from grams to tonnes

10.2 Project Emissions

Stock change and emissions resulting from project scenario ALM activities are calculated or modeled based on monitored inputs. Project scenario CO_2, CH_4, and N_2O emissions must be quantified following the approaches and equations found in section 10.2. For all equations, the subscript bsl

must be substituted by wp to make it clear that the relevant values are being quantified for the project scenario. Further, in situations where livestock are included in the baseline, the project must use at a minimum the average livestock value from the baseline evaluation period.

Model inputs such as SOC content to calculate SOC stocks are determined prior to the start of the project or modeled to t = 0 from measurements collected within 5 years of t = 0. Subsequent measurements are required every five years or less. The SOC content is directly measured via conventional analytical laboratory methods, such as dry combustion, and proximal sensing techniques. Bulk density is determined prior to project intervention via direct measurements to calculate the SOC stocks as per section 10.2.1.5. Project proponents must consider continuous monitoring of climate variables, such as precipitation, temperature, etc. at the closest weather station, <50 km from the sample field.

In the project scenario, SOC stocks ($SOC_{wp,i,t}$) are quantified using an equivalent soil mass (ESM) basis, determined by multiplying the SOC content within each quantification unit or stratum at t − 1, as measured directly in individual sample fields. If bulk density measurements follow a fixed-depth approach, mass corrections may be applied to ensure compliance with ESM requirements.

Project emissions are calculated for each sample field using applicable default values and any monitored parameters. The most accurately available emission factor applicable to the project conditions must be used, in the following descending order of preference:

1) Where available, a project-specific emission factor from a peer-reviewed scientific publication must be used.
2) Where there is no relevant peer-reviewed scientific literature, the project proponent may propose alternative sources of information (e.g., government databases, industry publications) to establish the default factor(s) and must provide evidence that the alternative source of information is robust and credible (e.g., independent expert attestation).
3) Where no alternative information source is available that is applicable to the project conditions, project proponents may derive emission factors using activity data collected during the project by following the guidance to derive Tier 2 emission factors in the respective sections of the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.
4) Where project proponents justify a lack of sufficient activity data and project-specific information sources, Tier 1 and Tier 1a emission factors from the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories may be selected.

10.3 Emission reductions due to rewetting and fire management (Fire Reduction Premium)

This methodology addresses GHG emissions originating from anthropogenic fires occurring in the agricultural land, such as those resulting from crop residue burning or land clearing practices.

A key feature of this approach is the establishment of a conservative default value for fire-related emissions. This value is determined based on the historical frequency and extent of anthropogenic fires within the specific agricultural land in the baseline scenario. By utilizing this pre-defined, conservative premium, the methodology aims to simplify and avoid the direct, complex assessment of GHG emissions from fires in both the baseline and project scenarios. This allows for a more

efficient quantification of emission reductions achieved through improved agricultural practices that prevent fires.

This methodology is only applicable if no anthropogenic fires occur within the agricultural land in the project scenario. This means that successful implementation of sustainable crop management and fire prevention activities must eliminate human-caused fires (e.g., crop residue burning) within the project area throughout the project's duration.

If the Fire Reduction Premium approach is utilized to estimate emissions from fires in agricultural land, the use of fire as a crop management tool is strictly prohibited in the project scenario. This includes, but is not limited to, using fire for clearing crop residues, weed control, pest management, or any other human-induced burning, regardless of scale or intent.

The 20% Fire Reduction Premium offers a rapid and conservative method to account for emission reductions achieved by preventing fires on agricultural land. This approach significantly simplifies the process by removing the need to develop complex baseline scenarios specifically for agricultural fires. While the direct correlation to water table depth isn't applicable to all agricultural lands, the fundamental principle holds fire events on agricultural land led to disproportionately high carbon losses compared to other routine, annual carbon emissions from agricultural activity. For instance, carbon losses from fires (e.g., crop residue burning) per hectare burned can be approximately 10 times larger than the annual carbon emissions from typical agricultural practices in temperate zones, and even greater in certain tropical contexts.

The 20% default premium is a conservative value derived from the significant impact of fires. For example, if at least 25% of the project's agricultural area were to burn at least once every 10 years in the baseline scenario, and if project activities (like improved crop residue management or robust fire prevention measures) successfully halted all carbon losses from these fires, the avoided fire emissions would naturally represent 25% of the total potential emission reduction from avoiding routine carbon losses. The 20% premium therefore conservatively accounts for this potential emission reduction from fire prevention. To ensure data integrity and prevent deliberate fires to meet eligibility criteria, the fire reference period is fixed to a period prior to project start. A minimum assessment period of 10 years is required to ensure a representative timeframe that accurately reflects the historical frequency of fires in the baseline agricultural area.

The project will only be eligible to claim this premium if the following conditions apply:

- Over a period of 10 to 15 years, ending 2 years before the project start date, the cumulative area of organic soil burnt within the project area must have exceeded 10% of the total project area. It is important that repeated burning of the same area adds to this cumulative percentage. Evidence for this must be provided using statistics and/or maps from official reports and/or remote sensing data.
- In the baseline scenario, the agricultural area is currently, and will foreseeably remain, under significant risk of anthropogenic fires. This must be demonstrated through current and historic fire statistics and/or fire maps for the project area, combined with information on current and future land use practices.
- The fire management plan proposed by the project proponent at validation must reflect the best

practices available with respect to fire prevention and control. This plan should be determined by relevant authorities and must explicitly take into account the specific circumstances of the project area and its agricultural activities.
- At each verification, comprehensive documentation must be provided, clearly demonstrating that fire management activities have been implemented strictly according to the proposed plan.

The premium's value adjusts based on the past fire history:

- If fires in the baseline were more frequent (e.g., more than once every 10 years) or covered a larger area (more than 25% cumulatively), the 20% premium remains the maximum, making it an even more conservative estimate.
- If baseline fires were less frequent or covered less than 25% of the area, the premium awarded will be proportionally smaller.
- Crucially, if the cumulative area burned in the baseline is less than 10% of the project area, no Fire Reduction Premium will be awarded.

The emission reductions due to rewetting and fire management can be estimated using section 8.3 of VM0036 version 1.0.

10.4Leakage

Improved ALM projects may result in leakage through: new application of organic amendments from outside the project area (i.e., organic amendments applied in the project from outside of the project area, that were not previously applied in the baseline evaluation period); productivity declines; displacement of livestock outside of the project boundary; and/or diversion of biomass residues that were used for bioenergy applications in the baseline scenario. Guidance on how to account for each type of leakage is provided below. Where the sum of increases in GHG emissions from any leakage source is less than 5% of the total net anthropogenic reductions and removals due to the project, such sources may be deemed de minimis and may be ignored. This must be demonstrated via application of the CDM Tool for testing significance of GHG emissions in A/R CDM project activities.

10.4.1 Activity-shifting leakage and market leakage

Activity-shifting leakage occurs when emissions reductions within a project boundary result in increased emissions elsewhere due to the displacement of activities. Undertaking restrictions on the use of fertilizers within the project site may push these activities into nearby regions, undermining the overall mitigation efforts. Where new or additional manure, compost, or biosolids are applied in the project that were not applied in the historical look-back period, there is a risk of activity-shifting leakage. To account for this type of leakage, a deduction must be used unless any of the following apply: 1) The manure or compost applied in the project are produced on-site from farms within the project area; 2) The manure is documented to have been diverted from an uncontrolled anaerobic lagoon, pond, tank, or pit from which there is no recovery of methane for generation of heat and/or electricity; or 3) The manure, compost, or biosolids are documented to not have been used as a soil amendment. The deduction represents the portion of manure, compost, or biosolids carbon that remains in the project area without degrading, and which would have otherwise been applied to agricultural land outside of the project area. Equation (16) estimates the leakage from imported

manure, compost, or biosolids that are diverted from other applications and could have led to an increase in SOC outside the project boundary in the absence of the project activity. The total amount of carbon applied is reduced to 12% based on the global manure C retention coefficient from Maillard and Angers (2014). This value reflects the fraction of carbon manure expected to remain in project area soils. While derived for manure, the equation is also conservatively applied to compost or biosolids in this methodology.

$$LE_{OA,t} = \sum_l (M_OA_{wp,l,t} \times CC_{wp,OA,t} \times 0.12 \times \frac{44}{12}) \quad (14)$$

Where:

$LE_{OA,t}$)	= Leakage from organic amendments in year t (t CO2e)
$M_OA_{wp,l,t}$	= Mass of organic amendment applied as fertilizer in the project area in year t, disaggregated by livestock type l for manure (tons)
$CC_{wp,OA,t}$	= Carbon content of organic amendment applied as fertilizer in the project area in year t, disaggregated by livestock type l for manure (t C/t organic amendment)
0.12	= Fraction of manure (i.e., organic amendment) carbon expected to remain in project area soils (unitless)
44/12	= Ratio of molecular weight of carbon dioxide to carbon

Market leakage arises when project-driven constraints on resource availability cause broader economic reactions, leading to increased emissions beyond the project boundary. Market leakage is likely to be negligible because the land remains in agricultural production in the project scenario. Further, producers are unlikely to implement and maintain ALM practices that result in productivity declines, since their livelihoods depend on crop harvests and/or livestock outputs as a source of income. Nevertheless, to ensure leakage is not occurring, the following steps must be completed every 10 years:

Step 1: Demonstrate that the productivity of each crop/livestock product has not declined by more than 5% in the project scenario by:

1) Comparing average with-project productivity (excluding years with extreme48 weather events) during the project period to average baseline productivity during the historical look-back period, by crop/livestock product, using the following equation (15):

$$\Delta P = \frac{P_{wp,p} - P_{bsl,p}}{P_{bsl,p}} \times 100 \quad (15)$$

Where:

ΔP	= Change in productivity (%)
$P_{wp,p}$	= Average productivity for product p during the project period (output/ha)
$P_{bsl,p}$	= Average productivity for product p during the historical look back period (output/ha)
P	= Crop/livestock product

2) Comparing the ratio of average baseline productivity to average regional productivity during the historical look-back period with the ratio of average with-project productivity to average regional productivity during the project period, by crop/livestock product, using Equation (16)

and regional data from government (e.g., USDA Actual Production History (APH) data), industry, peer-reviewed, academic, or international organization (e.g., FAO) sources.

$$\Delta PR = \frac{P_{wp,p}}{RP_{wp,p}} - \frac{P_{bsl,p}}{RP_{bsl,p}} \times 100 \quad (16)$$

Where:

ΔPR	= Change in productivity ratio per hectare (%)
$P_{wp,p}$	= Average productivity for crop/livestock product p during the project period (output/ha)
$P_{bsl,p}$	= Average productivity for product p during the historical look back period (output/ha)
$RP_{wp,p}$	= Average regional productivity for product p during the project period (output/ha) (36)
$RP_{bsl,p}$	= Average regional productivity for product p during the baseline evaluation period (output/ha)
P	= Crop/livestock product

New crop/livestock products introduced as part of the project (e.g., new crop in rotation, introduction of livestock) that are not present in the historical look-back period should use regional data sources instead of project-specific data sources to determine historical productivity of the crop/livestock product and set $P_{bsl,p}$ equal to $RP_{bsl,p}$. With-project productivity averages must be based on data collected in the previous 10 years. Productivity averages must not include data that is more than 10 years old. Where productivity has improved, stayed constant, or declined by less than 5% for a crop/livestock product, no further action is needed. Where a reduction in productivity of greater than 5% is observed in one or more crop/livestock products, complete Step 2 for these products.

Step 2: Determine whether the crop/livestock productivity decline was caused by a short-term productivity decrease by repeating the calculation in Step 1 excluding all data inputs from the first three years of project implementation. Where the with-project productivity of the crop/livestock product with the first three years excluded is within 5% of the baseline productivity of the same crop/livestock product, no further action is needed.50 Where a reduction in productivity of greater than 5% is still observed in one or more crop/livestock products, complete Step 3 for these products.

Step 3: Determine whether the productivity decline is limited to a certain combination of factors by stratifying the analysis by: 1) Practice change category, 2) Practice change category combinations, 3) Crop type, 4) Soil type, and/or 5) Climatic zone. Where the productivity decline is limited to a certain combination of factors, that combination becomes ineligible for future crediting. For example, where a 10% decline in corn yields was observed and stratification showed that the yield decline was linked to fertilizer rate reductions, rate reduction practices on corn fields would no longer be eligible for future crediting. Where the project proponent is unable to isolate the source(s) of leakage through stratification, the entire crop/livestock product becomes ineligible for future crediting.

10.4.2 Ecological leakage

Where manure or crop residue management is a component of the project activity, and the manure or crop residues are diverted from energy applications (e.g., fuel for cookstoves or biomass power

generation) in the baseline scenario there is a risk of leakage. Implementation of the project activity may force these competing energy applications to use inputs which are not carbon neutral. Leakage emissions $LE_{BR,Div,t}$ must be determined following procedures in the CDM's TOOL16: Project and leakage emissions from biomass.

10.5Net GHG Emission Reductions and Removals

GHG emission reductions occur when:

1) Carbon stocks decrease from year t to year t + 1 in the baseline scenario and, to a lesser extent, in the project scenario. The cumulative carbon stock change in the project scenario is negative or zero (i.e., the project carbon stock at the end of the verification period is less than or equal to the carbon stock at the project start date).
2) Carbon stocks decrease from year t to year t + 1 in the baseline scenario and carbon stocks increase in the project scenario. Note that this variation may also generate carbon removals.
3) CO_2 emissions from fossil fuel combustion and liming are lower in the project than in the baseline scenario.
4) CH_4 emissions from the SOC pool (i.e., through soil methanogenesis), livestock enteric fermentation, manure deposition, and biomass burning are lower in the project than in the baseline scenario.
5) N_2O emissions from nitrogen fertilizers and nitrogen-fixing species, manure deposition, and biomass burning are lower in the project than in the baseline scenario.

10.5.1 Calculation of net GHG emissions reductions

GHG emission reductions before allocation of leakage emissions are quantified as:

$$ER_t = I(\Delta CO2_{wp}) \times (\Delta CO2_{ff_t} + \Delta CO2_{lime_t} + \Delta CH4_{ent_t} + \Delta CH4_{md_t} + \Delta CH4_{bb_t} + \left(\Delta CH4_{soil_t} \times \left(1 - UNC_{t,CH4_{soil}}\right)\right) + \left(\Delta N2O_{soil_t} \times \left(1 - UNC_{t,N2O_{soil}}\right)\right) + \Delta N2O_{bb_t} + MIN\left(0, \Delta CO2_{wp,t}\right) - MIN\left(0, \Delta CO2_{bsl,t}\right) + (1 - I\left(\Delta CO2_{wp}\right)) \times (\Delta CO2_{ff_t} + \Delta CO2_{lime_t} + \Delta CH4_{ent_t} + \Delta CH4_{md_t} + \Delta CH4_{bb_t} + \left(\Delta CH4_{soil_t} \times \left(1 - UNC_{t,CH4_{soil}}\right)\right) + \left(\Delta N2O_{soil_t} \times \left(1 - UNC_{t,N2O_{soil}}\right)\right) + \Delta N2O_{bb_t} + MIN\left(0, \Delta CO2_{wp,t}\right) - MIN\left(0, \Delta CO2_{bsl,t}\right) + MAX\left(0, \Delta CO2_{wp,t}\right) - MAX\left(0, \Delta CO2_{bsl,t}\right)) \quad (17)$$

Where:

$I(\Delta CO2_{wp})$	= 1 if $\sum_1^t \Delta CO2_{wp,t} \geq 0$
$I(\Delta CO2_{wp})$	= 0 if $\sum_1^t \Delta CO2_{wp,t} \leq 0$
$I(\Delta CO2_{wp})$	= Switches on the first part of Equation (17) when the cumulative carbon stock change in the project scenario is positive, and the second part when the carbon stock change is negative
ER_t	= Estimated reductions in year t (t CO2e)
$\Delta CO2_{ff_t}$	= Total GHG emission reductions from fossil fuel combustion in year t (t CO2e)
$\Delta CO2_{lime_t}$	= Total carbon dioxide emission reductions from liming in year t (t CO2e)

$\Delta CH4_{ent_t}$ = Total methane emission reductions from livestock enteric fermentation in year t (t CO2e)
$\Delta CH4_{md_t}$ = Total methane emission reductions from manure deposition in year t (t CO2e).
$\Delta CH4_{bb_t}$ = Total methane emission reductions from avoided or reduced biomass burning in year t (t CO2e)
$\Delta CH4_{soil_t}$ = Total methane emission reductions from increasing uptake into the SOC pool in year t (t CO2e)
$UNC_{t,CH4_{soil}}$ = Uncertainty deduction in year t when using Quantification Approach 1 to model methane emission reductions from increasing uptake into the SOC pool (fraction between 0 and 1)
$\Delta N2O_{soil_t}$ = Total nitrous oxide emission reductions from nitrification/denitrification in year t (t CO2e)
$UNC_{t,N2O_{soil}}$ = Uncertainty deduction in year t when using Quantification Approach 1 to model nitrous oxide emission reductions from nitrification/denitrification (fraction between 0 and 1)
$\Delta N2O_{bb_t}$ = Total nitrous oxide emission reductions from avoided or reduced biomass burning in year t (t CO2e)
$0, \Delta CO2_{wp,t}$ = Total carbon stock change in the project scenario in year t (t CO2e)
$\Delta CO2_{wp,t}$ = Total carbon stock change in the baseline scenario in year t (t CO2e)

Net GHG emission reductions are quantified as:

$$ER_{NET,t} = ER_t - LK_{ER,t} \quad (18)$$

Where:
$ER_{NET,t}$ = Estimated net GHG emission reductions in year t (t CO2e)
$LK_{ER,t}$ = Leakage allocated to GHG emission reductions in year t (tCO2e)

Leakage allocated to emission reductions ($LK_{ER,t}$) is calculated as:

$$LK_{ER,t} = (LE_{OA,t} + LE_{BR,t}) \times \frac{ER_t}{ER_t + CR_t} \quad (19)$$

Where:
$LE_{BR,t}$ = Leakage emissions from the diversion of manure or crop residues from baseline energy applications in year t (t CO2e)
CR_t = Estimated carbon dioxide removals in year t (t CO2e)

Carbon dioxide removals occur when the cumulative carbon stock change in the project scenario is positive (i.e., the project carbon stock is higher than at the project start date). Then, possible annual stock variation includes:

1) Carbon stocks increase from year t to year t + 1 in the baseline scenario and, to a greater extent, in the project scenario.

2) Carbon stocks decrease from year t to year t + 1 in the baseline scenario and carbon stocks increase from year t to year t + 1 in the project scenario.

Carbon dioxide removals are quantified as:

$$CR_t = I(\Delta CO2_{wp}) \times (MAX(0, \Delta CO2_{wp,t}) - MAX(0, \Delta CO2_{bsl,t})) \quad (20)$$

Where:

$I(\Delta CO2_{wp})$ = 1 if $\sum_1^t \Delta CO2_{wp,t} \geq 0$

$I(\Delta CO2_{wp})$ = 0 if $\sum_1^t \Delta CO2_{wp,t} \leq 0$

$I(\Delta CO2_{wp})$ = Switches Equation (19) on when the cumulative carbon stock change in the project scenario is positive, and off when the change is negative

Net carbon dioxide removals are quantified as:

$$CR_{NET,t} = CR_t - LK_{CR,t} \quad (21)$$

Where:

$CR_{NET,t}$ = Estimated net carbon dioxide removals in year t (t CO2e)

$LK_{CR,t}$ = Leakage allocated to carbon dioxide removals in year t (t CO2e)

Leakage allocated to carbon dioxide removals ($LK_{CR,t}$) is calculated as:

$$LK_{CR,t} = (LE_{OA,t} + LE_{BR,t}) \times \frac{CR_t}{ER_t + CR_t} \quad (22)$$

Net reductions and removals are quantified as:

$$ERR_{NET,t} = ER_{NET,t} + CR_{NET,t} \quad (23)$$

Where:

$ERR_{NET,t}$ = Estimated net reductions and removals in year t (t CO2e)

Methane emission reductions from the SOC pool are quantified as:

$$\Delta CH4_soil_t = \sum_{i=1}^{n} (\overline{CH4_soil}_{nsl,i,t} - \overline{CH4_soil}_{wp,i,t}) \times A_i \quad (24)$$

Where:

$\overline{CH4_soil}_{nsl,i,t}$ = Areal mean methane emissions from SOC pool in the baseline scenario for quantification unit i in year t (t CO2e/ha)

$\overline{CH4_soil}_{wp,i,t}$ = Areal mean methane emissions from SOC pool in the project scenario for quantification unit i in year t (t CO2e/ha)

Methane emission reductions from livestock enteric fermentation are quantified as:

$$\Delta CH4_ent_t = \sum_{i=1}^{n} (\overline{CH4_ent}_{bsl,i,t} - \overline{CH4_ent}_{p,i,t}) \times A_i \quad (25)$$

Where:

$\overline{CH4_soil}_{bsl,i,t}$ = Areal mean methane emissions from livestock enteric fermentation in the baseline scenario for quantification unit i in year t (t CO2e/ha)

$\overline{CH4_ent}_{p,i,t}$ =Areal mean methane emissions from livestock enteric fermentation in the project scenario for quantification unit i in year t (t CO2e/ha)

Methane emission reductions from manure deposition are quantified as:

$$\Delta CH4_md_t = \sum_{i=1}^{n}(\overline{CH4_md}_{bsl,i,t} - \overline{CH4_md}_{wp,i,t}) \times A_i \quad (26)$$

Where:

$\overline{CH4_md}_{bsl,i,t}$ = Areal mean methane emissions from manure deposition in the baseline scenario for quantification unit i in year t (t CO2e/ha)

$\overline{CH4_md}_{wp,i,t}$ = Areal mean methane emissions from manure deposition in the project scenario for quantification unit i in year t (t CO2e/ha)

Methane emission reductions **from** avoided or reduced biomass burning are quantified as:

$$\Delta CH4_bb_t = \sum_{i=1}^{n}(\overline{CH4_bb}_{bsl,i,t} - \overline{CH4_bb}_{wp,i,t}) \times A_i \quad (27)$$

Where:

$\overline{CH4_bb}_{bsl,i,t}$ = Areal mean methane emissions from biomass burning in the baseline scenario for quantification unit i in year t (t CO2e/ha)

$\overline{CH4_bb}_{wp,i,t}$ = Areal mean methane emissions from biomass burning in the project scenario for quantification unit i in year t (t CO2e/ha)

Nitrous oxide emission reductions from nitrification/**denitrification are quantified as:**

$$\Delta N2O_soil_t = \sum_{i=1}^{n}(\overline{N2O_soil}_{bsl,i,t} - \overline{N2O_soil}_{wp,i,t}) \times A_i \quad (28)$$

Where:

$\overline{N2O_soil}_{bsl,i,t}$ = Areal mean nitrous oxide emissions from nitrogen inputs to soils in the baseline scenario for quantification unit i in year t (t CO2e/ha)

$\overline{N2O_soil}_{wp,i,t}$ = Areal mean nitrous oxide emissions from nitrogen inputs to soils in the project scenario for quantification unit i in year t (t CO2e/ha)

Nitrous oxide emission reductions from biomass burning are quantified as:

$$\Delta N2O_bb_t = \sum_{i=1}^{n}(\overline{N2O_bb}_{bsl,i,t} - \overline{N2O_bb}_{wp,i,t}) \times A_i \quad (29)$$

Where:

$\overline{N2O_bb}_{bsl,i,t}$ = Nitrous oxide emissions from biomass burning in the baseline scenario for quantification unit i in year t (t CO2e/ha)

$\overline{N2O_bb}_{wp,i,t}$ = Nitrous oxide emissions from biomass burning in the project scenario for quantification unit i in year t (t CO2e/ha)

10.5.2 Estimation of uncertainty

Uncertainty deductions are estimated separately for each GHG source within a project. Deductions are based on an estimate of the total error of the project's calculated reductions and removals for that source over a given verification period. Key sources of uncertainty that contribute to this error differ for each quantification approach. This section details these sources of error and methods to estimate such errors for use in an uncertainty assessment and calculation of the required uncertainty deduction.

Uncertainty guidance provided here assumes that all soil sampling/analysis and modeling occur on a point basis. In other words, the model is run in a manner to represent a single point in space at which initial soil data and management data have been collected, and uncertainty is calculated by combining estimates of sampling, modeling, and measurement error based on the design chosen to select the points. Alternative approaches (e.g., modeling on an aerial basis) are considered a deviation and project proponents must demonstrate that such approaches will not negatively impact the conservativeness of reduction and removal estimates per the most recent version of VM0042.

Across quantification approaches, a key source of error is sampling error, which emerges from only being able to measure/model a portion of the total project area. Appropriate estimates of this source of error are specific to the sample design employed. This methodology requires that stratified random sampling is used. Strata should be based on physical and management factors that minimize within-strata variability. Individual sample points are allocated randomly within those strata on a proportional basis by area.

The remainder of this section is based on a simplified example of a stratified random sampling design in which the entire project is divided into strata and points within those strata are placed using simple random sampling with replacement. Where a project proponent elects to use an alternative design via a methodology deviation, they must provide a similar demonstration of uncertainty calculations that consider the same sources of error identified here and that are appropriate to the chosen design.

10.5.2.1 Quantification Approach 1

Quantification Approach 1 is a measure and model approach in which a biogeochemical model is used to simulate changes in SOC stocks and GHG fluxes over a given time period in both the project and baseline scenarios. Initial measures of SOC are taken at project start for use within the model. SOC is periodically remeasured throughout the project period to true-up modeled estimates of SOC stock changes. Key sources of error accounted for under Quantification Approach include:

1) Model prediction error resulting from uncertainty in model parameters or model structural errors (i.e., inaccurate representation of actual biogeochemical processes). Model prediction error is calculated using independent statistical validation datasets per the processes outlined in VMD0053. Alternatively, project proponents may account for model prediction error by calibrating models to include parameter uncertainty (e.g., a Bayesian implementation of the model) and using error propagation approach.
2) Sampling error resulting from measuring/modeling only a portion of the project area. Estimates of sampling error are contingent on the sampling design employed by the project proponent.
3) Measurement error of model inputs, including initial SOC content, bulk density, soil texture, and management data, where applicable. In many cases, the impact of these measurement errors on the error of estimated reductions and removals is assumed to be captured in model prediction error and/or sampling error.

For each carbon pool or GHG flux, these sources of error are estimated separately and then combined to estimate a single uncertainty deduction for that carbon pool or GHG flux across the entire project.

Analytical calculation of error propagation can be used to estimate the uncertainty. In this approach, the various sources of error outlined above are independently estimated for each GHG source or carbon pool that results in a reduction or removal (e.g., SOC, N2O). The estimated errors are then combined to provide an estimate of the total variance of the areal mean emission reductions and removals across the project for each source in each verification period. This is used to determine an appropriate uncertainty deduction.

Uncertainty related to estimation of area is considered to be negligible provided that GIS boundaries of the project area are accurately delineated and that the necessary QA/QC procedures to remove irrelevant features. Measurement error of physical properties (e.g., precipitation, soil texture) used as model inputs may also be a source of error, although this has generally been found to be less significant than model structural error (Ogle et al., 2010; Peltoniemi et al., 2006). Provided that measurement errors in model inputs translate to measurement errors in model predictions that are uncorrelated across sample points, these errors are automatically captured by the estimate of sample error discussed below. Similarly, for inputs such as precipitation, which are the same across baseline and project scenarios and for which estimates are retrieved for a given point from the same data source (e.g., GIS data products, digital soil maps), the influence of such measurement error on estimates of reductions and removals is captured in the estimate of model prediction error generated through model calibration/validation procedures. Remeasurement and true up provide additional opportunities to refine these error estimates.

Where soil spectroscopy tools are used in place of conventional analytical techniques to determine SOC content at sampling points, it must not be assumed that measurement error from such methods is automatically captured in the estimate of model prediction error or that the impact of such errors is negligible. Soil spectroscopy methods may have high measurement error under different circumstances and may be biased (i.e., error differs depending on the carbon content of the sample under consideration and the coverage of datasets used to calibrate/validate the soil spectroscopy model). Biogeochemical models are sensitive to initial starting SOC content, meaning error in estimates will have a non-linear impact on model simulations of both the baseline and project scenarios. Therefore, where soil spectroscopy is used to determine SOC content data for use as an input to biogeochemical models, the MC simulation approach must be used, unless project proponents demonstrate that measurement error from the tool used is unbiased and has a de minimis impact on model simulations.

Sampling error derives from only measuring or modeling a subset of the entire project area, resulting in a potentially inaccurate estimate of the true variance of a GHG flux or carbon stock change. Sampling error is determined by calculating the approximate standard error of GHG fluxes or carbon stock changes as simulated by the model for a given verification period. The uncertainty estimator used must be based on the sampling design employed.

10.5.2.2 Quantification Approach 2

Quantification Approach 2 is applicable particularly for SOC stocks. The baseline is represented by control sites that are linked to one or more project quantification units. The SOC stock difference and

its uncertainty is calculated based on comparisons of control sites and paired project quantification units.

Key sources of error accounted for under Quantification Approach 2 include:

1. Sampling error resulting from measuring/modeling only a portion of the project area.
2. Measurement error of methods used to determine SOC stock equivalents (t C02e per unit area) at sample points. Where samples are collected using ESM approaches and analyzed using dry combustion via a lab with demonstrated proficiency and quality control (e.g., through participation in the North American Proficiency Testing program), these errors are assumed to be unbiased and negligible. Where alternative measurement approaches such as soil spectroscopy techniques are used, measurement error must be estimated and propagated through estimates of the total change in SOC.

These sources of error are estimated separately and then combined to estimate a single uncertainty deduction for SOC stocks across the entire project.

10.5.2.3 Quantification Approach 3

In Quantification Approach 3, reductions and removals are estimated using emission factors (EF) determined to be most relevant for the project area. While these EFs are likely to include some prediction error, availability of source data for estimating that error may be inconsistent. As such, the prediction error of EFs is presumed to be zero for the purpose of calculating an uncertainty deduction. Project proponents must use the available EF that results in the most conservative reduction and removal estimates when applied across both the baseline and project scenarios.

It is expected that management data is collected across all quantification units in the project area according to the hierarchy outlined in section 8.1, and as such sampling error does not factor into uncertainty deductions. However, where management data cannot be collected across the entire project area, sampling error must be accounted. The uncertainty estimators must be based on the sampling design used. Project proponents must provide a description of the sampling design and a justification as to why management data are not collected across all quantification units.

10.5.3 Calculation of carbon credits

To calculate the number of carbon credits or Verified Carbon Units (VCUs) that may be issued, the project proponent must consider the number of buffer credits that must be deposited in the AFOLU pooled buffer account. The number of buffer credits that must be deposited is calculated by multiplying the non-permanence risk rating by the net change in carbon stocks. The buffer credits are quantified as:

$$Bu_{ER,t} = I(\Delta CO2_{wp}) \times \left(MIN(0, \Delta CO2_{wp,t}) - MIN(0, \Delta CO2_{bsl,t})\right) \times NPR\% + (1 - I(\Delta CO2_{wp}) \times (MIN(0, \Delta CO2_{wp,t}) - MIN(0, \Delta CO2_{bsl,t}) + MAX(0, CO2_{bsl,t}) \times NPR\% \quad (30)$$

Where:

$I(\Delta CO2_{wp})$ = 1 if $\sum_1^t \Delta CO2_{wp,t} > 0$

$I(\Delta CO2_{wp})$ = 0 if $\sum_1^t \Delta CO2_{wp,t} \leq 0$
$Bu_{ER,t}$ = Buffer credits to be deducted from reductions in year t (t CO2e)

$$Bu_{CR,t} = I(\Delta CO2_{wp}) \times \left(MAX(0, \Delta CO2_{wp,t}) - MAX(0, \Delta CO2_{bsl,t})\right) \times NPR\% \quad (31)$$

Where:
$I(\Delta CO2_{wp})$ = 1 if $\sum_1^t \Delta CO2_{wp,t} > 0$
$I(\Delta CO2_{wp})$ = 0 if $\sum_1^t \Delta CO2_{wp,t} \leq 0$
$Bu_{CR,t}$ = Buffer credits to be deducted from removals in year t (t CO2e)
$\Delta CO2_{wp,t}$ = Total carbon stock change in the project scenario in year t (t CO2e)
$\Delta CO2_{bsl,t}$ = Total carbon stock change in the baseline scenario in year t (t CO2e)
NPR% = Overall project non-permanence risk rating converted to a percentage

The number of VCUs resulting from project activities leading to reductions that may be issued in year t is calculated as:

$$VCU_{ER,t} = ER_{NET,t} - Bu_{ER,t} \quad (32)$$

Where:
$VCU_{ER,t}$ = Number of VCU resulting from project activities leading to reduction in year t
$ER_{NET,t}$ = Estimated net reductions in year t (t CO2e)

The number of VCUs resulting from project activities leading to removals that may be issued in year t is calculated as:

$$VCU_{CR,t} = CR_{NET,t} - Bu_{CR,t} \quad (33)$$

Where:
$VCU_{CR,t}$ = Number of VCUs resulting from project activities leading to removals in year t
$CR_{NET,t}$ = Estimated net removals in year t (t CO2e)

The number of VCUs that may be issued in year t is calculated as:

$$VCU_t = VCU_{ER,t} + VCU_{CR,t} \quad (34)$$

Where:
VCU_t = Number of VCUs in year t (t CO2e)

10.6 Non-permanence Risk and Buffer determination

Project proponents must undergo a non-permanence risk assessment at the start of the project and at every monitoring stage as per VCS Geologic Carbon Storage Non-Permanence Risk Tool. A validation/verification body shall evaluate and assess all data, rationales, assumptions, justifications and documentation supporting the non-permanence risk rating. The project must include plant removal, death, and lack of maintenance leading to plant removal/substitution or death as major

factors for non-permanence risk assessment. In addition to this, management quality, financial viability, commitment to maintenance, monitoring rigor and institutional arrangements must be scored for risk assessment. High risk projects, including minimal maintenance, non-contractual plant placement, and weak monitoring would require a higher buffer. Low risk projects, such as institutionally managed with robust guarantees, contractual obligations to replace plants, regular third-party audit may require a lower buffer. Project proponents must periodically repeat the non-permanence risk assessment and include it in the report.

Table 7 Risk factors and Buffer calculation

Risk category	Description/Criteria	Mitigation	Buffer increase%
Plant maintenance	Regular care, watering, pruning, pest management	None	0%
Lack of maintenance	Irregular watering, drying of plant leaves, pests	Yes	0%
		No	10%
Plant removal/substitution	Insufficient carbon sequestration	Yes	0%
Plant death	Improper care	Yes	0%
		No	20%
Management quality	Maintenance equipment/plan	No	10%
Financial viability	Funds allocation	Insufficient	5%
Monitoring rigor	Staff and personnel	No	5%
Institutional arrangements	Building space, office space, open space	Transfer/redevelopment	10%

11 MONITORING

Where discretion exists in the selection of a value for a parameter, the principle of conservativeness must be applied.

11.1 Data and Parameters Available at Validation

Data/Parameter	AR
Data unit	Percent
Description	Weighted mean adoption rate in the region under common practice assessment
Equations	(1)
Source of data	Calculated for the project across the group or all activity instances
Value applied	Must be less than or equal to 20%
Justification of choice of data or description of measurement methods and procedures applied	See Section 9
Purpose of data	Common practice assessment
Comments	Grouped projects must include one or more sets of eligibility criteria for the inclusion of new project activity instances, ensuring that new project activity instances have characteristics with respect to additionality that are consistent with the initial instances for the specified project activity and geographic area (see most recent version of VM0042).

Data/Parameter	EA_{ay}
Data unit	Percent
Description	Adoption rate of the y most common (by area covered) proposed project activity in the region under common practice assessment
Equations	(1)
Source of data	Publicly available information contained in agricultural census or other government (e.g., survey) data, peer-reviewed scientific literature, independent research data, or reports/assessments compiled by industry associations. Where all of these sources are unavailable, a signed and dated attestation statement from a qualified independent local expert.
Value applied	Conditional on data source
Justification of choice of data or description of	See “Source of data” and Section 9

measurement methods and procedures applied	
Purpose of data	Common practice assessment
Comments	Grouped projects must include one or more sets of eligibility criteria for the inclusion of new project activity instances, ensuring that new project activity instances have characteristics with respect to additionality that are consistent with the initial instances for the specified project activity and geographic area (see most recent version of VM0042).

Data/Parameter	PA_{ay}
Data unit	Dimensionless
Description	Ratio of the areas of proposed project-level adoption of activity ay in the project area relative to the sum of the project areas under common practice assessment
Equations	(1)
Source of data	Farm records and project activity commitments used with publicly available information contained in agricultural census or other government (e.g., survey) data, peer-reviewed scientific literature, independent research data or reports/assessments compiled by industry associations, or signed attestation from a qualified independent local expert.
Value applied	Conditional on data source
Justification of choice of data or description of measurement methods and procedures applied	See Section 9
Purpose of data	Common practice assessment
Comments	None

Data/Parameter	$Area_{ay}$
Data unit	Hectare (ha)
Description	Area of proposed project-level adoption of activity ay in the project area
Equations	(1)
Source of data	Farm records and project activity commitments
Value applied	Proposed project-level adoption of activity ay

Justification of choice of data or description of measurement methods and procedures applied	See Section 9
Purpose of data	Common practice assessment
Comments	Any significant features such as rock piles, waterways, or other features not under management must be subtracted from the area estimate. Grouped projects must include one or more sets of eligibility criteria for the inclusion of new project activity instances, ensuring that new project activity instances have characteristics with respect to additionality that are consistent with the initial instances for the specified project activity and geographic area (see most recent version of VM0042). Other units used to determine area (e.g., acres) must be converted to hectares.

Data/Parameter	ay
Data unit	unitless
Description	Proposed project activity commitments a1 to ay, where a1 covers the largest area in the project area
Equations	(1)
Source of data	Documentation of activities (intended farm management change, for example target fertilizer application rate) to be implemented in the project for each quantification unit
Value applied	Dependent on project activities
Justification of choice of data or description of measurement methods and procedures applied	See “Source of data” and Section 9
Purpose of data	Common practice assessment, basis for parameters Areaay and PAay
Comments	Appendix 1 lists the main categories of practices expected to enhance SOC stocks and/or reduce GHG emissions from soils under a broad range of cropping and livestock systems. This list is non-exhaustive. Grouped projects must include one or more sets of eligibility criteria for the inclusion of new project activity instances, ensuring that new project activity instances have characteristics with respect to additionality that are consistent with the initial instances for the specified project activity and geographic area (see most recent version of VM0042).

Data/Parameter	$FFC_{bsl,j,i,t}$
Data unit	Liters
Description	Consumption of fossil fuel type j (gasoline or diesel) for quantification unit i in year t in the baseline scenario
Equations	(8)
Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of measurement methods and procedures applied	Fossil fuel consumption may be monitored or the amount of fossil fuel combusted may be estimated using fuel efficiency (e.g., l/100 km, l/t km, l/hour) of the vehicle and the appropriate unit of use for the selected fuel efficiency (e.g., km driven where efficiency is given in l/100 km).
Purpose of data	Calculation of baseline emissions
Comments	Peer-reviewed published data may be used to determine fuel efficiency. For example, fuel efficiency factors may be obtained from Chapter 3, Volume 2 of IPCC (2019).

Data/Parameter	$ML_{imestone,bsl,i,t}$ and $MD_{olomite,bsl,i,t}$
Data unit	tonnes/year
Description	Amount of calcitic limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) applied to quantification unit i in year t in the baseline scenario
Equations	(10)
Source of data	See Box 1
Value applied	Amount of calcitic limestone ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$) applied to quantification unit i in year t
Justification of choice of data or description of measurement methods and procedures applied	All limestone and dolomite applied to soils should be included, even the proportion applied in mixture with fertilizers. Use of oxides (e.g., CaO) and hydroxides of lime for soil liming is not required to be included in the calculations to estimate CO_2 emissions from liming. Because these materials do not contain inorganic carbon, CO_2 is not released following soil application; it is only produced during material manufacture.
Purpose of data	Calculation of baseline emissions
Comments	None

Data/Parameter	$Pop_{bsl,l,i,t,P}$
Data unit	Head
Description	Population of grazing livestock of type l in the baseline scenario in quantification unit i for productivity system P in year t
Equations	(12), (13), (29)
Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of measurement methods and procedures applied	Record of number of grazing livestock by type
Purpose of data	Calculation of baseline emissions
Comments	None

Data/Parameter	GWP_{CH4}
Data unit	t CO_2e/t CH_4
Description	Global warming potential for CH_4
Equations	(11)–(13), (15)
Source of data	IPCC Fifth Assessment Report (IPCC, 2013)
Value applied	28
Justification of choice of data or description of measurement methods and procedures applied	See "Source of data." Global warming potential values must be applied as described in the most recent version of the VM0042 and derived from IPCC Assessment Reports.
Purpose of data	Calculation of baseline and project emissions
Comments	None

Data/Parameter	$W_{bsl,l,i,t,P}$
Data unit	kg animal mass/head
Description	Average weight in the baseline scenario of livestock type l for quantification unit i in productivity system P in year t
Equations	(14)
Source of data	See Box 1. Where project proponents justify a lack of sufficient activity data and project-specific information sources, Tier 1 values

	from Table 10A.5, Chapter 10, Volume 4 in IPCC (2019) may be selected.
Value applied	See "Source of data"
Justification of choice of data or description of measurement methods and procedures applied	See "Source of data"
Purpose of data	Calculation of project emissions
Comments	None

Data/Parameter	$MB_{bsl,c,i,t}$
Data unit	kg
Description	Mass of agricultural residues of type c burned in the baseline scenario for quantification unit i in year t
Equations	(15), (33)
Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of measurement methods and procedures applied	Peer-reviewed published data may be used to estimate the aboveground biomass prior to burning.
Purpose of data	Calculation of baseline emissions
Comments	Mass of residues burned is a function of the amount of aboveground biomass, the removal of aboveground biomass, and whether remaining residues are burned. It is assumed that 100% of aboveground biomass is burned in the baseline scenario.

Data/Parameter	GWP_{N2O}
Data unit	t CO_2e/t N_2O
Description	Global warming potential for N_2O
Equations	(16), (19), (23)–(25), (28), (31)–(33)
Source of data	IPCC Fifth Assessment Report (IPCC, 2013)
Value applied	265
Justification of choice of data or description of	See "Source of data." Global warming potential values must be applied as described in the most recent version of the VM0042 and derived from IPCC Assessment Reports.

measurement methods and procedures applied	
Purpose of data	Calculation of baseline and project emissions
Comments	None

Data/Parameter	$M_{bsl,SF,i,t}$
Data unit	t fertilizer
Description	Mass of N-containing synthetic fertilizer type SF applied in quantification unit i in year t in the baseline scenario
Equations	(20)
Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of measurement methods and procedures applied	See Box 1
Purpose of data	Calculation of baseline emissions
Comments	None

Data/Parameter	$M_{bsl,OF,i,t}$
Data unit	t fertilizer
Description	Mass of N-containing organic fertilizer type OF applied in the baseline scenario for quantification unit i in year t
Equations	(21)
Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of measurement methods and procedures applied	See Box 1
Purpose of data	Calculation of baseline emissions
Comments	None

Data/Parameter	$MB_{g,bsl,i,t}$
Data unit	t d.m.
Description	Annual aboveground and belowground dry matter of N-fixing species g returned to soils in the baseline scenario for quantification unit i in year t
Equations	(26)
Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of measurement methods and procedures applied	See Box 1
Purpose of data	Calculation of baseline emissions
Comments	None

Data/Parameter	$MS_{bsl,l,i,t}$
Data unit	Fraction of N deposited
Description	Fraction of nitrogen excretion by livestock type l that is deposited in quantification unit i in year t in the baseline scenario
Equations	(29)
Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of measurement methods and procedures applied	The fraction of nitrogen deposited on the project area is determined based on the amount of time spent grazing on the project area during year t for each livestock type l. In the absence of data available according to Box 1 (or to conservatively reduce the effort of project development), a value of 1 may be applied with no additional support. This would conservatively assume that livestock deposit 100% of their excreted N on the project area for the entirety of year t.
Purpose of data	Calculation of baseline and project emissions
Comments	None

Data/Parameter	$P_{bsl,p}$
Data unit	Output (e.g., kg)/ha

Description	Average productivity for product p during the historical look-back period
Equations	(35), (36)
Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of measurement methods and procedures applied	Average productivity for each livestock/crop product following guidance in Section 10.4.3
Purpose of data	Determination of baseline productivity for future market leakage analysis
Comments	None

Data/Parameter	$RP_{bsl,p}$
Data unit	Output (e.g., kg)/ha
Description	Average regional productivity for product p during the historical look back period
Equations	(36)
Source of data	Secondary evidence sources of regional productivity (e.g., peer reviewed literature, industry associations, international databases, government databases)
Justification of choice of data or description of measurement methods and procedures applied	Average regional productivity for each livestock/crop product following guidance in Section 10.4.3
Purpose of data	Determination of baseline productivity ratio for future market leakage analysis
Comments	None

Data/Parameter	A
Data unit	Hectare (ha)
Description	Project area
Equations	(63), (64), (66)Error! Reference source not found., (68)–(73)
Source of data	Measured in project area
Value applied	The project area is measured prior to validation.

Justification of choice of data or description of measurement methods and procedures applied	Delineation of the project area may use a combination of GIS coverages, ground survey data, remote imagery (satellite or aerial photographs), and other appropriate data. Any imagery or GIS datasets used must be geo-registered referencing corner points, landmarks, or other intersection points.
Purpose of data	Calculation of baseline and project emissions
Comments	Other units used to determine project area (e.g., acres) must be converted to hectares.

11.2 Data and Parameters Monitored

Data/Parameter	MDD
Data unit	t CO_2e/ha
Description	Minimum detectable difference in SOC stocks between two points in time
Equations	(2), (3)
Source of data	Estimation of the smallest difference in SOC stocks between two monitoring events that can be detected as statistically significant
Description of measurement methods and procedures to be applied	See Section 10.2.1
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See Section 10.2.1 and further guidance in FAO (2019)
Purpose of data	Development of sampling strategy for baseline setting and measurements for monitoring
Calculation method	See Section 10.2.1
Comments	Calculating the number of samples required to detect a minimum difference is optional.

Data/Parameter	S
Data unit	Dimensionless
Description	Standard deviation of the difference in SOC stocks between t_0 and t_1
Equations	(2), (3)
Source of data	Estimation of the smallest difference in SOC stocks between two monitoring events that may be detected as statistically significant
Description of measurement methods and procedures to be applied	See Section 10.2.1

Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See Section 10.2.1 and further guidance in FAO (2019)
Purpose of data	Development of sampling strategy for baseline setting and measurements for monitoring
Calculation method	See Section 10.2.1
Comments	Calculation of the number of samples required to detect a minimum difference is optional.

Data/Parameter	n
Data unit	Dimensionless
Description	Number of samples required to detect a minimum difference
Equations	(2), (3)
Source of data	Estimation of the smallest difference in SOC stocks between two monitoring events that can be detected as statistically significant
Description of measurement methods and procedures to be applied	See Section 10.2.1
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See Section 10.2.1 and further guidance in FAO (2019)
Purpose of data	Development of sampling strategy for baseline setting and measurements for monitoring
Calculation method	See Section 10.2.1
Comments	Calculating the number of samples required to detect a minimum difference is optional.

Data/Parameter	$n - 1$
Data unit	Dimensionless
Description	Degrees of freedom for the relevant t-distribution
Equations	(2), (3)
Source of data	Estimation of the smallest difference in SOC stocks between two monitoring events that can be detected as statistically significant
Description of measurement methods and procedures to be applied	See Section 10.2.1

Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See Section 10.2.1 and further guidance in FAO (2019)
Purpose of data	Development of sampling strategy for baseline setting and measurements for monitoring
Calculation method	See Section 10.2.1
Comments	Calculating the number of samples required to detect a minimum difference is optional.

Data/Parameter	$t_{x,\upsilon}$
Data unit	Dimensionless
Description	Values of the t-distribution given a certain power level (1 − b) and a significance level
Equations	(2), (3)
Source of data	Estimation of the smallest difference in SOC stocks between two monitoring events that can be detected as statistically significant
Description of measurement methods and procedures to be applied	See Section 10.2.1
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or, when following quantification approach 2, prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See Section 10.2.1 and further guidance in FAO (2019)
Purpose of data	Development of sampling strategy for baseline setting and measurements for monitoring
Calculation method	See Section 10.2.1
Comments	Calculating the number of samples required to detect a minimum difference is optional.

Data/Parameter	$M_{n,dl,SOC}$
Data unit	kg/ha
Description	SOC mass in soil sample n in depth layer dl
Equations	(4)
Source of data	Measured after soil sampling in the project area
Description of measurement methods and procedures to be applied	See Section 10.2.1

Frequency of monitoring/recording	Measurement of SOC stocks must be conducted at least every five years, or, when following quantification approach 2, prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See Section 10.2.1 Soil mass must not include particles greater than 2 mm in diameter (i.e., gravel/stones) nor plant material. Beem-Miller et al. (2016) provide a useful approach to ensuring high-quality sampling in rocky agricultural soils.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Wendt and Hauser (2013) and von Haden et al. (2020) provide spreadsheets and R scripts to standardize and facilitate calculations of SOC stock calculations with multiple soil depth increments.
Comments	None

Data/Parameter	$M_{n,dl,sample}$
Data unit	g
Description	Soil mass of sample n in depth layer dl
Equations	(4)
Source of data	Measured after soil sampling in the project area
Description of measurement methods and procedures to be applied	See Section 10.2.1
Frequency of monitoring/recording	Measurement of SOC stocks must be conducted at least every five years, or, when following quantification approach 2, prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See Section 10.2.1 Soil mass must not include particles greater than 2 mm in diameter (i.e., gravel/stones) nor plant material. Beem-Miller et al. (2016) provide a useful approach to ensuring high-quality sampling in rocky agricultural soils.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Mass of gravel/stones and plant material must be subtracted from the sample mass to obtain soil mass.
Comments	None

Data/Parameter	D
Data unit	mm

Description	Inside diameter of probe or auger
Equations	(4)
Source of data	Measured as part of project monitoring
Description of measurement methods and procedures to be applied	Information from product specifications of probe or auger
Frequency of monitoring/recording	Measurement of SOC stocks must be conducted at least every five years, or, when following quantification approach 2, prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See Section 10.2.1
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	N
Data unit	Unitless
Description	Number of cores sampled
Equations	(4)
Source of data	Measured in the project area
Description of measurement methods and procedures to be applied	The number of samples taken is determined as part of the development of a sampling strategy (see Section 10.2.1).
Frequency of monitoring/recording	Measurement of SOC stocks must be conducted at least every five years, or, when following quantification approach 2, prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See Section 10.2.1
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$OC_{n,dl}$
Data unit	g/kg

Description	Organic carbon content in sample n from depth layer dl
Equations	(4), (5)
Source of data	Measured in the project area
Description of measurement methods and procedures to be applied	When measuring SOC content via conventional analytical laboratory methods, the use of dry combustion is recommended over other techniques. Emerging technologies (INS, LIBS, MIR, and Vis-NIR) with known uncertainty may be applied to measure SOC concentration following the criteria in Appendix 4.
Frequency of monitoring/recording	Measurements of SOC stocks must be conducted at least every five years, or, when following quantification approach 2, prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See Section 10.2.1
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	BD_{corr}
Data unit	g/cm^3
Description	Corrected bulk density of the fine soil fraction (after subtracting the mass proportion of the coarse fragments)), for calibration of SOC models
Equations	(5)
Source of data	See VMD0053 for bulk density data requirements for model calibration and statistical validation
Description of measurement methods and procedures to be applied	See “Source of data”
Frequency of monitoring/recording	Measurements of SOC stocks must be conducted at least every five years.
QA/QC procedures to be applied	See Sections 10.2.1.3 and 10.2.1.5 for general sampling and measurement guidance relevant for bulk density data
Purpose of data	Modeling of baseline scenario, calculation of baseline and project emissions
Calculation method	Fine soil fraction mass minus mass proportion of the coarse fragments
Comments	Only required when following Quantification Approach 1 for SOC stock changes

Data/Parameter	d
Data unit	cm
Description	Soil depth
Equations	(5)
Source of data	See VMD0053 for requirements on calibration datasets
Description of measurement methods and procedures to be applied	Soil depth for each depth increment to be captured as part of data collection following requirements in VMD0053
Frequency of monitoring/recording	Measurements of SOC stocks must be conducted at least every five years.
QA/QC procedures to be applied	See VMD0053 for requirements on calibration datasets
Purpose of data	Modeling of baseline scenario, calculation of baseline and project emissions
Calculation method	Not applicable
Comments	Only required when following Quantification Approach 1 for SOC stock changes

Data/Parameter	$\int(SOC_{bsl,i,t})$
Data unit	t CO_2e/ha
Description	Modeled SOC stocks in the baseline scenario for quantification unit i at time t, calculated by modeling SOC stock changes over the course of the preceding year
Equations	(6)
Source of data	See VMD0053
Description of measurement methods and procedures to be applied	Modeled SOC stocks in the baseline scenario are determined according to the following equation: $SOC_soil_{bsl,i,t} = \int SOC(Val\ A_{bsl,i,t}, Val\ B_{bsl,i,t}, \ldots)$ Where: $SOC_soil_{bsl,i,t}$ = Modeled SOC stocks in the baseline scenario for quantification unit i at time t (t CO_2e/ha) $\int SOC$ = Model predicting carbon dioxide emissions from the SOC pool (t CO_2e/ha) $Val\ A_{bsl,i,t}$ = Value of model input variable A in the project scenario for quantification unit i at time t (units unspecified)

	Val $B_{bsl,i,t}$ = Value of model input variable B in the project scenario for quantification unit i at time t (units unspecified) quantification unitquantification unitquantification unitSee Box 1 for sources of data and description of measurement methods and procedures to be applied to obtain values for model input variables.
Frequency of monitoring/recording	Measurements must be conducted at least every five years. Modeling as means of monitoring must be conducted prior to each verification event where verification occurs more frequently than once every five years.
QA/QC procedures to be applied	See VMD0053
Purpose of data	Calculation of baseline emissions following Quantification Approach 1
Calculation method	Not applicable
Comments	The SOC stocks at time t = 0 are calculated based on directly measured SOC content and bulk density at t = 0 or (back-) modeled to t = 0 from measurements within ±5 years of t = 0. See Section 10.2.1 for requirements for SOC content and bulk density measurements.

Data/Parameter	i
Data unit	Dimensionless
Description	Quantification unit. Defined area that is selected for measurement and monitoring, such as a field or stratum. See also definition in Section 3.
Equations	(6)–(33), (46)–(59)
Source of data	Determined in project area
Description of measurement methods and procedures to be applied	The quantification units are determined prior to verification.
Frequency of monitoring/recording	The quantification units must be reported at every verification, including adaptations from the previous verification periods.
QA/QC procedures to be applied	See definition in Section 3 for considerations on defining quantification units
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	Ai
Data unit	Hectare
Description	Area of quantification unit i
Equations	(7), (9), (12), (13), (15), (19), (22), (25), (28), (30), (33), (46)–(59)
Source of data	Measurement of each quantification unit within the project area
Description of measurement methods and procedures to be applied	The quantification unit area is measured prior to verification.
Frequency of monitoring/recording	The quantification units must be reported at every verification, including adaptations from the previous verification periods.
QA/QC procedures to be applied	Delineation of the quantification unit area may be determined using a combination of GIS coverages, ground survey data, remote imagery (satellite or aerial photographs), and other appropriate data. Any imagery or GIS datasets used must be geo-registered referencing corner points, landmarks, or other intersection points.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	Other units used to determine area (e.g., acres) must be converted to hectares.

Data/Parameter	j
Data unit	Dimensionless
Description	Type of fossil fuel combusted
Equations	(7), (8)
Source of data	Determined in quantification unit i
Description of measurement methods and procedures to be applied	See Box 1. Fossil fuel type is determined prior to verification.
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See Box 1
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$EF_{CO2,j}$
Data unit	t CO_2e/liter
Description	Emission factor for fossil fuel j (gasoline, diesel or other) combusted
Equations	(8)
Source of data	See Section 10.3 under Quantification Approach 3. For gasoline or diesel, EFs listed in Table 3.3.1 Chapter 3 Volume 2 in IPCC (2019) may be applied.
Description of measurement methods and procedures to be applied	For gasoline EF_{CO2} = 0.002810 t CO_2e per liter. For diesel EF_{CO2} = 0.002886 t CO_2e per liter
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 10.3 under Quantification Approach 3.
QA/QC procedures to be applied	See "Source of data"
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	Assumes four-stroke gasoline engine for gasoline combustion and default values for energy content of 47.1 GJ/t and 45.66 GJ/t for gasoline and diesel respectively (IEA, 2004)

Data/Parameter	$FFC_{wp,j,i,t}$
Data unit	Liters
Description	Consumption of fossil fuel type j for quantification unit i in year t in the project scenario
Equations	(8)
Source of data	See Box 1
Description of measurement methods and procedures to be applied	Fossil fuel consumption may be monitored or the amount of fossil fuel combusted may be estimated using fuel efficiency (e.g., l/100 km, l/t- km, l/hour) of the vehicle type and the appropriate unit of use for the selected fuel efficiency (e.g., km driven where efficiency is given in l/100 km).
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of project emissions

Calculation method	Fuel efficiency factors may be obtained from Chapter 3, Volume 2 of IPCC (2019).
Comments	For all equations, the subscript bsl must be substituted by wp to make clear that the relevant values are being quantified for the project scenario.

Data/Parameter	$EF_{Limestone}$ and $EF_{Dolomite}$
Data unit	t C/(t limestone or dolomite)
Description	Emission factor for the application of calcitic limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) (i.e., liming)
Equations	(10)
Source of data	Section 11.3, Chapter 11, Volume 4 in IPCC (2019)
Description of measurement methods and procedures to be applied	IPCC (2019) values: • For calcitic limestone $EF_{Limestone}$ = 0.12 t C/t limestone • For dolomite, $EF_{Dolomite}$ = 0.13 t C/t dolomite
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 10.3 under Quantification Approach 3.
QA/QC procedures to be applied	See "Source of Data" and Section 8.3 under Quantification Approach 3
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$f(CH4_soil_{bsl,i,t})$
Data unit	t CH_4/ha
Description	Modeled methane emissions from soil in the baseline scenario for quantification unit i at time t, calculated by modeling soil methane fluxes over the course of the preceding year
Equations	(11)
Source of data	Modeled in the project area
Description of measurement methods and procedures to be applied	Modeled methane emissions from soil in the baseline scenario are determined according to the following equation: $f(CH4_soil_{bsl,i,t}) = \int_{CH4soil}(Var\ A_{bsl,i,t}, Var\ B_{bsl,i,t}, \ldots)$ Where:

	$f(CH4_soil_{bsl,i,t})$= Modeled methane emissions from the SOC pool in the baseline scenario for quantification unit i at time t (t CH_4/ha) $f_{CH4soil}$ = Model predicting methane emissions from the soil pool Val $A_{bsl,i,t}$ = Value of model input variable A in the baseline scenario for quantification unit i at time t (units unspecified) Val $B_{bsl,i,t}$ = Value of model input variable B in the baseline scenario for quantification unit i at time t (units unspecified) quantification unitquantification unitquantification unitSee Box 1 for sources of data and description of measurement methods and procedures to be applied to obtain values for model input variables.
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See VMD0053
Purpose of data	Calculation of baseline and project emissions in Quantification Approach 1
Calculation method	Methods are specific to the model used.
Comments	None

Data/Parameter	$EF_{ent,l,P}$
Data unit	kg CH_4/(head × year)
Description	Enteric fermentation emission factor for livestock type l and productivity system P
Equations	(12)
Source of data	See Section 8.3 under Quantification Approach 3. Where no alternative information source is available that is applicable to the project conditions, project proponents may derive emission factors for each category of livestock estimated based on the gross energy intake and methane conversion factor for the category by following the guidance under "Tier 2 Approach for Methane Emissions from Enteric Fermentation" in Section 10.3.2, Chapter 10, Volume 4 of IPCC (2019). Where project proponents justify a lack of sufficient activity data and project-specific information sources, Tier 1 and Tier 1a enteric

	fermentation emission factors from Tables 10.10 or 10.11, Chapter 10, Volume 4 in IPCC (2019) may be selected.
Description of measurement methods and procedures to be applied	When using emission factors from Tables 10.10 and 10.11 (Chapter 10, Volume 4 in IPCC, 2019), the region most applicable to the project area must be selected. The tabulations in Annex 10A.1 (IPCC, 2019) provide details of the underlying animal characteristics such as weight, growth rate, and milk production used to develop the emission factors. Where project activities lead to agricultural systems transitioning from local low input productivity systems to higher productivity systems, more than one emission factor given for a specific animal category may be applied.
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 10.3 under Quantification Approach 3.
QA/QC procedures to be applied	See "Source of data" and Section 8.3 under Quantification Approach 3
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$Pop_{wp,l,i,t,P}$
Data unit	Head
Description	Population of grazing livestock of type l in the project scenario in quantification unit i for productivity system P in year t
Equations	(12), (13), (29)
Source of data	See Box 1
Description of measurement methods and procedures to be applied	Record of number of grazing livestock by type. Information is monitored via direct consultation with, and substantiated with a written attestation from, the farmer or landowner of the quantification unit. Any quantitative information (e.g., discrete or continuous numeric variables) on ALM practices must be supported by one or more forms of documented evidence pertaining to the selected quantification unit and relevant verification period (e.g., management logs, receipts or invoices, farm equipment specifications).
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.

QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of project emissions
Calculation method	Not applicable
Comments	For all equations, the subscript bsl must be substituted by wp to make clear that the relevant values are being quantified for the project scenario.

Data/Parameter	l
Data unit	Dimensionless
Description	Type of livestock
Equations	(12)–(14), (24), (29), (32), (34)
Source of data	Determined in quantification unit i
Description of measurement methods and procedures to be applied	See Box 1. Livestock type is determined prior to verification.
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See Box 1
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	P
Data unit	Unitless
Description	Productivity system
Equations	(12), (28), (29)
Source of data	Subsection "Definitions of High and Low Productivity Systems," Section 10.2, Chapter 10, Volume 4 of IPCC (2019)
Description of measurement methods and procedures to be applied	When using emission factors from IPCC (2019), project proponents must differentiate between high- and low productivity systems for each livestock species to define value from Lookup Tables 10A.1 to 10A.9. Information is monitored via direct consultation with, and substantiated with a written attestation

	from, the farmer or landowner of the quantification unit. See also Box 1.
Frequency of monitoring/recording	To confirm that the productivity system remains the same, monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently. Any changes to the productivity system must be documented in each monitoring report.
QA/QC procedures to be applied	See "Source of data" and Section 10.3 under Quantification Approach 3
Purpose of data	Calculation of baseline and project emissions
Calculation method	Following descriptions in IPCC (2019), basic population estimates may be applied (see "Source of data").
Comments	None

Data/Parameter	$AWMS_{l,i,t,P,S}$
Data unit	Dimensionless
Description	Fraction of total annual volatile solids for each livestock type l that is managed in manure management system S in the project area, for productivity system P
Equations	(13), (29)
Source of data	See Section 10.3 under Quantification Approach 3. Where project proponents justify a lack of sufficient activity data and project-specific information sources, Tier 1 average values for animal waste management systems (manure management systems) from Tables 10A.6 to 10A.9, Chapter 10, Volume 4 in IPCC (2019) may be selected.
Description of measurement methods and procedures to be applied	As emissions from manure management systems are highly temperature dependent, the climate zone associated with the entire project area where manure is managed must be considered.
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 10.3 under Quantification Approach 3.
QA/QC procedures to be applied	See "Source of data" and Section 8.3 under Quantification Approach 3
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$EF_{CH4,md,l,P,S}$
Data unit	g CH_4/(kg volatile solids)
Description	Emission factor for methane emissions from manure deposition for livestock type l in productivity system P and manure management system S
Equations	(13)
Source of data	See Section 10.3 under Quantification Approach 3. Where no information source is available that is applicable to the project conditions, project proponents may derive emission factors based on project-specific manure characteristics and animal waste management system characteristics following the guidance under Tier 2 in Section 10.4.2, Chapter 10, Volume 4 of IPCC (2019). Where project proponents justify a lack of sufficient activity data and project-specific information sources, Tier 1 and Tier 1a values from Tables 10.14 and 10.15, Chapter 10, Volume 4 in IPCC (2019) may be selected.
Description of measurement methods and procedures to be applied	See "Source of data"
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 10.3 under Quantification Approach 3.
QA/QC procedures to be applied	See "Source of data" and Section 10.3 under Quantification Approach 3
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	S
Data unit	Unitless
Description	Manure management system
Equations	(13), (23), (24), (28), (29)
Source of data	Table 10.18, Chapter 10, Volume 4 in IPCC (2019)
Description of measurement methods and procedures to be applied	See Section 10.3 under Quantification Approach 3. When using methane and nitrous oxide emission factors from IPCC (2019), project proponents must differentiate between manure management systems to define value from Lookup Tables 10.14

	and 10.17. The referenced table of IPCC (2019) provides Tier 1a emission factors, which consider different aeration and mixing regimes as well as other factors such as water content, which influence CH_4 and N_2O emissions differently.
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 10.3 under Quantification Approach 3.
QA/QC procedures to be applied	See "Source of data" and Section 10.3 under Quantification Approach 3
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$VS_{rate,l,P}$
Data unit	kg volatile solids/(1000 kg animal mass × day)
Description	Default volatile solids excretion rate for livestock type l and productivity system P
Equations	(14)
Source of data	See Section 10.3 under Quantification Approach 3. Where no information source is available that is applicable to the project conditions, project proponents may derive default factors using Equation 10.24 in Chapter 10, Volume 4 in IPCC (2019). Where project proponents justify a lack of sufficient activity data and project-specific information sources, Tier 1 and Tier 1a values from Table 10.13a, Chapter 10, Volume 4 in IPCC (2019) may be selected.
Description of measurement methods and procedures to be applied	The volatile solids excretion rate is determined based on livestock type. Where agricultural systems are differentiated into low and high productivity systems in Table 10.13a in Chapter 10, Volume 4 in IPCC (2019), the mean value may be selected.
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 8.3 under Quantification Approach 3.
QA/QC procedures to be applied	See "Source of data" and Section 10.3 under Quantification Approach 3
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable

Comments	None

Data/Parameter	$W_{wp,l,i,t,P}$
Data unit	kg animal mass/head
Description	Average weight in the project scenario of livestock type l for quantification unit i in productivity system P in year t
Equations	(14)
Source of data	Estimated based on management records from project area
Description of measurement methods and procedures to be applied	Information is monitored via direct consultation with, and substantiated with a written attestation from, the farmer or landowner of the quantification unit. Any quantitative information (e.g., discrete or continuous numeric variables) on ALM practices must be supported by one or more forms of documented evidence pertaining to the selected quantification unit and relevant verification period (e.g., management logs, receipts or invoices, farm equipment specifications).
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of project emissions
Calculation method	Not applicable
Comments	For all equations, the subscript bsl must be substituted by wp to make clear that the relevant values are being quantified for the project scenario.

Data/Parameter	CF_c
Data unit	Proportion of pre-fire fuel biomass consumed
Description	Combustion factor for agricultural residue type c
Equations	(15), (33)
Source of data	Table 2.6, Chapter 2, Volume 4 in IPCC (2019)
Description of measurement methods and procedures to be applied	The combustion factor is selected based on the agricultural residue type burned.
Frequency of monitoring/recording	Source of data for combustion factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following

	the guidance in Section 8.3 under Quantification Approach 3.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$EF_{c,CH4}$
Data unit	g CH4/kg dry matter burnt
Description	Methane emission factor for the burning of agricultural residue type c
Equations	(15)
Source of data	Table 2.5, Chapter 2, Volume 4 in IPCC (2019)
Description of measurement methods and procedures to be applied	The emission factor is selected based on the agricultural residue type burned.
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 8.3 under Quantification Approach 3.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	c
Data unit	Dimensionless
Description	Type of agricultural residue
Equations	(15), (33)
Source of data	Determined in quantification unit i
Description of measurement methods and procedures to be applied	See Box 1. Agricultural residue type is determined prior to verification.

Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$MB_{wp,c,i,t}$
Data unit	kg
Description	Mass of agricultural residues of type c burned in the project for quantification unit i in year t
Equations	(15), (33)
Source of data	See Box 1
Description of measurement methods and procedures to be applied	Estimate the aboveground biomass of grassland before burning for at least three plots (1 m × 1 m). The difference in the aboveground biomass is the aboveground biomass burned.
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of project emissions
Calculation method	Not applicable
Comments	For all equations, the subscript bsl must be substituted by wp to make clear that the relevant values are being quantified for the project scenario.

Data/Parameter	$f(N2O_soil_{bsl,i,t})$
Data unit	t N_2O/ha
Description	Modeled nitrous oxide emissions from soil in the baseline scenario for quantification unit i in year t, calculated by modeling soil fluxes of nitrogen forms over the course of the preceding year
Equations	(16)
Source of data	Modeled in the project area
Description of measurement methods and procedures to be applied	Modeled nitrous oxide emissions from soil in the baseline scenario are determined according to the following equation:

	$f(N2O_soil_{bsl,i,t}) = \int_{N2Osoil}(Var\ A_{bsl,i,t}, Var\ B_{bsl,i,t}, \ldots)$ Where: $f(N2O_soil_{bsl,i,t})$ = Modeled nitrous oxide emissions from soil in the baseline scenario for quantification unit i in year t, calculated by modeling soil fluxes of nitrogen forms over the course of the preceding year (t N_2O/ha) $\int_{N2Osoil}$ = Model predicting nitrous oxide emissions from the soil pool Val $A_{bsl,i,t}$ = Value of model input variable A in the baseline scenario for quantification unit i at time t (units unspecified) Val $B_{bsl,i,t}$ = Value of model input variable B in the baseline scenario for quantification unit i at time t (units unspecified)
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See VMD0053
Purpose of data	Calculation of baseline and project emissions in Quantification Approach 1
Calculation method	Not applicable
Comments	None

Data/Parameter	$EF_{Ndirect}$
Data unit	t N_2O-N/t N applied
Description	Emission factor for direct nitrous oxide emissions from N additions from synthetic fertilizers, organic amendments, and crop residues
Equations	(19), (25)
Source of data	See Section 10.3 under Quantification Approach 3. Where no information source is available that is applicable to the project conditions, project proponents may derive emission factors following the guidance in Chapter 11 Section 11.2.1.1 and Chapter 2 Section 2.2.4 in IPCC (2019). The emission factors

	will depend on, for example, SOC content, soil texture, drainage, soil pH, N application rate per fertilizer type, fertilizer type, liquid or solid form of organic fertilizer, irrigation, and type of crop with differences between legumes, non-leguminous arable crops, and grass. Where project proponents justify a lack of sufficient activity data and project-specific information sources, an appropriate disaggregated Tier 1 value from Table 11.1, Chapter 11, Volume 4 in IPCC (2019) may be selected.
Description of measurement methods and procedures to be applied	See "Source of data"
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 10.3 under Quantification Approach 3.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	The emission factor is applicable to N additions from mineral fertilizers, organic amendments, and crop residues, and N mineralized from mineral soil as a result of SOC loss. Wet climates occur in temperate and boreal zones where the ratio of annual precipitation to potential evapotranspiration is greater than 1, and in tropical zones where annual precipitation is greater than 1000 mm. Dry climates occur in temperate and boreal zones where the ratio of annual precipitation to potential evapotranspiration is less than 1, and in tropical zones where annual precipitation is less than 1000 mm.

Data/Parameter	NC_{SF}
Data unit	t N/t fertilizer
Description	N content of synthetic fertilizer type SF
Equations	(20)
Source of data	See Box 1
Description of measurement methods and procedures to be applied	N content is determined following fertilizer manufacturer's specifications.
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently. Parameter value must be updated when synthetic fertilizer product is changed or when new manufacturer's specifications are issued.
QA/QC procedures to be applied	See "Source of data" and Section 10.3 under Quantification Approach 3
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	SF
Data unit	Dimensionless
Description	Type of synthetic N fertilizer
Equations	(20)
Source of data	Determined in quantification unit i
Description of measurement methods and procedures to be applied	See Box 1. Synthetic fertilizer type is determined prior to verification.
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$M_{wp,SF,i,t}$
Data unit	t fertilizer
Description	Mass of N-containing synthetic fertilizer type SF applied in the project for quantification unit i in year t
Equations	(20)
Source of data	Management records from project area
Description of measurement methods and procedures to be applied	Information is monitored via direct consultation with, and substantiated with a written attestation from, the farmer or landowner of the quantification unit. Any quantitative information (e.g., discrete or continuous numeric variables) on ALM practices must be supported by one or more forms of documented evidence pertaining to the selected quantification unit and relevant verification period (e.g., management logs, receipts or invoices, farm equipment specifications).
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of project emissions
Calculation method	Not applicable
Comments	For all equations, the subscript bsl must be substituted by wp to make clear that the relevant values are being quantified for the project scenario.

Data/Parameter	NC_{OF}
Data unit	t N/t fertilizer
Description	N content of organic fertilizer type OF
Equations	(21)
Source of data	Peer-reviewed published data may be used. For example, default manure N content may be selected from Edmonds et al. (2003) cited in US EPA (2011) or other regionally appropriate sources such as the European Environment Agency.
Description of measurement methods and procedures to be applied	See “Source of data”
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently. Parameter value must be updated when organic fertilizer product is changed or as new default values become available in peer-reviewed publications or databases.

QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	OF
Data unit	Dimensionless
Description	Type of organic N fertilizer
Equations	(21)
Source of data	Determined in quantification unit i
Description of measurement methods and procedures to be applied	See Box 1. Organic fertilizer type is determined prior to verification.
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$M_{wp,OF,i,t}$
Data unit	t fertilizer
Description	Mass of N-containing organic fertilizer type OF applied in the project for quantification unit i in year t
Equations	(21)
Source of data	Management records from project area
Description of measurement methods and procedures to be applied	Information is monitored via direct consultation with, and substantiated with a written attestation from, the farmer or landowner of the quantification unit. Any quantitative information (e.g., discrete or continuous numeric variables) on ALM practices must be supported by one or more forms of documented evidence pertaining to the selected quantification unit and relevant verification period (e.g., management logs, receipts or invoices, farm equipment specifications).

Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of project emissions
Calculation method	Not applicable
Comments	For all equations, the subscript bsl must be substituted by wp to make clear that the relevant values are being quantified for the project scenario.

Data/Parameter	$Frac_{GASF}$
Data unit	kg N volatilized/kg N applied
Description	Fraction of all synthetic N added to soils that volatilizes as NH_3 and NO_x
Equations	(23)
Source of data	See Section 10.3 under Quantification Approach 3. When no information source is available that is applicable to the project conditions, project proponents may define value from Lookup Table 11.3, Chapter 11, Volume 4 in IPCC (2019).
Description of measurement methods and procedures to be applied	See "Source of data"
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 10.3 under Quantification Approach 3.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$Frac_{GASM}$
Data unit	kg N volatilized/kg N applied
Description	Fraction of all organic N added to soils and N in manure and urine deposited on soils that volatilizes as NH_3 and NO_x
Equations	(23), (31)

Source of data	See Section 8.3 under Quantification Approach 3. When no information source is available that is applicable to the project conditions, project proponents may define value from Lookup Table 11.3, Chapter 11, Volume 4 in IPCC (2019).
Description of measurement methods and procedures to be applied	See "Source of data"
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 10.3 under Quantification Approach 3
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$Frac_{LEACH}$
Data unit	kg N/kg N additions
Description	Fraction of N (synthetic or organic) added to soils and N in manure and urine deposited on soils that is lost through leaching and runoff, in regions where leaching and runoff occurs
Equations	(24), (32)
Source of data	See Section 10.3 under Quantification Approach 3. When no information source is available that is applicable to the project conditions, project proponents may define value from Lookup Table 11.3, Chapter 11, Volume 4 in IPCC (2019).
Description of measurement methods and procedures to be applied	When using values from IPCC (2019), for wet climates and for dry climate regions where irrigation (other than drip irrigation) is used, a value of 0.24 is applied. For all other dry climate regions, a value of zero is applied.
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 10.3 under Quantification Approach 3.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable

Comments	Wet climates occur in temperate and boreal zones where the ratio of annual precipitation to potential evapotranspiration is greater than 1, and in tropical zones where annual precipitation is greater than 1000 mm. Dry climates occur in temperate and boreal zones where the ratio of annual precipitation to potential evapotranspiration is less than 1, and in tropical zones where annual precipitation is less than 1000 mm.

Data/Parameter	EF_{Nleach}
Data unit	t N_2O-N/t N leached and runoff
Description	Emission factor for nitrous oxide emissions from leaching and runoff
Equations	(24), (32)
Source of data	See Section 10.3 under Quantification Approach 3. When no information source is available that is applicable to the project conditions, project proponents may define value from Lookup Table 11.3, Chapter 11, Volume 4 in IPCC (2019).
Description of measurement methods and procedures to be applied	See "Source of data"
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 10.3 under Quantification Approach 3.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$MB_{g,wp,i,t}$
Data unit	t d.m.
Description	Annual aboveground and belowground dry matter of N-fixing species g returned to soils for quantification unit i in year t
Equations	(26)
Source of data	Aboveground and belowground dry matter in N-fixing species g returned to soil may be directly measured or peer-reviewed published data may be used.

Description of measurement methods and procedures to be applied	Information is monitored via direct consultation with, and substantiated with a written attestation from, the farmer or landowner of the quantification unit. Any quantitative information (e.g., discrete or continuous numeric variables) on ALM practices must be supported by one or more forms of documented evidence pertaining to the selected quantification unit and relevant verification period (e.g., management logs, receipts or invoices, farm equipment specifications).
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of project emissions
Calculation method	Not applicable
Comments	For all equations, the subscript bsl must be substituted by wp to make clear that the relevant values are being quantified for the project scenario.

Data/Parameter	$N_{content,g}$
Data unit	t N/t d.m
Description	Fraction of N in dry matter for N-fixing species g
Equations	(26)
Source of data	See Section 10.3 under Quantification Approach 3. When no information source is available that is applicable to the project conditions, project proponents may define value from Lookup Table 11.2, Chapter 11, Volume 4 in IPCC (2019).
Description of measurement methods and procedures to be applied	The fraction of N in dry matter is determined based on the N-fixing species type.
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 10.3 under Quantification Approach 3.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	g
Data unit	Dimensionless
Description	Type of N-fixing species
Equations	(26)
Source of data	Determined in quantification unit i
Description of measurement methods and procedures to be applied	See Box 1. N-fixing species type is determined prior to verification.
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$EF_{N2O,md,l,S}$
Data unit	kg N_2O-N/kg N input
Description	Emission factor for nitrous oxide from manure and urine deposited on soils by livestock type l and manure management system S
Equations	(28)
Source of data	See Section 10.3 under Quantification Approach 3. Where project proponents justify a lack of sufficient activity data and project-specific information sources, Tier 1 and Tier 1a values from Table 10.21, Chapter 10, Volume 4 in IPCC (2019) may be selected.
Description of measurement methods and procedures to be applied	See "Source of data"
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 10.3 under Quantification Approach 3.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$Nex_{l,P}$
Data unit	kg N deposited/(head × year)
Description	Annual average nitrogen excretion per head of livestock type l in productivity system P
Equations	(29)
Source of data	See Section 10.3 under Quantification Approach 3. Where no alternative information source is available that is applicable to the project conditions, project proponents may derive default factors using Equations 10.31 or 10.31a in Chapter 10, Volume 4 in IPCC (2019). Where project proponents justify a lack of sufficient activity data and project-specific information sources, Tier 1 and Tier 1a values from Table 10.19, Chapter 10, Volume 4 in IPCC (2019) may be selected.
Description of measurement methods and procedures to be applied	See "Source of data"
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 10.3 under Quantification Approach 3.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	EF_{Nvolat}
Data unit	t N_2O-N/(t NH_3-N + NO_x-N volatilized)
Description	Emission factor for nitrous oxide emissions from atmospheric deposition of N on soils and water surfaces
Equations	(23), (31)
Source of data	See Section 10.3 under Quantification Approach 3. When no information source is available that is applicable to the project conditions, project proponents may define value from Lookup Table 11.3, Chapter 11, Volume 4 in IPCC (2019).
Description of measurement methods and procedures to be applied	See "Source of data"
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to

	the project conditions become available following the guidance in Section 10.3 under Quantification Approach 3.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$EF_{c,N2O}$
Data unit	g N_2O/kg dry matter burned
Description	Nitrous oxide emission factor for the burning of agricultural residue type c
Equations	(33)
Source of data	See Section 10.3 under Quantification Approach 3. When no information source is available that is applicable to the project conditions, project proponents may define value from Lookup Table 2.5, Chapter 2, Volume 4 in IPCC (2019).
Description of measurement methods and procedures to be applied	The emission factor is selected based on the agricultural residue type.
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 10.3 under Quantification Approach 3.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$M_OA_{wp,I,t}$
Data unit	tonnes
Description	Mass of organic amendment applied as fertilizer (disaggregated by livestock type l for manure) on the project area in year t
Equations	(34)
Source of data	Management records from project area

Description of measurement methods and procedures to be applied	For manure application, data should be disaggregated for each livestock type l
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of leakage from application of new organic amendments from outside of the project area
Calculation method	Not applicable
Comments	None

Data/Parameter	$CC_{wp,oa,t}$
Data unit	t C/t organic amendment
Description	Carbon content of organic amendment (disaggregated by livestock type l for manure) applied as fertilizer on the project area in year t
Equations	(34)
Source of data	Carbon content provided by retailer of organic amendment may be used. Peer-reviewed published data may be used.
Description of measurement methods and procedures to be applied	Record of carbon content of organic amendment, where available. For manure application, data should be disaggregated for each livestock type I.
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of leakage from application of new organic amendments from outside of the project area
Calculation method	Not applicable
Comments	None

Data/Parameter	$P_{wp,p}$
Data unit	Output (e.g., kg)/ha
Description	Average productivity for product p during the project period
Equations	(35), (36)
Source of data	Farm productivity (e.g., yield) records

Description of measurement methods and procedures to be applied	Measured using locally available technologies (e.g., mobile weighing devices, commercial scales, storage volume measurements, fixed scales, weigh scale tickets)
Frequency of monitoring/recording	Each growing season
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Determination of project productivity for market leakage analysis
Calculation method	Not applicable
Comments	None

Data/Parameter	p
Data unit	Categorical variable
Description	Crop/livestock product
Equations	(35), (36)
Source of data	See Box 1
Description of measurement methods and procedures to be applied	Not applicable
Frequency of monitoring/recording	Each growing season
QA/QC procedures to be applied	See Box 1
Purpose of data	Identification of crop/livestock product for market leakage analysis
Calculation method	Not applicable
Comments	None

Data/Parameter	$RP_{wp,p}$
Data unit	Output (e.g., kg)/ha
Description	Average regional productivity for product p during the project period
Equations	(36)
Source of data	Regional productivity data from government (e.g., USDA Actual Production History data), industry, published, academic, or international organization (e.g., FAO) sources

Description of measurement methods and procedures to be applied	Not applicable
Frequency of monitoring/recording	Every 10 years
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Determination of project productivity ratio for market leakage analysis
Calculation method	Not applicable
Comments	None

Data/Parameter	$SOC_{bsl,i,t}$
Data unit	t CO_2e/ha
Description	Areal mean SOC stocks in the baseline scenario for quantification unit i in year t
Equations	(46)
Source of data	Modeled in the project area or measured in baseline control sites
Description of measurement methods and procedures to be applied	See parameter table for $f(SOC_{bsl,i,t})$ for modeled SOC stocks under Quantification Approach 1. Measured SOC under Quantification Approach 2 must be determined from samples collected from sample plots located within each baseline control site. See Section 10.2.1 for requirements for SOC content and bulk density measurements.
Frequency of monitoring/recording	Measurements must be conducted at least every five years. Modeling as means of monitoring must be conducted prior to each verification event where verification occurs more frequently than once every five years. SOC stocks in the baseline scenario for quantification unit i must be reported every five years or more frequently.
QA/QC procedures to be applied	See Section 10.2.1 and, for Quantification Approach 1, VMD0053
Purpose of data	Calculation of baseline emissions
Calculation method	Not applicable
Comments	SOC stocks at time t = 0 are calculated based on directly measured SOC content and ESM at t = 0 or (back-) modeled to t = 0 from measurements collected within ±5 years of t = 0. This initially measured SOC is the same in both the baseline and project scenarios at the outset of the project (i.e., SOCwp,i,0 = SOCbsl,i,0) in Quantification Approach 1.

Data/Parameter	$\overline{SOC_{bsl,i,t-x}}$
Data unit	t CO_2e/ha
Description	Areal mean SOC stocks in the baseline scenario for quantification unit i in year t − x
Equations	(46)
Source of data	Modeled in the project area or measured in baseline control sites
Description of measurement methods and procedures to be applied	See parameter table for $SOC_{bsl,i,t}$
Frequency of monitoring/recording	Measurements must be conducted at least every five years. Modeling as means of monitoring must be conducted prior to each verification event where verification occurs more frequently than once every five years. SOC stocks in the baseline scenario for quantification unit i must be reported every five years or more frequently.
QA/QC procedures to be applied	See Section 10.2.1 and, for Quantification Approach 1, VMD0053
Purpose of data	Calculation of baseline emissions
Calculation method	Not applicable
Comments	See parameter table for $SOC_{bsl,i,t}$ See Section 10.2.1 for requirements for SOC content and bulk density measurements

Data/Parameter	$\overline{SOC_{wp,i,t}}$
Data unit	t CO_2e/ha
Description	Areal mean SOC stocks in the project scenario for quantification unit i in year t
Equations	(47)
Source of data	Modeled or measured in the project area
Description of measurement methods and procedures to be applied	Modeled SOC stocks in the project scenario are determined following the guidance in VMD0053 and according to the following equation: $f(SOC_{wp,i,t}) = \int_{SOC}(Var\ A_{wp,i,t}, Var\ B_{wp,i,t}, \dots)$ Where: $f(SOC_{wp,i,t})$ = Modeled carbon dioxide emissions from SOC pool in the project for quantification unit i at time t (t CO2e/ha)

	$\int_{SOC}$ = Model predicting carbon dioxide emissions from the SOC pool (t CO2e/ha) Val $A_{wp,i,t}$ = Value of model input variable A in the project scenario for quantification unit i at time t (units unspecified) Val $B_{wp,i,t}$ = Value of model input variable B in the project scenario for quantification unit i at time t (units unspecified) See Box 1 for sources of data and description of measurement methods and procedures to be applied to obtain values for model input variables.
Frequency of monitoring/recording	Measurements must be conducted at least every five years. Modeling as means of monitoring must be conducted prior to each verification event where verification occurs more frequently than once every five years.
QA/QC procedures to be applied	See Section 10.2.1 and for Quantification Approach 1, VMD0053
Purpose of data	Calculation of project emissions
Calculation method	Not applicable
Comments	Initially measured SOC stocks are the same in both the baseline and project scenarios at the outset of the project (i.e., $SOC_{wp,i,0} = SOC_{bsl,i,0}$) under Quantification Approach 1. SOC stocks at time t = 0 are calculated based on directly measured SOC content and ESM at t = 0 or (back-) modeled to t = 0 from measurements collected within ±5 years of t = 0. SOC stocks in the project scenario for quantification unit i must be reported every five years or more frequently under Quantification Approaches 1 and 2.

Data/Parameter	$SOC_{wp,i,t-x}$
Data unit	t CO_2e/ha
Description	Areal mean SOC stocks in the project scenario for quantification unit i in year t − x
Equations	(47)
Source of data	Modeled or measured in the project area
Description of measurement methods and procedures to be applied	See parameter table for $SOC_{wp,i,t}$
Frequency of monitoring/recording	Measurements must be conducted at least every five years. Modeling

	as means of monitoring must be conducted prior to each verification event where verification occurs more frequently than once every five years.
QA/QC procedures to be applied	See parameter table for $SOC_{wp,i,t}$
Purpose of data	Calculation of project emissions
Calculation method	Not applicable
Comments	See parameter table for $SOC_{wp,i,t}$

Data/Parameter	$\Delta C_{TREE,bsl,i,t}$
Data unit	t CO_2e/ha
Description	Areal mean baseline carbon stock change in tree biomass for quantification unit i in year t
Equations	Section 10.2.2 and (48)
Source of data	Determined in project area
Description of measurement methods and procedures to be applied	Calculated using the CDM A/R tools Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities and Simplified baseline and monitoring methodology for small scale CDM afforestation and reforestation project activities implemented on lands other than wetlands
Frequency of monitoring/recording	Monitoring must be conducted at least every five years or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See “Description of measurement methods and procedures to be applied”
Purpose of data	Calculation of baseline emissions
Calculation method	See “Description of measurement methods and procedures to be applied”
Comments	None

Data/Parameter	$\Delta C_{SHRUB,bsl,i,t}$
Data unit	t CO_2e/ha
Description	Areal mean baseline carbon stock change in shrub biomass for quantification unit i in year t
Equations	Section 10.2.2 and (50)
Source of data	Determined in project area

Description of measurement methods and procedures to be applied	Calculated using the CDM A/R tools Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities and Simplified baseline and monitoring methodology for small scale CDM afforestation and reforestation project activities implemented on lands other than wetlands
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See "Description of measurement methods and procedures to be applied"
Purpose of data	Calculation of baseline emissions
Calculation method	See "Description of measurement methods and procedures to be applied"
Comments	None

Data/Parameter	$\overline{\Delta C_{TREE,wp,i,t}}$
Data unit	t CO_2e/ha
Description	Areal mean project scenario carbon stock change in tree biomass for quantification unit i in year t
Equations	Section 10.2.2 and (49)
Source of data	Determined in project area
Description of measurement methods and procedures to be applied	Calculated using the CDM A/R tools Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities and Simplified baseline and monitoring methodology for small scale CDM afforestation and reforestation project activities implemented on lands other than wetlands. Where woody biomass is harvested, projects must calculate the long-term average GHG benefit following guidance in the most recent versions of the VCS Methodology Requirements and VM0042.
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See "Description of measurement methods and procedures to be applied"
Purpose of data	Calculation of project emissions
Calculation method	See "Description of measurement methods and procedures to be applied"
Comments	None

Data/Parameter	$\overline{\Delta C_{SHRUB,wp,i,t}}$

Data unit	t CO_2e/ha
Description	Areal mean project scenario carbon stock change in shrub biomass for quantification unit i in year t
Equations	Section 10.2.2 and (51)
Source of data	Determined in project area
Description of measurement methods and procedures to be applied	Calculated using the CDM A/R tools Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities and Simplified baseline and monitoring methodology for small scale CDM afforestation and reforestation project activities implemented on lands other than wetlands. Where woody biomass is harvested, projects must calculate the long-term average GHG benefit following guidance in the most recent versions of the VCS Methodology Requirements and VM0042.
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See "Description of measurement methods and procedures to be applied"
Purpose of data	Calculation of project emissions
Calculation method	See "Description of measurement methods and procedures to be applied"
Comments	None

Data/Parameter	•
Data unit	Dimensionless
Description	Gas or pool
Equations	(60)–(63)
Source of data	Determined in quantification unit i
Description of measurement methods and procedures to be applied	Not applicable
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Not applicable
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$\overline{\Delta \bullet}_{\overline{h},\overline{t}}$ and $\overline{\Delta \bullet}_{\overline{t}}$
Data unit	t CO_2e/ha
Description	Areal mean emission reductions in gas or pool • (in stratum h) in year t
Equations	(62)Error! Reference source not found., (63)
Source of data	Calculated from modeled or calculated values in the project area
Description of measurement methods and procedures to be applied	Not applicable
Frequency of monitoring/recording	Calculations and recording must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Comparison of project results with values from peer-reviewed literature under similar conditions. Raw data from laboratory analysis as well as calculation spreadsheets and/or computer code used for calculations must be provided as requested by the VVB.
Purpose of data	Calculation of emission reductions
Calculation method	Estimated using unbiased statistical approaches, such as from Cochran (1977). Application of this methodology may employ quantification units of unequal sizes, which would necessitate proper weighting of samples to derive means.
Comments	None

Data/Parameter	$Bu_{ER,t}$
Data unit	t CO_2e
Description	Number of buffer credits to be deducted from reductions in year t
Equations	(75)
Source of data	The number of buffer credits to be contributed to the AFOLU pooled buffer account must be determined by applying the most recent version of the VCS AFOLU Non-Permanence Risk Tool.
Description of measurement methods and procedures to be applied	Not applicable
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	The number of buffer credits to be contributed to the AFOLU pooled buffer account must be determined by applying the most recent version of the VCS AFOLU Non-Permanence Risk Tool.

Purpose of data	Calculation of project emissions
Calculation method	The number of buffer credits to be contributed to the AFOLU pooled buffer account must be determined by applying the most recent version of the VCS AFOLU Non-Permanence Risk Tool.
Comments	None

Data/Parameter	$BuC_{R,t}$
Data unit	t CO_2e
Description	Number of buffer credits to be deducted from reductions in year t
Equations	(76)
Source of data	The number of buffer credits to be contributed to the AFOLU pooled buffer account must be determined by applying the most recent version of the VCS AFOLU Non-Permanence Risk Tool.
Description of measurement methods and procedures to be applied	Not applicable
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	The number of buffer credits to be contributed to the AFOLU pooled buffer account must be determined by applying the most recent version of the VCS AFOLU Non-Permanence Risk Tool.
Purpose of data	Calculation of project emissions
Calculation method	The number of buffer credits to be contributed to the AFOLU pooled buffer account must be determined by applying the most recent version of the VCS AFOLU Non-Permanence Risk Tool.
Comments	None

11.3 Description of the Monitoring Plan

The main objective of monitoring is to quantify stock change of SOC and emissions of CO_2, CH_4, and N_2O resulting from the project scenario during the verification period.

Project proponents must detail the procedures for collecting and reporting all data. The monitoring plan must contain at least the following information:

- Description of each monitoring task to be undertaken, and the technical requirements therein;
- Definition of the accounting boundary, spatially delineating any differences in the accounting boundaries and/or quantification approaches;
- Parameters to be measured, including any parameters required for the selected model (additional to those specified in this methodology);
- Data to be collected and data collection techniques and sample designs for directly sampled parameters;

- Baseline control site management plans, where applicable, including location, boundaries, and demonstration of similarity criteria (see Table 7, VM0042) for each baseline control site, with adequate detail to permit implementation of the annual schedule of activities for the linked quantification unit(s);
- Ten-year baseline re-evaluation plan, detailing source of regional (sub-national) agricultural production data and procedures to revise the baseline schedule of activities;
- Quality assurance and quality control (QA/QC) procedures to ensure accurate data collection; screen for, and where necessary, correct anomalous values; ensure completeness; perform independent checks on analysis results; and other safeguards as appropriate;
- Data archiving procedures, including procedures for any anticipated updates to electronic file formats. All data collected as part of monitoring, including QA/QC data, must be archived electronically and kept for at least two years after the end of the last project crediting period;
- Roles, responsibilities, and capacity of monitoring team and management; and
- Modeling plan, where Quantification Approach 1 is applied. The project modeling plan must describe the model(s) selected, describe the datasets used for model validation and calibration, including their sources, and specify the baseline schedule of ALM activities for each quantification unit (fixed ex ante).

11.4 Data, Parameters, and Description of the Monitoring Plan to Practice the Strategy and Plan of Action 2023 -2030 of the International Partnership for the Satoyama Initiative

The project proponent must establish, maintain, and apply a monitoring plan and GHG information system that includes criteria and procedures for obtaining, recording, compiling, and analyzing data, parameters, and other information that is important for quantifying and reporting GHG emissions relevant to the project and dynamic baseline scenarios.

Monitoring procedures must address the following:

1) Types of data and information to be reported
2) Units of measurement
3) Origin of the data
4) Monitoring methodologies (e.g., estimation, modeling, measurement, and calculation)
5) Type of equipment used
6) Monitoring times and frequencies
7) QA/QC procedures
8) Monitoring roles and responsibilities, including experience and training requirements
9) GHG information management systems, including the location, backup, and retention of stored data

Where measurement and monitoring equipment is used, the project proponent must ensure the equipment is calibrated according to current good practice (e.g., relevant industry standards).

Quality assurance/quality control (QA/QC) procedures must include, but are not limited to:

a) Data gathering, input, and handling measures

b) Checking input data for typical errors, including inconsistent physical units and unit conversion errors
c) Checking for typographical errors caused by data transcription from one document to another and missing data for specific time periods or physical units
d) Checking input time series data for unexpected variations (e.g., orders of magnitude) that may indicate input errors
e) Use of version control for all electronic files to ensure consistency
f) Physical protection of monitoring equipment
g) Physical protection of records of monitored data (e.g., hard copy and electronic records)
h) Checking and documenting input data units
i) Documenting all sources of data, assumptions, and emission factors.

Additional criteria and procedures for monitoring are established in respective capture, transport, and storage modules and related VCS and CDM tools.

The methodology is inherently designed to align with the principles of the International Partnership for the Satoyama Initiative Plan of Action 2023 – 2030. By monitoring land health, productivity, and carbon balance, the methodology helps assess and ensure resource use remains within ecological limits. Project proponents support practices like organic matter recycling, which enhances carbon sequestration, and monitors the impact of such cycles. The methodology emphasizes on the integration of local traditional knowledge and socio-cultural data in the assessment of SEPLS, and requires collaboration among researchers, farmers, and local communities for data collection, validation, and decision-making. The continuous monitoring framework allows for iterative adjustments to land management strategies based on observed outcomes and changing conditions. By considering economic parameters and livelihood resilience, the methodology ensures that sustainable practices are also economically beneficial for local communities.

11.5 Data, Parameters, and Description of the Monitoring Plan to Practice the Kunming-Montreal Global Biodiversity Framework

The methodology also considers the guidelines of the Kunming-Montreal Global Biodiversity Framework. Project proponents must ensure that all areas are under participatory planning, which this methodology supports by providing data for informed land use planning and stakeholder engagement. Restoring degraded ecosystems, where remote sensing helps identify degraded areas and monitor restoration progress, and sustainable management of biodiversity in agricultural areas, directly supported by monitoring agrobiodiversity and promoting practices that enhance ecosystem functionality are core principles of the methodology. Additionally, minimizing the impact of climate change on biodiversity, addressed by promoting carbon sequestration and GHG capture, sustainable management of wild species, supported by monitoring habitat connectivity and biodiversity within SEPLS, sustainable management of agriculture, aquaculture, and forestry, directly addressed by providing data for optimizing agricultural practices, restoring, maintaining, and enhancing nature's contributions to people, and increasing the use of biodiversity-inclusive spatial planning, where remote sensing provides the spatial data needed for such planning must be considered.

The Kunming-Montreal Global Biodiversity Framework has 23 action-oriented global targets for urgent action over the decade to 2030. The actions set out in each target need to be initiated

immediately and completed by 2030. Together, the results will enable the achievement of the outcome-oriented goals for 2050. Actions to reach these targets should be implemented consistently and in harmony with the Convention on Biological Diversity and its Protocols and other relevant international obligations, considering national circumstances, priorities, and socioeconomic conditions.

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APPENDIX 1

Guidance On Potential Emerging Technologies To Measure SOC Content

Project proponents may use emerging technologies to determine SOC content where sufficient scientific progress has been achieved in calibrating and validating measurements, and uncertainty is well described. This appendix provides guidance on requirements for using such emerging technologies and a non-exhaustive list of potential technologies (with a focus on proximal sensing) to determine SOC content and criteria to ensure their robustness and reliability.

The applicability of a selected technology to measure SOC in a project must be demonstrated in at least three peer-reviewed scientific articles. Project proponents must provide evidence of the ability of an emerging technology to predict SOC content with sufficient accuracy through the development and application of adequate calibration with data obtained from classical laboratory methods, such as dry combustion. The site characteristics for the underlying calibration must match the project site conditions, including range of SOC stocks, soil types, and land use. While project proponents may use the services of companies measuring SOC, the specificities of the applied measurement technology, including calibration methods, must be made available for review by the validation/verification bodies (VVB). Access must not be restricted through intellectual property rights.

Although proximal sensing techniques may not be as precise per individual measurement compared to conventional analytical laboratory methods (e.g., dry combustion), proximal sensing may be more cost-efficient and provide a better balance between accuracy and cost. Although each individual measurement may be less accurate, many more measurements can be made across time and space than would be feasible with conventional methods, enabling an overall estimate of SOC stock that is of similar or better accuracy than lower density sampling measured with conventional analytical laboratory methods. Since many more proximal devices may be used in a project than would be used were all samples sent to a single laboratory, care must be taken to demonstrate device-to-device calibration and precision. Project proponents must provide details to the VVB on the criteria and considerations of the emerging SOC measurement technology

Projects must maintain adherence to these criteria over time to ensure that measurement and remeasurement are conducted under the same conditions and are thus comparable.

The following information must be included in the monitoring plan and reports on where emerging technologies are applied:

1) Standard Operating Procedures for sample processing (including drying, sieving, rock and root removal, grinding) and analysis adapted to the proximal sensing technique to be applied
2) For in-field or laboratory measurements without sample processing, a detailed explanation of strategies to overcome potential measurement obstacles due to signal interference related to differences in soil moisture, soil aggregates, sunlight, shadow, coarse fragments, and other factors
3) Description of the technology and specific equipment and instruments to be applied, including spectral range covered by the instrument applied and the actual resolution of the measurements
4) Description of pretreatment or preprocessing methods to analyze raw spectral data
5) Description of the modeling approach applied for estimating SOC content based on proximal sensing data, including model type (e.g., partial least squares regression) and model features/parameters
6) Description of randomized data-splitting for model calibration/training and validation/testing. Commonly, 70% of the sample data is used for calibration/training and 30% for validation/testing. Other methods for data-splitting include k-fold cross-validation and bootstrapping.
7) Demonstration that calibration and statistical validation data are representative of the actual project area in terms of SOC content, clay type, clay content, Munsell soil color, and application of organic amendments, where relevant. For field-moist measurements, extensive verification of predictive performance across a wide range of moisture contents is required.
8) Goodness-of-fit metrics and descriptive statistics from the dataset, such as root mean square error (RMSE), R^2, ratio of performance to interquartile range (RPIQ), bias, and Lin's concordance correlation coefficient (CCC), or other suitable parameters
9) Description of the approach used to generate posterior predictive distributions (PPDs) or intervals used to propagate error from the spectroscopy model to calculations of the uncertainty deduction. PPDs may be based on Bayesian modeling methods that incorporate parameter uncertainty in the calibration/validation phase. Alternatively, PPDs may be based on estimates of model uncertainty derived by comparing results of dry combustion analysis for 10–15% of the samples from the project area to estimate SOC via spectroscopy at every verification event
10) Demonstration that samples must be chosen in an unbiased manner such that they are representative of the project conditions and sampling design. For example, where a stratified random sampling approach is employed, selection of points should be area-weighted based on the area of each stratum relative to the total project area

Satellite imagery is a potentially emerging proximal sensing technology which hold promises for streamlining SOC measurements. Specific methods to evaluate and measure SOC content can be selected based on VM0042 v2.1 or other specific methodologies.

Method	Criteria and Considerations to Ensure Robustness and Reliability
Satellite Imagery	Data acquisition and pre-processing Standards • Sensor Selection: The choice of satellite sensors is paramount, favoring those with appropriate spectral resolution (e.g., multispectral sensors like FORMOSAT-5, and ONGLAISAT (2-10 m spatial resolution). The availability of the visible and NIR spectrum bands can monitor vegetation health and land cover classification in urban areas. FORMOSAT-8 (1 m spatial resolution) is useful for revisiting the area and collecting images. • Cloud and Shadow Masking: Comprehensive masking of clouds and cloud shadows is vital, as these obscurities completely block or alter the spectral signal, leading to erroneous SOC estimations. • Topographic Correction: For undulating terrains, topographic correction is necessary to normalize reflectance variations caused by varying illumination angles due to relief.

APPENDIX 2

Stakeholders Consultation and Feedback

Project proponents shall employ multiple, accessible consultation and feedback methods to ensure participation of all relevant stakeholders, including farmers, landholders, community representatives, local authorities, women's groups, indigenous peoples, and environmental organizations. Consultation shall occur at project inception and continue at regular intervals during monitoring periods throughout the project lifecycle.

1. Public meetings, workshops, and community gatherings shall be held at accessible locations and times compatible with agricultural schedules and cultural observances. Separate focus group discussions shall be conducted for specific stakeholder groups (women, youth, smallholders, landless laborers, ethnic minorities) to ensure inclusive participation. One-on-one interviews with key stakeholders shall document individual perspectives and concerns. All physical consultations should use simplified, non-technical language with visual aids (maps, diagrams, photographs) and

employ translators where multiple languages are spoken.

2. Online platforms, email surveys, and digital questionnaires shall be made available for stakeholders unable to attend physical meetings. All remote feedback shall be formally recorded and documented.
3. Public notices announcing project plans, meetings, and feedback opportunities shall be posted on community notice boards at schools and public places. Written notices must be provided in local language and read aloud in public settings to ensure accessibility for illiterate populations.

All stakeholders shall have transparent opportunities to submit feedback or questions throughout the project lifetime. Feedback channels shall include:

(i) Input and Grievance Expression Book maintained at accessible community locations (municipality offices, cooperative centers, schools)
(ii) Designated email and contact points clearly advertised for ease of access
(iii) Feedback forms distributed at public consultations
(iv) Feedback and suggestions must be made publicly available for transparency

A formal two-round stakeholder consultation process shall be conducted. Round 1 comprises physical meetings during which project design, expected impacts, and monitoring procedures are presented, and initial feedback is collected and documented. Round 2 is a minimum 60-day Stakeholder Feedback Period during which project proponents shall publish a Comment-Response Table—detailing each substantive stakeholder comment received, the action taken, and rationale if no change was made—alongside revised project documentation in physical and digital formats accessible to all stakeholders.

All grievances shall be formally logged, acknowledged in writing, investigated transparently, and addressed with a proposed resolution. Outcomes of all grievance resolutions shall be documented and included in annual monitoring reports for auditor review.

Capacity building and Training

1. Periodic sstructured training programs should equip stakeholders and participants with practical knowledge and skills in: (i) reduced tillage, cover cropping, crop rotation, agroforestry, composting, nutrient management; (ii) soil carbon measurement, sampling procedures, and use of carbon capture assessment tools; (iii) record-keeping, documentation, and monitoring verification procedures. Training shall be conducted in local languages, adapted to participant literacy levels, scheduled at times compatible with agricultural work.
2. On-farm demonstration showcasing improved practices shall be established in each project boundary, allowing farmers and locals to observe and learn practical benefits before participation

commitment. Community-based field schools and farmer cooperatives shall be formed to facilitate knowledge sharing and collective participation in project benefits and decision-making.

3. Government officials, validators, and project implementers shall receive specialized training on carbon certification requirements, additionality assessment, baseline determination, MRV procedures ensuring institutional readiness and credibility in supporting project implementation and monitoring.

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SATOYAMA INITIATIVE

Methodology

Me0005

Methodology for Wetland and Seagrass Restoration

Version 1.0
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Version 1.0 of this methodology was developed by Ph.D. Ya-Hui Chang (National Cheng Kung University)., Assoc. Prof. Shu-Mei Wang (National Taiwan University).

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1 Source

This project methodology for tidal wetland and seagrass restoration is designed to be compatible with the Verra/VCS AFOLU Standard Framework.

The methodology leverages specific tools and procedures from both the Clean Development Mechanism (CDM) and the Verified Carbon Standard (VCS) to ensure robustness, transparency, and market alignment:

VCS Tools and Modules Utilized:

(1) VCS Module VMD0019, "Methodology for Predicting Future Conditions": Applied to forecast future GHG emissions and to integrate the dynamic impacts of climate variables, particularly sea level rise, on the baseline scenario.
(2) VCS Module VDM0052, "Demonstration of Additionality of Tidal Wetland Restoration and Conservation Project Activities": Used to demonstrate the project's additionality by meeting regulatory surplus and assessing low activity penetration.
(3) VCS AFOLU Non-Permanence Risk Tool: Utilized to assess the future impacts of erosion and submergence caused by sea level rise on the project’s carbon stocks, thereby determining the required contribution to the AFOLU pooled buffer account.

CDM Tools and Procedures Cited:

(1) CDM Tool AR-Tool02: Comprehensive tool for identifying baseline scenarios and demonstrating the additionality of A/R CDM project activities.
(2) CDM Tool AR-Tool05: Estimation of greenhouse gas emissions related to fossil fuel combustion in A/R CDM project activities.
(3) CDM Tool AR-Tool14: Calculating changes in carbon stocks of trees and shrubs.
(4) CDM Tool AR-Tool05: Estimating CO2 emissions from fossil fuel combustion.

2 Summary Description of the Methodology

This project's activities aims to quantify the greenhouse gas (GHG) emission reduction and removal benefits achieved through the restoration of tidal wetlands and seagrass meadows. This methodology seeks to realize a vision of harmonious coexistence between people and nature, aligning with relevant targets of the Kunming-Montreal Global Biodiversity Framework (GBF).

This methodology achieves GHG emission reductions and removals primarily through four mechanisms: increased biomass, increased autochthonous soil organic carbon, reduced methane (CH4) and/or nitrous oxide (N2O) emissions, and reduced carbon dioxide (CO2) emissions due to avoided soil carbon loss.

The determination of the baseline scenario must utilize the latest version of the CDM tool AR-Tool02, "Combined tool to identify the baseline scenario and demonstrate additionality for A/R CDM project activities." The estimation of GHG emissions in the baseline scenario is attributed to biomass carbon pools, soil processes, or a combination of both. Additionally, emissions from fossil fuel use are quantified if relevant. Before predicting the project implementation in year 0 of the baseline scenario, an annual enabling schedule will be developed by reviewing historical data for at least the preceding 3 years. When forecasting future GHG emissions, carbon stock losses may occur due to land submergence caused by sea-level rise, including above-ground biomass carbon loss to the atmosphere, and soil carbon stocks potentially remaining intact or being eroded and carried out of the project area. Therefore, the latest version of the VCS module VMD0019, "Methodology for Predicting Future Conditions," must be applied.

To enhance data accuracy, consistency, and timeliness, a system to system integration approach shall be adopted across all relevant data sources. This includes automated data exchange between remote sensing platforms, ecological monitoring systems, climate databases, and project-level carbon accounting tools. Such integration enables real-time updates of biomass and soil carbon metrics, facilitates seamless incorporation of sea-level rise projections, and ensures that fossil fuel usage data from infrastructure systems is consistently captured. The system to system architecture also supports transparent data flow for verification and reporting purposes, reducing manual errors and improving governance.

The methodology achieves a dynamic baseline through periodic reassessments of the baseline scenario and the utilization of the VMD0019 module. However, the baseline is not static; it adjusts over time based on new information and environmental changes. Consequently, the baseline scenario must be reassessed every 10 years to ensure it reflects actual changes in land use, infrastructure, vegetation succession, and climate variable trends.

3 Relation to Strategy and Plan of Action 2023 -2030 of the International Partnership for the Satoyama Initiative

This methodology is related to the five goals of the " International Partnership for the Satoyama Initiative (IPSI) Strategy and Action Plan 2023-2030" in the following ways:

(1) Knowledge Co-Production, Management, and Uptake

Quantitative tools are used to collect specific data on tidal wetland and seagrass restoration projects, such as carbon sequestration amounts and environmental changes. These data contribute to the expansion of ecological system restoration and climate benefit knowledge systems while promoting synergies between modern science and traditional knowledge systems.

(2) Institutional Frameworks and Capacity Development

Standardized methodologies can serve as trusted and adoptable tools integrated into national and international climate and biodiversity policies, like carbon markets (e.g., VCS mechanism), helping establish policy incentives supporting wetland restoration and enhancing the abilities of relevant sectors and project implementers in eco-restoration and carbon accounting, thereby strengthening related institutional frameworks.

(3) Area-Based Conservation Measures

Ecosystem restoration activities can enhance the ecological integrity and connectivity of coastal ecosystems. Successful restoration projects can expand the effective area of healthy ecosystems, contributing to landscape and seascape conservation targets. Additionally, this methodology takes into account the impact of sea level rise on the geographic boundaries of project sites, which is a critical regional conservation consideration for dynamic coastal environments.

(4) Ecosystem Restoration

By quantifying the greenhouse gas emissions reductions and removals achieved through restoration activities, direct support can be provided for IPSI's ecosystem recovery goals. This provides a powerful and verifiable framework for measuring and validating the climate impacts of these restoration works.

(5) Sustainable Value Chain Development

The creation of new "verified carbon units (VCUs)" value mechanisms incentivizes more investment in restoration, allowing businesses or organizations to purchase carbon credits to offset their carbon footprints. This not only helps meet climate goals but also integrates sustainable development strategies, indirectly promoting funds flowing toward nature-friendly sustainable practices and economic activities.

In summary, the methodology is related to IPSI's objectives in multiple ways. This demonstrates that applying scientific methods to actual ecological restoration produces concrete results and positively influences relevant knowledge accumulation and policy making.

4 Relation to Kunming-Montreal Global Biodiversity Framework (GBF)

The vision of the Kunming-Montreal Global Biodiversity Framework is a world of living in harmony with nature where "by 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people."

4.1 Description

The Kunming-Montreal Global Biodiversity Framework sets forth 23 action-oriented global targets for urgent action by 2030. The specified actions for each target must be initiated immediately and completed no later than 2030, facilitating progress towards the outcome-focused goals for 2050. These actions should be consistently implemented in harmony with the Convention on Biological Diversity and its Protocols, along with other international commitments, taking into account national circumstances, priorities, and socioeconomic conditions.

4.2 Basic Information

Table 1 Basic Information

Rationale
The strategic mission of the International Partnership for the Satoyama Initiative (IPSI) is to promote the sustainable management and revitalization of Socio-ecological Production Landscapes and Seascapes (SEPLS), valuing the knowledge of Indigenous Peoples and local communities. Through international collaboration, IPSI aims to enhance SEPLS' contributions to global goals such as biodiversity conservation, climate change response, disaster risk reduction, and sustainable development, including, but not limited to, the 2030 Agenda for Sustainable Development, the Kunming-Montreal Global Biodiversity Framework, and the United Nations Decade on Ecosystem Restoration, while highlighting their multiple benefits for both the environment and human well-being.
Objectives
The Kunming-Montreal Global Biodiversity Framework has four long-term goals for 2050 related to the 2050 Vision for biodiversity. Protect and Restore Prosper with Nature Share Benefits Fairly Invest and Collaborate
Activities and/or practices employed
Collect and share SEPLS knowledge, support case studies, integrate science and traditional knowledge, promote collaborative research, conduct outreach, synthesize IPSI case studies, and explore biocultural diversity to enhance benefits to nature and people.
Monitoring methodology

To evaluate implementation effectiveness, an adaptive and multi-stakeholder monitoring approach will be established to continuously track progress in achieving strategic objectives and priority actions, as well as to assess overall policy impact. Progress will be publicly disclosed through annual activity reports and program implementation reports, providing partners and sponsors with detailed yearly summaries. These reports will include updates on partnerships, major events, collaborative initiatives, knowledge outputs, and Steering Committee decisions, ensuring alignment of annual achievement indicators in the results framework with the principles of SEPLS (Socio-Ecological Production Landscapes and Seascapes) and the Satoyama Initiative. This will guide the organization in achieving key performance milestones and fostering globally significant impacts.

Additionally, a final implementation report (covering 2023–2030) will comprehensively assess contributions to the Kunming-Montreal Global Biodiversity Framework (GBF), the Sustainable Development Goals (SDGs), and other relevant initiatives. It will include a survey of IPSI member contributions, a synthesis of lessons learned, and provide a foundation for the next phase of the IPSI Strategy and Plan of Action.

4.3 Landscape & Seascape Approaches

To ensure the clear and verifiable relationship between the activities of methodological work and the goals of the Kunming-Montreal Global Biodiversity Framework (KMGBF), this section has been streamlined to only include targets that have a direct or specific relation to tidal wetland and seagrass restoration activities. This methodology, which quantifies the greenhouse gas (GHG) emission reduction and removal benefits achieved through restoration, supports the GBF through four key implementation pillars:

1. Ecological Restoration: Directly quantifying GHG emission reductions and removals achieved through restoration activities (KMGBF Target 2).
2. Climate Resilience: Requiring the explicit integration of sea level rise projections and the assessment of associated carbon stock loss risks using the VCS AFOLU Non-Permanence Risk Tool (KMGBF Target 8).
3. Spatial Planning: Mandating precise delineation and stratification of geographic boundaries, which supports biodiversity-inclusive spatial planning (KMGBF Target 1).
4. Governance Ability: Serving as a standardized, adoptable tool integrated into national policies to strengthen institutional frameworks and capacity development (KMGBF Targets 19, 20).

For each retained target, clear reasons will be provided regarding how this carbon reduction methodology supports its achievement through these essential pillars and the broader landscape approach.

The following is a list of indicators related to the way landscape and sea view are managed, emphasizing their linkages with methodology for ecological restoration, climate resilience, spatial planning, and governance ability in KMGBF 23: These indicators focus on how to integrate and manage the aforementioned elements to achieve sustainable development and improve people's quality of life. By monitoring these critical fields, measures can be taken to ensure that developmental activities do not harm the environment while still benefiting local communities. This approach helps realize a balanced and inclusive growth model that meets the needs of both present and future generations, aligning with the vision of harmonious coexistence between people and nature.

Table 2 Specifically, biochar contributes to the following targets

1. Reducing threats to biodiversity
TARGET 1: Plan and Manage all Areas To Reduce Biodiversity Loss
Possible landscape & seascape -related indicators
Number of local authorities applying landscape approaches in a country Percentage of land and seas covered by biodiversity-inclusive spatial plans Progress towards sustainable water management Number of integrated landscape initiatives Availability of geospatial mapping tools to support decision-making and landscape planning
TARGET 2: Restore 30% of all Degraded Ecosystems

Possible landscape & seascape -related indicators
Percentage of land and seas covered by biodiversity-inclusive spatial plans Progress towards sustainable water management Number of integrated landscape initiatives Area of landscapes with continuous vegetative cover
TARGET 3: Conserve 30% of Land, Waters and Seas
Possible landscape & seascape -related indicators
Number of local authorities applying landscape approaches in a country Progress towards sustainable water management Number of integrated landscape initiatives Area covered by OECMs and mixed-us protected areas
TARGET 4: Halt Species Extinction, Protect Genetic Diversity, and Manage Human-Wildlife Conflicts
Possible landscape & seascape -related indicators
Percentage of land and seas covered by biodiversity-inclusive spatial plans Progress towards sustainable water management Percentage improvement in the multiple dimensions of human well-being of households within a landscape
TARGET 8: Minimize the Impacts of Climate Change on Biodiversity and Build Resilience
Possible landscape & seascape -related indicators
Level of cross-sector involvement in compiling an SEPLS carbon credit programs including National Biodiversity Strategy and Action Plans (NBSAPs). Number of local authorities applying landscape approaches in a country Percentage of land and seas covered by biodiversity-inclusive spatial plans Number of integrated landscape initiatives
2. Meeting people's needs through sustainable use and benefit-sharing
TARGET 9: Manage Wild Species Sustainably To Benefit People
Possible landscape & seascape -related indicators
Level of cross-sector involvement in compiling an SEPLS carbon credit programs including NBSAPs Percentage of land and seas covered by biodiversity-inclusive spatial plans Percentage of the population in traditional occupations Progress towards sustainable water management Number of integrated landscape initiatives National policy support for integrated landscape management National policy support for integrated basin management
TARGET 10: Enhance Biodiversity and Sustainability in Agriculture, Aquaculture, Fisheries, and Forestry
Possible landscape & seascape -related indicators

Level of cross-sector involvement in compiling an SEPLS carbon credit programs including NBSAPs Percentage of land and seas covered by biodiversity-inclusive spatial plans Progress towards sustainable water management Number of integrated landscape initiatives National policy support for integrated landscape management National policy support for integrated basin management Degree of application of a legal/regulatory/policy/institutional framework which recognizes and protects access rights for small-scale fisheries
TARGET 11: Restore, Maintain and Enhance Nature's Contributions to People
Possible landscape & seascape -related indicators
Percentage of land and seas covered by biodiversity-inclusive spatial plans Proportion of agricultural area under productive and sustainable agriculture Progress towards sustainable forest management Progress towards sustainable water management Proportion of agricultural area managed with climate-, water- and biodiversity-friendly practices Area of landscapes with continuous vegetative cover Percentage improvement in the multiple dimensions of human well-being of households within a landscape
TARGET 12: Enhance Green Spaces and Urban Planning for Human Well-Being and Biodiversity
Possible landscape & seascape -related indicators
Number of local authorities applying landscape approaches in a country Percentage of land and seas covered by biodiversity-inclusive spatial plans Area of landscapes with continuous vegetative cover National policy support for integrated landscape management National policy support for integrated basin management Percentage improvement in the multiple dimensions of human well-being of households within a landscape
3. Tools and solutions for implementation and mainstreaming
TARGET 19: Mobilize $200 Billion per Year for Biodiversity From all Sources, Including $30 Billion Through International Finance
Possible landscape & seascape -related indicators
Level of cross-sector involvement in compiling an SEPLS carbon credit programs including NBSAPs Number of companies reporting on disclosures of risks, dependencies and impacts biodiversity Number of integrated landscape initiatives National policy support for integrated landscape management National policy support for integrated basin management
TARGET 20: Strengthen Capacity-Building, Technology Transfer, and Scientific and Technical Cooperation for Biodiversity

Possible landscape & seascape -related indicators
Level of cross-sector involvement in compiling an SEPLS carbon credit programs including NBSAPs Percentage of the population in traditional occupations Number of companies reporting on disclosures of risks, dependencies and impacts biodiversity National policy support for integrated landscape management National policy support for integrated basin management Percentage improvement in the multiple dimensions of human well-being of households within a landscape
TARGET 21: Ensure That Knowledge Is Available and Accessible To Guide Biodiversity Action
Possible landscape & seascape -related indicators
Number of local authorities applying SEPLS carbon credit regional revitalization approaches in a country Percentage of land and seas covered by biodiversity-inclusive spatial plans Percentage of the population in traditional occupations National policy support for integrated landscape management National policy support for integrated basin management Percentage improvement in the multiple dimensions of human well-being of households within a landscape
TARGET 22: Ensure Participation in Decision-Making and Access to Justice and Information Related to Biodiversity for all
Possible landscape & seascape -related indicators
Number of local authorities applying SEPLS carbon credit regional revitalization approaches in a country Percentage of land and seas covered by biodiversity-inclusive spatial plans Percentage of the population in traditional occupations National policy support for integrated landscape management National policy support for integrated basin management Percentage improvement in the multiple dimensions of human well-being of households within a landscape Proportion of IPLC groups involved in landscape and seascape planning Proportion of the adult population with secure tenure rights to land, across genders

5 DEFINITIONS

Additionality

The demonstration that the proposed green hydrogen project would not occur in the absence of carbon finance, typically due to economic, regulatory, or technological barriers.

Leakage

GHG emissions that occur outside the project boundary as a result of project activities. In this methodology, leakage is generally negligible.

Autochthonous Soil Organic Carbon

Soil organic carbon originating or forming in the project area (e.g., from vegetation)

Carbon Preservation Depositional Environment (CPDE)

Type of sub-aquatic sediment deposition environment that impacts the amount of deposited organic carbon that is preserved. Carbon preservation is affected by mineral grain size, sediment accumulation and burial rates, O2 availability in the overlying water column and sediment hydraulic conductivity.

Degraded wetland

A wetland which has been altered by human or natural impact through the impairment of physical, chemical and/or biological properties, and in which the alteration has resulted in a reduction of the diversity of wetland-associated species, soil carbon or the complexity of other ecosystem functions which previously existed in the wetland.

Deltaic Fluidized Mud

A Carbon Preservation Depositional Environment (CPDE) type. This subaquatic depositional environment is characterized by sediment accumulation rates generally greater than 0.4 g sediment per cm2 per year in deltaic settings, consisting primarily of fluidized (unconsolidated) fine-grain materials. Surface sediments may be re-suspended by waves and tides, but deposited organic matter will be buried. Examples of these can be found in the Amazon and Mississippi deltas.

Extreme Accumulation Rate

A Carbon Preservation Depositional Environment (CPDE) type. This subaquatic depositional environment is characterized by accumulation rates generally greater than 1 g sediment per cm2 per year resulting in rapid and long-term burial of deposited sediments. Examples of these systems can be found in the Ganges-Brahmaputra and Rhone River deltas.

Impounded Water

A pool of water formed by a dam or pit

Marsh

A subset of wetlands characterized by emergent soft-stemmed vegetation adapted to saturated soil conditions1

Mudflat

A subset of tidal wetlands consisting of soft substrate not supporting emergent vegetation

Normal marine

A Carbon Preservation Depositional Environment (CPDE) type. This is a depositional

environment that does not meet the definition of the other four defined conditions (i.e., deltaic fluidized mu Normal marine environments typically have low sedimentation rates and high O2 availability inoverlying sediments.

Open Water

An area in which water levels do not fall to an elevation that exposes the underlying substrate

Organic Soil

Soil with a surface layer of material that has a sufficient depth and percentage of organic carbon to meet thresholds set by the IPCC (Wetlands supplement) for organic soil. Where used in this methodology, the term peat is used to refer to organic soil.

Oxygen (O2) Depletion Zone

A Carbon Preservation Depositional Environment (CPDE) type. This is a depositional

environment with low O2 levels in water overlying sediments due to restricted hydrologic circulation or impaired water quality that leads to hypoxic or anaerobic conditions (including euxinic and semi-euxinic).

Salinity Average

The average water salinity value of a wetland ecosystem used to represent variation in salinity during periods of peak CH4 emissions (e.g., during the growing season in temperate ecosystems)

Salinity Low Point

The minimum water salinity value of a wetland ecosystem used to represent variation in salinity during periods of peak CH4 emissions (e.g., during the growing season in temperate ecosystems)

Seagrass Meadow

An accumulation of seagrass plants over a mappable area2

Small Mountainous River

A Carbon Preservation Depositional Environment (CPDE) type. This is a depositional environment from which the sediment is supplied from small mountainous rivers, most commonly found in tectonically active margins and small steep gradients. Sediment accumulation rates are generally greater than 0.27 g sediment per cm2 per year. Examples of these systems can be found in the rivers flowing from the island of Taiwan and the Eel River of California.

Tidal Wetland

A subset of wetlands under the influence of the wetting and drying cycles of the tides (e.g.,marshes, seagrass meadows, tidal forested wetlands, and mangroves). Sub-tidal seagrassd, extreme accumulation rate, oxygen depletion zone, or small mountainous river). meadows are not subject to drying cycles but are still included in this definition.

Tidal Wetland Restoration

Re-establishing or improving the hydrology, salinity, water quality, sediment supply and/or vegetation in degraded or converted tidal wetlands. For the purpose of this methodology, this definition also includes activities that create wetland ecological conditions on uplands under the influence of sea level rise or activities that convert one wetland type to another or activities that convert open water to wetland.

Water Table Depth

Depth of sub-soil or above-soil surface of water, relative to the soil surface

6 APPLICABILITY CONDITIONS

This methodology applies to tidal wetland restoration project activities (tidal wetland restorationas defined in Section 3 above) under the following applicability conditions:

(1) Project activities which restore tidal wetlands (including seagrass meadows, per this methodology's definition of tidal wetland) are eligible.

(2) Project activities may include any of the following, or combinations of the following:

(a) Creating, restoring and/or managing hydrological conditions (e.g., removing tidal barriers, improving hydrological connectivity, restoring tidal flow to wetlands or lowering water levels on impounded wetlands)

(b) Altering sediment supply (e.g., beneficial use of dredge material or diverting river sediments to sediment-starved areas)

(c) Changing salinity characteristics (e.g., restoring tidal flow to tidally restricted areas)

(d) Improving water quality (e.g., reducing nutrient loads leading to improved water clarity to expand seagrass meadows, recovering tidal and other hydrologic flushing and exchange, or reducing nutrient residence time)

(e) (Re-)introducing native plant communities (e.g., reseeding or replanting)

(f) Improving management practice(s) (e.g., removing invasive species, reduced grazing)

(3) Prior to the project start date, the project area:

(a) Is free of any land use that could be displaced outside the project area, as demonstrated by at least one of the following, where relevant:

(i) The project area has been abandoned for two or more years prior to the project start date; or

(ii) Use of the project area for commercial purposes (i.e., trade) is not profitable as a result of salinity intrusion, market forces or other factors. In addition, timber harvesting in the baseline scenario within the project area does not occur; or

(iii) Degradation of additional wetlands for new agricultural sites within the country will not occur or is prohibited by enforced law.

OR

(b) Is under a land use that could be displaced outside the project area), although in such case baseline emissions from this land use must not be accounted for, and where

degradation of additional wetlands for new agricultural/aquacultural sites within the country will not occur or is prohibited by enforced law.

OR

(c) Is under a land use that will continue at a similar level of service or production during the project crediting period (e.g., reed or hay harvesting, collection of fuelwood, subsistence harvesting).

The project proponent must demonstrate (a), (b) or (c) above based on verifiable information such as laws and bylaws, management plans, annual reports, annual accounts, market studies, government studies or land use planning reports and documents.

(4) Live tree vegetation may be present in the project area and may be subject to carbon stock changes (e.g., due to harvesting) in both the baseline and project scenarios.

(5) The prescribed burning of herbaceous and shrub aboveground biomass (cover burns) as a project activity may occur.

(6) Where the project proponent intends to claim emission reductions from reduced frequency of peat fires, project activities must include a combination of rewetting and fire management.

(7) Where the project proponent intends to claim emission reductions from reduced frequency of peat fires, it must be demonstrated that a threat of frequent on-site fires exists, and the overwhelming cause of ignition of the organic soil is anthropogenic (e.g., drainage of the peat, arson).

(8) In strata with organic soil, afforestation, reforestation, and revegetation (ARR) activities must be combined with rewetting.

This methodology is not applicable under the following conditions:

(1) Project activities qualify as IFM or REDD.

(2) Baseline activities include commercial forestry.

(3) Project activities lower the water table, unless the project converts open water to tidal wetlands, or improves the hydrological connection to impounded waters.

(4) Hydrological connectivity of the project area with adjacent areas leads to a significant increase in GHG emissions outside the project area.

(5) Project activities include the burning of organic soil.

(6) Nitrogen fertilizer(s), such as chemical fertilizer or manure, are applied in the project area during the project crediting period.

7 PROJECT BOUNDARY

Project Boundary clearly defines the spatial and temporal scope of project activities, as well as the carbon pools and greenhouse gas (GHG) sources to be included or excluded within those boundaries.

7.1 Temporal Boundaries

7.1.1 Activity-shifting leakage and market leakage

Drained peat is subject to oxidation and subsidence and areas with peat at $t = 0$ may lose all peat before the end of the crediting period. The time at which all peat has disappeared, or at which the peat depth reaches a level where no further oxidation or other losses occur (e.g., at the average water table depth), is referred to as the PDT. Projects that do not quantify reductions of baseline emissions (i.e., those which limit their accounting to GHG removals in biomass and/or soil) need not estimate PDT.

PDT ($t_{PDT\text{-}BSL,i}$) for a stratum in the baseline scenario limits the period during which the project is eligible to claim soil emission reductions from rewetting, and is estimated at the project start date for each stratum i as:

$$t_{PDT\text{-}BSL,i} = Depth_{peat,i,t0} \,/\, Rate_{peatloss\text{-}BSL,I} \qquad (1)$$

Where:

$t_{PDT\text{-}BSL,I}$	= PDT in the baseline scenario in stratum i (in years elapsed since the project start date); yr
$Depth_{peat,i,t0}$	= Average organic soil depth above the drainage limit in stratum i at the project start date; m
$Rate_{peatloss\text{-}BSL,I}$	= Rate of organic soil loss due to subsidence and fire in the baseline scenario in stratum i; a conservative (high) value must be applied that remains constant over the time from $t = 0$ to PDT; m yr^{-1}.
I	= 1, 2, 3 …*MBSL* strata in the baseline scenario

7.1.2 Soil Organic Carbon Depletion Time (SDT)

SDT is the time at which soil organic carbon is depleted. Its purpose is to limit the period during which the project is eligible to claim emission reductions from restoration. This time point is estimated at the project start date for each stratum. Projects that do not quantify reductions of baseline emissions (i.e., those which limit their accounting to GHG removals in biomass and/or soil) need not estimate SDT.

SDT ($t_{SDT\text{-}BSL,i}$) for a stratum in the baseline scenario limits the period during which the project is eligible to claim emission reductions from restoration, and is estimated at the project start date for each stratum i as follows:

For strata with eroded soils:

$$t_{SDT\text{-}BSL,i} = 5 \text{ years}$$

For strata with soils exposed to an aerobic environment through excavation or drainage, use the following equation.

$$t_{SDT\text{-}BSL,i} = C_{BSL,i,t0} / Rate_{Closs\text{-}BSL,i} \quad (2)$$

Where:

$t_{SDT\text{-}BSL,i}$	= SDT in the baseline scenario in stratum i (in years elapsed since the project start date); yr
$C_{BSL,i,t0}$	= Average organic carbon stock in the baseline scenario in mineral soil in stratum i at the project start date; t C ha^{-1} (see Equation 10)
$Rate_{Closs\text{-}BSL,I}$	= Rate of soil organic carbon loss due to oxidation in the baseline scenario in stratum i; a conservative (high) value must be applied that remains constant over the time from t = 0 to SDT; t C ha^{-1} yr^{-1}.
I	= 1, 2, 3 … M_{BSL} strata in the baseline scenario

7.2 Geographic Boundaries

The definition of the Geographic Boundary is crucial for quantifying and verifying project greenhouse gas benefits, with its core lying in ensuring the accuracy, traceability, and completeness of the project scope. At the initiation of the project activities, the project proponent must precisely delineate and provide accurate geographical coordinates, including subtidal seagrass areas, and associated maps, utilizing official documentation such as remote sensing data, public maps, and land tenure records. If the project encompasses multiple independent land areas, each must be assigned a unique geographical identifier, and further detailed information including its name, digital map, total area, and specifics of land tenure and use rights must be provided.

7.2.1 Activity-shifting leakage and market leakage

The project proposer must delineate the geographical boundaries of the project area at the commencement of the project operation. The project proposer should present the latitude and longitude coordinates for the lands (including subtidal seagrass beds, if applicable) within the project area to accurately define the project region. Remote sensing and sensing data, published topographic maps and data, land management and ownership records, and/or other formal documents that assist in clearly defining the project region can be utilized.

The project operation may comprise one or more discrete terrestrial areas. Each discrete terrestrial area must possess a unique geographical identifier.

When describing physical project boundaries, the following information must be provided for each discrete area:

- Name of the project area (including compartment numbers, local name (if any)).
- Unique identifier for each discrete parcel of land.
- Map(s) of the area (preferably in digital format).
- The project area must be geo-referenced and provided in digital format in accordance with VCS rules.
- Total area.
- Details of land rights holder and user rights.

7.2.2 Soil Organic Carbon Depletion Time (SDT)

Where the project area on the project start date is not homogeneous, stratification may be carried out to improve the accuracy and precision of carbon stock and GHG flux estimates.

If stratification is employed, different stratifications could be required for the baseline and project scenarios to achieve optimal accuracy of net GHG emission reduction and removal estimates. Strata can be defined based on soil type and depth (including eligibility assessment), water table depth, vegetation cover and/or vegetation composition, salinity, land type (open water, channel, and unvegetated sand or mudflat), or expected changes in these characteristics.

Strata must be spatially discrete, and stratum areas must be known. The total project area should equal the sum of individual strata areas. Strata must be identifiable using spatial data (e.g., maps, GIS coverage, classified imagery, sampling grids) to determine their areas accurately.

Land use/land cover maps, in particular, must be ground-truthed and no older than 10 years unless it can be demonstrated that they remain accurate. Strata must be distinguishable while following good practice for stratum limit and boundary definition accuracy. The type of spatial data and its justification should be indicated in the project description.

The project area can be stratified ex ante, and this stratification may be revised ex post for monitoring purposes. Established strata can be merged if their separate establishment reasons are no longer meaningful or have proven irrelevant to estimating net GHG emission reductions and removals. Baseline stratification must remain fixed until a baseline scenario reassessment occurs. Stratification in the project scenario must be reviewed before each monitoring event verification and revised if necessary.

7.2.3 Sea level rise

The project must take into account projected relative sea level rise and assess the potential for inland expansion of the project boundary to accommodate wetland migration, inundation, and erosion. Sea level rise projections must be based on IPCC regional forecasts or peer-reviewed literature relevant to the specific area; expert judgment may also be used. It is important to note that global average sea level rise scenarios are not applicable. If such scenarios are used, they must be appropriately downscaled to regional conditions that include vertical land movements (e.g., subsidence).

The assessment of wetland migration, inundation, and erosion must consider factors such as topographical slope, land use and management, sediment supply, and tidal range. To evaluate the risk of erosion and inundation affecting carbon stocks in the project scenario, the VCS AFOLU Non-Permanence Risk Tool must be applied. In cases where sea level rise leads to inundation of the project area, the aboveground biomass carbon stock is assumed to oxidize and be released entirely and immediately to the atmosphere. Soil carbon stocks may remain intact or may be eroded and exported outside the project boundary. However, in inundated areas without wave action, the loss of soil organic carbon is considered negligible.

The project must present maps showing the projected wetland boundaries from the project start date through the end of the verification period, as well as projections at year t=100.

7.2.4 Ineligible wetland areas

For projects aiming to quantify CO2 emission reductions, areas within the project boundary where the cumulative carbon loss over 100 years after the project start date does not achieve a significant difference (i.e., less than 5%) are deemed ineligible for crediting baseline emission reductions, and these areas must be mapped.

The methodology establishes a maximum quantity of GHG emission reductions that can be claimed from the soil carbon pool, limiting it to the net GHG benefit generated by the project 100 years after its start date. Project proponents must calculate this maximum quantity upfront using conservative parameters, choosing between two approaches: the Total Stock Approach or the Stock Loss Approach. The Total Stock Approach determines the difference in remaining soil organic carbon stock between the project and baseline scenarios at t=100 years. A difference is considered "significant" if the total carbon stock in the project scenario is at least 1.05 times that of the baseline scenario at t=100 years. The Stock Loss Approach, alternatively, calculates this maximum based on the cumulative soil organic carbon loss in both scenarios from the project start date up to t=100 years. Regardless of the chosen method, project proponents are required to present maps illustrating the projected wetland boundaries from the project start date to the end of the crediting period, and specifically at t=100 years, with intervals adjusted to the rate of sea level rise.

7.2.5 Buffer zones

If buffer zones are established in the project, they must be spatially mapped in accordance with the VCS requirements.

7.3 Carbon Pools

Aboveground tree biomass, aboveground non-tree biomass, below-ground biomass, soil, and wood products are all included within the project's carbon pools. If the total decrease in carbon stocks or increase in GHG emissions from these carbon pools amounts to less than 5% of the total GHG benefit generated by the project, they may be deemed "de minimis" and do not need to be accounted for. Projects should utilize relevant tools, such as the CDM tool AR-Tool04 Tool for testing significance

of GHG emissions in A/R CDM project activities, to make this determination, thereby ensuring the accuracy and practicality of carbon accounting.

7.4 Sources of Greenhouse Gases (GHGs)

Greenhouse gas (GHG) sources within the project boundary are identified for both baseline and project scenarios. A crucial rule is that if the combined decrease in carbon stocks or increase in GHG emissions from these sources amounts to less than 5% of the total GHG benefit generated by the project, they can be considered "de minimis" and do not require accounting; project proponents can verify this using peer-reviewed literature or the CDM tool AR-Tool04.

In the baseline scenario, microbial methane (CH_4) and nitrous oxide (N_2O) from denitrification/nitrification can often be conservatively excluded. Emissions from the burning of biomass and organic soil (CO_2, CH_4, N_2O) are implicitly handled by the Fire Reduction Premium approach, and fossil fuel use emissions (CO_2, CH_4, N_2O) can also be conservatively excluded.

Conversely, in the project scenario, microbial methane (CH_4) is a potential major emission source, especially in low salinity and freshwater areas. Nitrous oxide (N_2O) from denitrification/nitrification may increase due to project activities. While CO_2 from biomass burning is addressed in carbon stock change procedures, CH_4 and N_2O from fires are potential major sources. Fossil fuel use (CO_2, CH_4, N_2O) can be a significant CO_2 source if it involves heavy machinery for soil movement, but not if limited to planting without soil disturbance. CH_4 and N_2O from fuel use are generally not considered significant in the project context. This detailed classification helps ensure accurate and practical carbon accounting in tidal wetland and seagrass restoration projects.

8 BASELINE SCENARIOS

8.1 Determination of the Most Plausible Baseline Scenario

The identification of the baseline scenario requires using the CDM tool AR-Tool2.0 version: 'A comprehensive tool for identifying A/R CDM project activities and demonstrating additivity.' There is a limitation in applying it under this methodology: all elements related to 'addivity' must be excluded.

8.2 Reassessment of the Baseline Scenario

The project proponent must reassess the baseline scenario in accordance with VCS requirements. If the Fire Reduction Premium approach is used for reassessing the baseline scenario, the historic reference period must be extended to include the original reference period and all subsequent monitoring periods up to the beginning of the current monitoring period. However, the fire reference period remains fixed as a 10-year period ending 5 years before the project start date. In addition, the project proponent must re-determine the PDT, where applicable, every 10 years according to the specified procedures, and update data sources when new information relevant to the project area becomes available.

8.3 Integration of Satellite measurements

Satellites play a fundamental role in environmental monitoring and managing dynamic baseline scenarios. They offer comprehensive spatial and temporal data, enabling accurate delineation of geographic boundaries for project areas. With satellite imagery and geospatial tools, project developers can stratify regions based on land use, vegetation types, and elevation, improving the precision of carbon estimates.

Provide historical imagery crucial for building time-series datasets. These datasets enable analysts to quantify past changes in vegetation cover, burned areas, and land use, which are essential for modeling greenhouse gas emissions in baseline scenarios. Remote sensing also supports the projection of future environmental conditions by feeding key parameters into predictive models.

Monitoring natural carbon stores, such as peat and soil organic carbon. By analyzing elevation changes and subsidence over time, satellites help estimate the depletion rates of these carbon reserves across large areas, even in locations that are difficult to access by land.

Assessing the effects of rising sea levels. It helps identify areas vulnerable to flooding and erosion, informs predictions of wetland migration, and supports long-term mapping of potential changes to coastlines and ecosystems.

Satellite data ensures that baseline scenarios remain dynamic and scientifically credible. By providing updated imagery and observations, satellites allow project developers to reassess critical parameters every ten years, or whenever new information becomes available. This helps keep environmental models aligned with real-world changes.

8.4 Dynamic Baseline Scenario

At each recalculation, relevant data sources must be updated, especially when new information related to the project area is available. Satellite measurements are the key tool for obtaining these latest pieces of information.

Establishment and regular re-evaluation of baseline scenario

The project shall utilize the most advanced version of CDM tool AR-Tool02 to establish a reasonable baseline scenario and recalculate it every ten years, which includes revising peat depression time (PDT) and soil organic carbon depletion time (SDT).

Dynamic identification and monitoring of project geographical boundary and stratification

Stratifications in the project scenario need to be reviewed and adjusted as needed during each monitoring period. Satellite remote sensing techniques such as maps, geographic information system overlay maps or classified images can provide real-time and large-scale data to support these dynamic adjustments.

Land use/cover map

Verify and maintain the timeliness (update cycle not exceeding ten years) of land use/cover maps through satellite image analysis on site.

Quantification and prediction of future trends

Predict greenhouse gas emissions on each expected verification day during the project credit period. Satellite measurements can provide the necessary critical data and trend analysis, such as detecting changes in agricultural practices, vegetation cover, water resource management, and residue retention in the monitoring area, while considering sea level rise impacts. Based on IPCC regional predictions, provide sea level rise predictions and include these future wetland boundary projections into the map, ranging from the starting date of the project to the end of the credit period and even 100 years later. Satellite data can assist in monitoring and mapping how these changes affect carbon storage and emissions in the baseline scenario.

Application of database and machine learning model

Establish a change database using classified images for machine learning models to determine crop rotation options, thereby supporting dynamic predictions and further adjustments to the baseline for future land management scenarios.

Support for selection of new baseline control points

Satellites provide environmental information over large areas, helping support the selection of new baseline control points to ensure the accuracy of baseline assessments.

Sufficiency, reproducibility, and conservatism requirements for data

When satellite data is used to prove the dynamic updating of baselines, the project must be demonstrated that the images have sufficient spatial and temporal resolution, and the data must be repeatable, estimable, and conservative.

8.5 System to system

"System to System" focuses on the collaboration and integration of multiple data sources, analytical tools, and validation processes to ensure the accuracy, dynamism, and verifiability of baseline scenarios. Baseline scenarios are considered as dynamic systems that require continuous monitoring and adjustment. Specific applications include:

Systematic process for confirming baseline scenarios and predicting future trends, such as using AR-Tool02 to analyze the most reasonable baseline scenario and utilizing VCS module VMD0019 to quantify the impact of changes in the four driving factors on the baseline scenario.

Data collection and geographic spatial management systems, including precisely defining project areas using satellite measurements, remote sensing data, and GPS coordinates, as well as obtaining key input data through field measurements and monitoring.

Greenhouse Gas (GHG) emission quantification and tool integration system, employing VM0033 to provide GHG emission and removal quantification formulas while integrating other tools like AR-Tool14 (tree and shrub carbon sequestration change) and AR-Tool05 (fossil fuel use emissions).

Dynamic reassessment system for baseline scenarios, regularly reevaluating baseline scenarios to ensure they reflect the actual trends and natural evolution of greenhouse gas emissions or removals in the project area.

The limitations of the methodology include dependence on high-quality data, applicability of tools and modules, data collection difficulties, and uncertainties associated with predictive modeling.

9 ADDITIONALITY

9.1 Application of Module VDM0052

For this project activities, use Module VDM0052 Demonstration of Additionality of Tidal Wetland Restoration and Conservation Project Activities.

Step 1: Regulatory surplus

The project proponent must demonstrate regulatory surplus in accordance with the rules and requirements regarding regulatory surplus set out in the latest version of the VCS Standard.

Step 2: Positive list

The project must demonstrate that it meets all of the applicability conditions listed bellow, and in so doing, it is deemed as complying with the positive list. The positive list was established using the activity penetration option (Option A in the VCS Standard). Projects which meet the applicability conditions are deemed additional.

Project activities restoring tidal wetlands may include any of the following, or combinations of the following:

- Creating, restoring and/or managing hydrological conditions (e.g., removing tidal barriers,improving hydrological connectivity, restoring tidal flow to wetlands or lowering water levels on impounded wetlands)
- Altering sediment supply (e.g., beneficial use of dredge material or diverting river sediments to sediment-starved areas)
- Changing salinity characteristics (e.g., restoring tidal flow to tidally-restricted areas)
- Improving water quality (e.g., reducing nutrient loads leading to improved water clarity to expand seagrass meadows, recovering tidal and other hydrologic flushing and exchange or reducing nutrient residence time)
- (Re-)introducing native plant communities (e.g., reseeding or replanting)
- Improving management practice(s) (e.g., removing invasive species, reduced grazing)
- In RWE-ARR project activities, the prescribed burning of herbaceous and shrub aboveground biomass (cover burns) may occur

Project activities conserving tidal wetlands may include:

- Protecting at-risk wetlands (e.g., establishing conservation easements, establishing community supported management agreements, establishing protective government regulations, and preventing disruption of water and/ or sediment supply to wetland areas)
- Improving water management on drained wetlands
- Maintaining or improving water quality for seagrass meadows
- Recharging sediment to avoid drowning of coastal wetlands
- Creating accommodation space for wetlands migrating with sea-level rise.

Step 3: Analysis tidal wetland conservation projects

Tidal wetland conservation activities globally are at a low level of penetration relative to their maximum adoption potential. Specifically, the activity penetration level of such activities is conservatively calculated to be 3.6% (or lower), as demonstrated below. This level is below the 5% threshold specified in the VCS Standard. Therefore, tidal wetland conservation projects meeting the applicability conditions of this module are deemed additional.

Activity penetration is given as:

$$APy = OAy / MAPy \times 100$$

Where:

APy	= Activity penetration of the project activity in year y (percentage)
OAy	= Observed adoption of the project activity in year y
MAPy	= Maximum adoption potential of the project activity in year y

For tidal wetland conservation, these terms are further defined as follows:

OAy	= Geospatial data from United Nations Environment Programme's World Conservation Monitoring Centre (UNEP-WCMC) for world-protected areas
MAPy	= Geospatial data from UNEP-WCMC for mangrove, salt marsh, and seagrass ecosystems

9.2 Mechanism for Continuous Review of Policy and Regulatory Environment

To address the shifting regulatory and policy landscape and sustain the Additonality of the project throughout the crediting period, the project developer must integrate a thorough examination of the policy and regulatory environment during each decennial Baseline Reassessment. This assessment will concentrate on the following three dimensions:

1. Tracking of Legal and Regulatory Updates:

- Review any new or revised laws, regulations, or mandatory policies at the national and sub-national levels concerning wetland/seagrass restoration, land-use planning, and environmental protection since the last assessment.
- Evaluate whether these updates have created a legal enforceability requirement for the project activity area, potentially making the project activity legally required and thereby eliminating its additionality.

2. Evaluation of Non-Carbon Market Incentives:

- Investigate the availability of new government subsidies, grants, tax incentives, or public investment programs that could make the tidal wetland restoration activity financially viable without carbon credit revenue.
- If such changes are identified, the project's financial threshold must be reassessed according to the requirements of the CDM Tool AR-Tool02 to re-demonstrate additionality under the new economic circumstances.

3. Empirical Verification of Policy Implementation:

- Verify the actual enforcement and effectiveness of existing policies and regulations by reviewing official documents, annual reports, and conducting consultations with relevant competent authorities and project stakeholders.
- If a law or policy exists on paper but is not effectively implemented due to lack of resources, capacity, or enforcement, its impact on the baseline scenario should be considered minimal.

Application of Review Results:

The results of this policy review will serve as the basis for adjusting the baseline scenario, ensuring that it always reflects the reality most consistent with a 'no-project situation,' and thereby maintaining the integrity and added value of the project environment.

10 QUANTIFICATION OF GREENHOUSE GAS EMISSION REDUCTIONS AND REMOVALS

This methodology delineates a systematic approach for assessing the difference in greenhouse gas (GHG) benefits between project activity and baseline scenario conditions in tidal wetland and seagrass restoration projects.

10.1 Baseline Emissions

Baseline emissions are attributed to changes in carbon stocks within biomass and soil pools, or a combination thereof. Where applicable, emissions resulting from fossil fuel use may also be included in the calculation.

Baseline emissions are calculated as the sum of various emission sources in the baseline scenario. These sources include:

(1) Carbon dioxide (CO2) emissions from organic and mineral soils.
(2) Methane (CH4) emissions from soils.
(3) Nitrous oxide (N2O) emissions from soils.
(4) Emissions from biomass burning.
(5) Emissions from fossil fuel consumption.

The methodology provides detailed procedures and equations for estimating each of these baseline emission components, often allowing for different approaches such as proxy-based methods, published values, or default factors, depending on data availability and specific site conditions. It also addresses considerations like peat and soil organic carbon depletion times (PDT and SDT) to define the period over which baseline soil emissions are relevant. In some cases, certain emissions like CH4 or N2O can be conservatively set to zero in the baseline if it can be demonstrated that project activities do not increase them compared to the baseline.

10.1.1 General approach

Greenhouse gas (GHG) emissions in the baseline scenario (GHG_{BSL}) are estimated by summing the carbon stock changes in biomass carbon pools ($GHG_{BSL\text{-}biomass}$), emissions from soil organic carbon (SOC) pools ($GHG_{BSL\text{-}soil}$), and emissions from fossil fuel use ($GHG_{BSL\text{-}fuel}$).

The calculation formula is as follows:

$$\mathrm{GHG}_{BSL} = GHG_{\mathrm{BSL-biomass}} + GHG_{\mathrm{BSL-soil}} + GHG_{\mathrm{BSL-fuel}} \quad (3)$$

$$\mathrm{GHG}_{BSL-biomass} = -\sum_{t=1}^{t^*}\sum_{i=1}^{M_{BSL}}\left(\frac{44}{12} \times \Delta C_{BSL-biomass,i,t}\right) \quad (4)$$

$$\mathrm{GHG}_{BSL-biomass} = \sum_{t=1}^{t^*}\sum_{i=1}^{M_{BSL}} GHG_{BSL-soil,i,t} \quad (5)$$

$$GHG_{BSL-fuel} = \sum_{t=1}^{t^*} \sum_{i=1}^{M_{BSL}} GHG_{BSL-fuel,i,t} \quad (6)$$

Where:

GHG_{BSL}	=Net CO_2e emissions in the baseline scenario up to year t*; t CO_2e
$GHG_{BSL-biomass}$	= Net CO_2e emissions from biomass carbon pools in the baseline scenario up to year t*; t CO_2e
$GHG_{BSL-soil}$	= Net CO_2e emissions from the SOC pool in the baseline scenario up to year t*; t CO_2e
$GHG_{BSL-fuel}$	= Net CO_2e emissions from fossil fuel use in the baseline scenario up to year t*; t CO_2e
$\Delta C_{BSL-biomass,i,t}$	= Net carbon stock changes in biomass carbon pools in the baseline scenario in stratum i in year t; t C yr^{-1}
$GHG_{BSL-soil,i,t}$	= GHG emissions from the SOC pool in the baseline scenario in stratum i in year t; t CO_2e yr^{-1}
$GHG_{BSL-fuel,i,t}$	= GHG emissions from fossil fuel use the baseline scenario in stratum i in year t; tCO_2e yr^{-1}
I	= 1, 2, 3 …M_{BSL} strata in the baseline scenario
T	= 1, 2, 3, … t* years elapsed since the project start date

To forecast future GHG emissions under the baseline scenario, the latest version of VCS Module VMD0019 ("Methods to Project Future Conditions") must be applied. The methodology highlights four key drivers that may significantly influence the evolution of the site and affect baseline GHG dynamics over a 100-year timespan:

- Initial land use and development patterns
- Initial infrastructure that impedes natural tidal hydrology
- Natural plant succession for the physiographic region of the project
- Climate variables as likely drivers of changes in tidal hydrology within the 100-year timeframe of the project, influencing sea level rise, precipitation and associated freshwater delivery

I. Land Use and Development Patterns

To derive land use trends, assumptions about future development potential within the project area must be documented. These should reflect current zoning regulations, legal constraints, proximity to urban centers or transportation infrastructure, and anticipated population growth. The analysis must consider how land within and around the project site may develop and how these changes could alter hydrological conditions. Current development patterns and plausible future land use scenarios must be mapped at a sufficient scale to allow estimation of GHG emissions under the baseline scenario. Special attention must be given to any existing or future structures that act as barriers to tidal or river hydrology, sediment transport, or that limit wetlands from migrating landward due to sea level rise. If the baseline scenario involves abandonment of pre-project land uses, the project proponent must account for natural hydrological changes caused by the collapse of dikes or ditches and land subsidence. These changes can result in rising relative water levels, thinner aerobic soil layers, and reduced CO_2 emission rates.

II. Infrastructure Impediments to Tidal Hydrology

To estimate the trajectory of tidal wetland development, the baseline scenario must reflect the current and historic layout of tidal barriers and drainage systems. These features must be mapped at appropriate scale (e.g., 1:10,000 or justified alternative) to estimate water table depths. Historical layouts must be reconstructed using topographic and hydrological maps dating back to the onset of major hydrologic impacts, and covering at least 20 years prior to the project start. Collapsed drainage structures may still possess higher hydraulic conductivity than surrounding soils and serve as preferential flow paths. Likewise, old tidal barriers such as agricultural dikes and levees can restrict tidal flows and disrupt sedimentation. Their influence on current hydrological function must be assessed through hydrological modeling or expert judgment.

Historic aerial imagery showing past channel networks may inform trends in post-project channel formation. Such analysis should be supported by hydrological modeling that incorporates tidal volume, soil erodibility, and/or expert input. The baseline hydrological scenario must also consider the effects of climate variables and identify any impacts caused by planned interventions beyond the project boundary (e.g., dam construction or culvert modification), demonstrating a hydrological connection to those interventions.

III. Natural Plant Succession

Based on estimated changes in water table depth, the project proponent must derive a time series of vegetation composition using scientific literature or expert judgment. For instance, previously diked agricultural land may transition into forest, freshwater wetlands, tidal wetlands, upland habitats, or open water. This depends on land use projections, inundation levels, proximity to native or invasive seed sources, succession patterns of nearby natural areas, and anticipated maintenance practices (e.g., grazing, landscaping).

IV. Climate Variables

In line with sea level rise, project analysis must account for inundation and erosion impacts associated with the three factors above. Changes in rainfall and freshwater inflows should be considered, as well as expected human adaptations in response to these climate shifts.

V. Baseline Scenario Reassessment

Throughout the project's crediting period, proponents must reassess the baseline scenario every ten years. Revised assumptions and estimates must comply with reassessment criteria specified in Section 6 and be incorporated into updated baseline emission calculations. This process must include evaluation of the continued validity of GHG emission proxies used.

10.1.2 Accounting for sea level rise

The consequences of submergence of a given stratum due to sea level rise are:

(1) Carbon stocks from aboveground biomass are lost to oxidation, and
(2) Depending upon the geomorphic setting, soil carbon stocks may be held intact or be eroded and transported beyond the project area.

Regarding (1) above, where biomass is submerged, it is assumed that this carbon is immediately and entirely returned to the atmosphere. For such strata:

$$\Delta C_{BSL-agbiomass,i,t} = \frac{12}{44}\left(C_{BSL-agbiomass,i,t} - C_{BSL-agbiomass,i,(t-T)}\right)/T \qquad (7)$$

For the year of submergence: $C_{BSL-agbiomass,i,t} = 0$

Where:

$\Delta C_{BSL-agbiomass,i,t}$	= Net carbon stock change in aboveground biomass carbon pools in the baseline scenario in stratum *i* in year *t*; t C yr^{-1}
$C_{BSL-agbiomass,i,t}$	= Carbon stock in aboveground biomass in the baseline cenario in stratum *i* in year *t* (from the aboveground biomass omponents in $C_{TREE_BSL,t}$ and $C_{SHRUB_BSL,t}$ in *AR-Tool14* and $C_{BSL-herb,i,t}$); t CO_2e
i	= 1, 2, 3 …M_{BSL} strata in the baseline scenario
t	= 1, 2, 3, … t* years elapsed since the project start date
T	= Time elapsed between two successive estimations ($T = t2 - t1$)

Regarding point (2), The fate of SOC depends on geomorphology:

In areas submerged and forming ponds, SOC loss is considered negligible

SOC is assumed not to be released to the atmosphere unless supported by site-specific scientific evidence. Areas affected by wave action may experience sediment erosion and carbon removal.Assuming all carbon is redeposited and preserved (not oxidized) is a conservative estimate.

Restoration projects may be designed to demonstrate advantages over the baseline scenario in one or more of the following areas, and these must be quantified and justified in the project documentation:

The point in time when submergence or erosion occurs

The amount of carbon lost upon submergence

The oxidation rate of eroded soil organic matter (under conservative assumptions: the baseline scenario uses a rate of 0, and the project scenario a rate of 1)

10.1.3 Net carbon stock change in biomass carbon pools in baseline scenario

Net carbon stock change in biomass carbon pools in the baseline scenario are estimated as:

$$\Delta C_{BSL\text{-}biomass,i,t} = \Delta C_{BSL\text{-}tree/shrub,i,t} + \Delta C_{BSL\text{-}herb,i,t} \quad (8)$$

Where:

$\Delta C_{BSL\text{-}biomass,i,t}$ = Net carbon stock change in biomass carbon pools in the aseline scenario in stratum *i* in year *t*; t C yr^{-1}

$\Delta C_{BSL\text{-}tree/shrub,i,t}$ = Net carbon stock change in tree and shrub carbon pools in the baseline scenario in stratum *i* in year *t*; t C yr^{-1}

$\Delta C_{BSL\text{-}herb,i,t}$ = Net carbon stock change in herb carbon pools in the baseline scenario in stratum *i* in year *t*; t C yr^{-1}

i = 1, 2, 3 …M_{BSL} strata in the baseline scenario

t = 1, 2, 3, … *t** years elapsed since the project start

(1) Trees and shrubs

Net carbon stock change in trees and shrubs in the baseline scenario are estimated by applying the latest version of CDM tool AR-Tool14 Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities, noting that:

AR-Tool14 is only used to derive net carbon stock changes in tree and shrub carbon pools($\Delta C_{BSL\text{-}tree/shrub,i,t}$), and

The following equation applies:

$$\Delta C_{BSL-tree/shrub,i,t} = \frac{12}{44}\left(\Delta C_{TREE_BSL,t} + \Delta C_{SHRUB_BSL,t}\right) \quad (9)$$

Where:

$\Delta C_{BSL\text{-}tree/shrub,i,t}$ = Net carbon stock changes in tree and shrub carbon pools in the baseline scenario in stratum *i* in year *t*; t C yr^{-1}

$\Delta C_{TREE_BSL,t}$ = Change in carbon stock in baseline tree biomass within the project area in year *t*; t CO_2-e yr^{-1} (derived from application of AR-Tool14; calculations are done for each stratum *i*)

$\Delta C_{SHRUB_BSL,t}$ = Change in carbon stock in baseline shrub biomass within the project area in year *t*; t CO_2-e yr^{-1} (derived from application of *AR-Tool14*; calculations are done for each stratum *i*)

(2) Herbaceous vegetation

Net carbon stock change in herbaceous vegetation in the baseline scenario is estimated using a carbon stock change approach as follows:

$$\Delta C_{BSL\text{-}herb,i,t} = (C_{BSL\text{-}herb,i,t} - C_{BSL\text{-}herb,i,,(t\text{-}T)}) / T \qquad (10)$$

Where:

$\Delta C_{BSL\text{-}herb,i,t}$ = Net carbon stock change in herbaceous vegetation carbon pools in the baseline scenario in stratum *i* in year *t*; t C yr^{-1}

$C_{BSL\text{-}herb,i,t}$ = Carbon stock in herbaceous vegetation in the baseline scenario in stratum *i* in year *t*; t C

I = 1, 2, 3 …M_{BSL} strata in the baseline scenario

t = 1, 2, 3 … t* years elapsed since the project start date

T = Time elapsed between two successive estimations ($T = t2 - t1$)

10.1.4 Net GHG emissions from soil in baseline scenario

Net GHG emissions from soil in the baseline scenario are estimated as:

$$GHG_{BSL\text{-}soil,i,t} = A_{i,t} \times (GHG_{BSL\text{-}soil\text{-}CO2,i,t} - Deduction_{alloch} + GHG_{BSL\text{-}soil\text{-}CH4,i,t} + GHG_{BSL\text{-}soil\text{-}N2O,i,t})\ldots \qquad (11)$$

For organic soils where $t > t_{PDT\text{-}BSL,i}$: $GHG_{BSL\text{-}soil,i,t} = 0$

For mineral soils where $t > t_{SDT\text{-}BSL,i}$: $GH_{GBSL\text{-}soil,i,t} = 0$

Where:

$GHG_{BSL\text{-}soil,i,t}$ = GHG emissions from the SOC pool in the baseline scenario in stratum *i* in year *t*; t CO_2e yr^{-1}

$GHG_{BSL\text{-}soil\text{-}CO2,i,t}$ = CO_2 emissions from the SOC pool in the baseline scenario in stratum *i* in year *t*; t CO_2e ha^{-1} yr^{-1}

$Deduction_{alloch}$ = Deduction from CO_2 emissions from the SOC pool to account for the percentage of the carbon stock that is derived from allochthonous soil organic carbon; t CO_2e ha^{-1} yr^{-1}

$GHG_{BSL\text{-}soil\text{-}CH4,i,t}$ = CH_4 emissions from the SOC pool in the baseline scenario in stratum *i* in year *t*; t CO_2e ha^{-1} yr^{-1}

$GHG_{BSL\text{-}soil\text{-}N2O,i,t}$ = N_2O emissions from the SOC pool in the baseline scenario in stratum *i* in year *t*; t CO_2e ha^{-1} yr^{-1}

$A_{i,t}$ = Area of stratum *i* in year *t*; ha

$t_{PDT\text{-}BSL,I}$ = Peat depletion time in the baseline scenario in stratum *i* in years elapsed since the project start date; yr

$t_{SDT\text{-}BSL,I}$ = Soil organic carbon depletion time in the baseline scenario in stratum *i* in years elapsed since the project start date; yr

I = 1, 2, 3 …M_{BSL} strata in the baseline scenario

T = 1, 2, 3, … *t** years elapsed since the project start date

(1) CO_2 emissions from the SOC pool in the baseline scenario

$$GHG_{BSL\text{-}soil\text{-}CO2,i,t} = GHG_{BSL\text{-}insitu\text{-}CO2,i,t} + GHG_{BSL\text{-}eroded\text{-}CO2,i,t} + GHG_{BSL\text{-}excav\text{-}CO2,i,} \quad (12)$$

Where:

$GHG_{BSL\text{-}soil\text{-}CO2,i,t}$ = CO_2 emissions from the SOC pool in the baseline scenario in stratum i in year t; t CO_2e ha-1 yr-1

$GHG_{BSL\text{-}insitu\text{-}CO2,i,t}$ = CO_2 emissions from the SOC pool of in-situ soils in the baseline scenario in stratum i in year t; t CO_2e ha^{-1} yr^{-1}

$GHG_{BSL\text{-}eroded\text{-}CO2,i,t}$ = CO_2 emissions from the eroded SOC pool in the baseline scenario in stratum i in year t ; t CO_2e ha^{-1} y^{r-1}

$GHG_{BSL\text{-}excav\text{-}CO2,i,t}$ = CO_2 emissions from the SOC pool of soil exposed to an aerobic environment through excavation in the baseline scenario in stratum i in year t; t CO_2e ha^{-1} y^{r-1}

1) Hydrological Structures and Carbon Burial

Baseline scenarios may include construction of levees, dams, or land-use changes that alter runoff patterns. These processes may lead to increased carbon burial and reduced GHG emissions.

2) Accepted Methods for Estimating GHG Emissions

Project proponents may choose from the following approaches, based on project conditions and data availability. However, when high-quality local data is available, default values cannot be used.

Methods include:

- Use of Proxies
  Must be strongly correlated with the variable of interest, and validated for similar regional conditions, geomorphology, hydrology, and management practices.

- Use of Models
  Deterministic models may be applied if results are validated against direct measurements from ecologically and hydrologically similar systems.

- Use of Published Data

Peer-reviewed studies and reports following expert judgment guidelines (Section 9.3.3) may be used if relevant to similar systems in the same region.

- Use of Default Factors

  Must be derived from peer-reviewed literature, matched to the ecosystem and location, and periodically reassessed as per VCS methodology protocols.
  IPCC Tier 1 values may be used if deemed appropriate and justified for the specific project.

(2) CO2 Emissions from Soil Exposed to an Aerobic Environment Through Excavation

Calculating CO_2 emissions from soil exposed to oxygen in an aerobic environment for project proposals at each stratum and time step. Emissions may be determined either directly or indirectly by using the initial amount of carbon exposed ($C_{BSL\text{-}excav,i,t}$) and the percentage of exposed carbon released to the atmosphere ($C\%_{BSL\text{-}emitted,i,t}$). When estimating $C_{BSL\text{-}excav,i,t}$ following an aerobic exposure event, it is essential to account for the tendency of organic carbon concentrations in mineral soils to reach a steady-state equilibrium, which should be conservatively reflected in evaluations

Project proponents can use any combination of the following methods to calculate these terms:

(a) Proxies

(b) Published values

(c) Default factors

(d) Models

(e) Field-collected data, or

(f) Historical or chronosequence-derived data

$$GHG_{BSL\text{-}excav\text{-}CO2,i,t} = \frac{44}{12} \times C_{BSL\text{-}excav,i,t} \times C\%_{BSL\text{-}emitted,i,t} / 100 \quad (13)$$

$$C_{BSL\text{-}excav,i,t} = C\%_{BSL\text{-}excav,i,t} \times BD \times Depth_{_exBSL,i,t} \times 10 \quad (14)$$

Where:

$GHG_{BSL\text{-}excav\text{-}CO2,i,t}$ = CO_2 emissions from the SOC pool of soil exposed to an aerobic environment through excavation in the baseline scenario in stratum i in year t; t CO_2e ha^{-1} yr^{-1}

$C_{BSL\text{-}excav,i,t}$ = Soil organic carbon stock in soil exposed to an aerobic environment through excavation in the baseline scenario in stratum i in year t; t C ha^{-1}

$C\%_{BSL\text{-}emitted,i,t}$	= Organic carbon loss due to oxidation, as a percentage of C mass present in excavated soil material in the baseline scenario in stratum i in year t; %
$C\%_{BSL\text{-}excav,i,t}$	= Percentage of carbon of soil material excavated in the baseline scenario;%
BD	= Soil bulk density; kg m^{-3}
$Depth_{_exBSL,i,t}$	= Depth of the piled-up soil material due to excavation in the baseline scenario in stratum i in year t; m

(3) CH_4 emissions from soil

4 emissions from soil in the baseline scenario may be conservatively excluded if it can be demonstrated that conditions for CH_4 emissions in both the baseline and project scenarios will not differ or will decline. If this condition is met, these emissions need not be accounted for.

CH4 emissions from soils can be estimated using the following methods:

(a) Proxies

(b) Field-collected data

(c) Published values

(d) Default factors

(e) Models, or

(f) IPCC emission factors

If the project proponent takes into account CH_4 emissions in the baseline scenario, they may employ the options listed below to estimate such emissions.

10.2 Project Emissions

10.2.1 General approach

Project Emissions refer to the net greenhouse gas (GHG) emissions that are expected or actually occur as a result of tidal wetland and seagrass restoration project activities. This methodology outlines the procedures for estimating these emissions, which may originate from changes in carbon stocks, soil processes, organic soil combustion, or fossil fuel use.

Emissions in the project scenario are estimated as:

$$GHG_{WPS} = GHG_{WPS-biomass} + GHG_{WPS-soil} + GHG_{WPS-burn} + GHG_{WPS-fuel} \quad (15)$$

$$GHG_{WPS-biomass} = -\sum_{t=1}^{t^*}\sum_{i=1}^{M_{WPS}}\left(\frac{44}{12} \times \Delta C_{WPS-biomass}\right) \quad (16)$$

$$GHG_{WPS-soil} = -\sum_{t=1}^{t^*}\sum_{i=1}^{M_{WPS}}\left(\frac{44}{12}\times\Delta C_{WPS-soil,i,t}\right) \quad (17)$$

$$GHG_{WPS-burn} = -\sum_{t=1}^{t^*}\sum_{i=1}^{M_{WPS}}\left(\frac{44}{12}\times\Delta C_{WPS-burn,i,t}\right) \quad (18)$$

$$GHG_{WPS-fuel} = -\sum_{t=1}^{t^*}\sum_{i=1}^{M_{WPS}}\left(\frac{44}{12}\times\Delta C_{WPS-fuel,i,t}\right) \quad (19)$$

Where:

GHG_{WPS} = Net CO_2e emissions in the project scenario up to year t*; t CO_2e

$GHG_{WPS-biomass}$ = Net CO_2e emissions from biomass carbon pools in the project scenario up to year t*; t CO_2e

$GHG_{WPS-soil}$ = Net CO_2e emissions from the SOC pool in the project scenario up to year t*; t CO_2e

$GHG_{WPS-burn}$ = Net CO_2e emissions from prescribed burning in the project scenario up to year t*; t CO_2e

$GHG_{WPS-fuel}$ = Net CO_2e emissions from fossil fuel use in the project scenario up to year t*; t CO2e

$\Delta C_{WPS-biomass,i,t}$ = Net carbon stock change in biomass carbon pools in the project scenario in stratum i in year t; t C yr^{-1}

$GHG_{WPS-soil,i,t}$ = GHG emissions from the SOC pool in the project scenario in stratum i in year t; t CO_2e yr^{-1}

GHGWPS-burn,i,t= GHG emissions from prescribed burning in the project scenario in stratum i in year t; t CO_2e yr^{-1}

$GHG_{WPS-fuel,i,t}$ = GHG emissions from fossil fuel use the project scenario in stratum i in year t; t CO_2e yr^{-1}

I = 1, 2, 3 ⋯M_{WPS} strata in the project scenario

T = 1, 2, 3, ⋯ t* years elapsed since the project start date

10.2.2 Accounting for sea level rise

The VCS AFOLU Non-Permanence Risk Tool must be used to assess the future impacts of erosion and submergence caused by sea level rise on the project's carbon stocks, in order to determine the required contribution to the AFOLU pooled buffer account.

10.2.3 Net carbon stock change in biomass carbon pools in project scenario

Net carbon stock change in biomass carbon pools in the project scenario is estimated as:

$$\Delta C_{WPS-biomass,i,t} = \Delta C_{WPS-tree/shrub,i,t} + \Delta C_{WPS-herb,i,t} \quad (20)$$

Where:

$\Delta C_{WPS\text{-}biomass,i,t}$ = Net carbon stock change in biomass carbon pools in the project scenario in stratum i in year t; t C yr^{-1}

$\Delta C_{WPS\text{-}tree/shrub,i,t}$ = Net carbon stock change in tree and shrub carbon pools in the project scenario in stratum i in year t; t C yr^{-1}

$\Delta C_{WPS\text{-}herb,i,t}$ = Net carbon stock change in herb carbon pools in the project scenario in stratum i in year t; t C yr^{-1}

i = 1, 2, 3 …M_{WPS} strata in the project scenario

t = 1, 2, 3, … t* years elapsed since the project start date

(1) Trees and shrubs:

These changes are estimated using the CDM tool AR-Tool14 (Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities). If project activities involve harvesting, the GHG credit issued must not exceed the long-term average GHG benefit of the tree component. Projects may also consider the long-term carbon storage in wood products, especially when trees are harvested before dying.

(2) Herbaceous vegetation:

Estimated using the method of carbon stock changes, or by applying a default value of 3 tons of carbon per hectare (for areas with 100% herbaceous cover). For areas with less than full coverage, the value should be adjusted proportionally.

10.2.4 Net GHG emissions and removals from soil in project scenario

Net GHG emissions from soils in the project scenario are estimated as:

$$GHG_{WPS\text{-}soil,i,t} = A_{i,t} \times (GHG_{WPS\text{-}soil\text{-}CO2,i,t} - Deduction_{alloch} + GHG_{WPS\text{-}soil\text{-}CH4,i,t} + GHG_{WPS\text{-}soil\text{-}N2O,i,t}) \quad (21)$$

Where:

GHGWPS-soil,i,t= GHG emissions from the SOC pool in the project scenario in stratum i in year t; t CO_2e yr^{-1}

$GHG_{WPS\text{-}soil\text{-}CO2,i,t}$ = CO2 emissions from the SOC pool in the project scenario in stratum i in year t; t CO_2e ha^{-1} yr^{-1}

$Deduction_{alloch}$ = Deduction from CO_2 emissions from the SOC pool to account for the percentage of the carbon stock that is derived from allochthonous soil organic carbon; t CO_2e ha^{-1} yr^{-1}

$GHG_{WPS\text{-}soil\text{-}CH4,i,t}$ = CH4 emissions from the SOC pool in the project scenario in stratum i in year t; t CO_2e h^{a-1} yr^{-1}

$GHG_{WPS\text{-}soil\text{-}N2O,i,t}$ = N_2O emissions from the SOC pool in the project scenario in stratum i in year t; t CO_2e ha^{-1} yr^{-1}

Ai,t = Area of stratum i in year t; ha

i = 1, 2, 3 …M_{WPS} strata in the project scenario
t = 1, 2, 3, … t* years elapsed since the project start date

(1) CO_2 emissions:

These may originate from in-situ soils, eroded soils, or soils that have been exposed to aerobic conditions due to excavation. The estimation method follows the same procedures used for estimating soil CO_2 emissions in the baseline scenario (e.g., using proxy indicators, published values, default factors, models, or field-sampled data).

(2) Deduction of allochthonous SOC:

If the project area has accumulated carbon from sources outside the project boundaries (allochthonous carbon), this must be deducted—unless it can be demonstrated that such carbon would have been released as CO_2 to the atmosphere in the absence of the project.

(3) Methane (CH_4) and nitrous oxide (N_2O) emissions:

These emissions may be excluded from accounting if it can be demonstrated that CH_4 and N_2O emissions have not increased or will be reduced compared to the baseline scenario. For seagrass restoration projects, N_2O emissions do not need to be calculated.

10.2.5 Net non-CO2 emissions from prescribed burning in project scenario

If the project involves the planned burning of shrub and herbaceous biomass, emissions of methane (CH_4) and nitrous oxide (N_2O) must be calculated. This typically involves applying biomass emission factors to quantify these gases as follows:

$$GHG_{WPS\text{-}burn,i,t} = CO2eN_{2O,i,t} + CO_2e_{CH4,i,t} \quad (22)$$

$$CO_2e_{N2O,i,t} = Biomass_{i,t} \times EF_{N2O,burn} \times N_2O\text{-}GWP \times 10^{-6} \times A_{i,t} \quad (23)$$

$$CO_2eCH_{4,i,t} = Biomass_{i,t} \times EF_{CH4,burn} \times CH_4\text{-}GWP \times 10^{-6} \times A_{i,t} \quad (24)$$

Where:

$GHG_{WPS\text{-}burn,i,t}$ = GHG emissions from prescribed burning in the project scenario in stratum i in year t; t CO_2e yr^{-1}

$CO_2e_{N2O,i,t}$ = CO_2e emissions resulting from N_2O emissions due to prescribed burning in stratum i in year t; t CO_2e yr^{-1}.

$CO_2e_{CH4,i,t}$ = CO_2e emissions resulting from CH_4 emissions due to prescribed burning in stratum i in year t; t CO_2e yr^{-1}.

$Biomass_{i,t}$ = Aboveground shrub biomass in stratum i in year t (from Section 8.2.3), kg d.m. ha^{-1}

$EF_{N2O,burn}$ = Emission factor for N_2O for vegetation burning; g N_2O / kg dry biomass

$EF_{CH4,burn}$	= Emission factor for CH_4 for vegetation burning; g CH_4 / kg dry biomass
N_2O-GWP	= Global warming potential of N_2O; dimensionless
CH_4-GWP	= Global warming potential of CH_4; dimensionless
$A_{i,t}$	= Area of stratum i in year t; ha
I	= 1, 2, 3 …M_{WPS} strata in the project scenario
t	= 1, 2, 3, … t* years elapsed since the project start date

10.2.6 Emissions from fossil fuel use

If fossil fuel emissions from vehicles and machinery used in project activities—especially equipment involved in soil movement-exceed a negligible level, they must be estimated using the CDM tool AR-Tool05 (Estimation of GHG emissions related to fossil fuel combustion in A/R CDM project activities).The following equation applies:

$$GHG_{WPS\text{-}fuel,i,t} = ET_{FC,y} \quad (25)$$

Where:

$GHG_{WPS\text{-}fuel,i,t}$	= GHG emissions from fossil fuel use in the project scenario in stratum i in year t; t CO_2e yr^{-1}
$ET_{FC,y}$	= CO_2 emissions from fossil fuel combustion during the year y; t CO_2 (derived from application of CDM tool AR-Tool05 Estimation of GHG emissions related to fossil fuel combustion in A/R CDM project activities; calculations are done for each stratum i)
i	= 1, 2, 3 …M_{WPS} strata in the project scenario
t	= 1, 2, 3, … t* years elapsed since the project start date

10.3 Emission reductions due to rewetting and fire management (Fire Reduction Premium)

This methodology determines the emission reduction amount caused by reduced man-made fires in organic soils, which occur during drainage. It uses conservative assumption factors to estimate emissions based on baseline scenario data, avoiding direct assessment of fire emissions and requiring the use of the VCS module VMD0046 to estimate the Fire Reduction Project (FRP) of the project proponent for fires. For each layer of organic soil, parameters $E_{peatsoil\text{-}WPS}$ and $E_{peatsoil\text{-}BSL}$ from the $GHG_{WPS\text{-}soil}$ and $GHG_{BSLS\text{-}soil}$ modules are obtained to calculate greenhouse gas emissions in the project scenario and baseline scenario.

10.4Leakage

10.4.1 Activity-shifting leakage and market leakage

The applicability conditions of this methodology are structured to ensure that activity-shifting leakage and market leakage do not occur. Therefore, when these conditions are met, it is reasonable to assume that both forms of leakage are zero.

10.4.2 Ecological leakage

The importance of avoiding ecological leakage in project designs that meet the conditions of ecology-based methodologies. Ecological leakage refers to increased greenhouse gas emissions in neighboring areas caused by changes in hydrological connectivity. Ideally, project designs should not significantly alter groundwater levels or flood frequency and duration in adjacent regions. If such impacts are expected, the affected zones must be included in the project scope.

To ensure compliance, experts may rely on professional judgment, hydrologic modeling, and monitoring of water level variations. In tidal wetland restoration, downstream de-watering can be avoided if the project area encompasses zones affected by hydrological changes. Hydrologic models should account for water displacement and the influence on wetland boundaries and inlet connectivity. Additionally, tidal range and sediment supply to external wetlands must remain within system tolerance, as determined by tidal cycles and regional sediment budgets, using modeling and expert evaluation.

Table 3 presents avoidance criteria for various processes that may occur outside the project area due to an inappropriate design.

Table 3 Processes Associated with Ecological Leakage Outside Project Boundary and Related Criteria for their Avoidance

Ecological leakage process outside project boundary	Avoidance criterion
Lowering water table that causes increased soil carbon oxidation	Maintain wetland conditions (e.g., converting from impounded water to a wetland does not cause soil oxidation)
Lowering water table that causes increased N_2O emissions	No conversion of non-seagrass wetland to open water
Raising water table that causes increased CH_4 emissions	No conversion of non-wetland to wetland
Raising water table that causes decreased vegetation production that causes decreased new soil carbon sequestration	No causation of vegetated to non-vegetated (or poorly vegetated) conditions

10.5 Net GHG Emission Reductions and Removals

10.5.1 Calculation of net GHG emissions reductions

The total net GHG emission reductions from the RWE or ARR/RWE project activity are calculated as follows:

$$NER_{RWE} = GHG_{BSL} - GHG_{WPS} + FRP - GHG_{LK} \quad (26)$$

Where:

NER_{RWE}[31] = Net CO_2e emission reductions from the RWE project activity; t CO_2e
GHG_{BSL} = Net CO_2e emissions in the baseline scenario; t CO_2e
GHG_{WPS} = Net CO_2e emissions in the project scenario; t CO_2e
FRP = *Fire Reduction Premium* (net CO_2e emission reductions from organic soil combustion due to rewetting and fire management); t CO_2e
GHG_{LK} = Net CO_2e emissions due to leakage; t CO_2e

For projects asserting reductions in baseline GHE emissions or for conservation and restoration projects where sea level rise might lead to a loss of tidal wetland and associated biomass and/or soil organic carbon stocks, the maximum amount of GHE emission reductions or removals that can be claimed from the biomass and soil organic carbon pool is limited to the net GHB benefit generated by the project 100 years after its commencement date, as follows:

$$NER_{RWE\text{-}max} = NER_{RWE} \text{ at } t = 100 \qquad (27)$$

Where:
$NER_{RWE\text{-}max}$ = Maximum net CO_2e emission reductions or removals that can be claimed from the RWE project activity at any point in time during the crediting period; t CO_2e
NER_{RWE} = Net CO_2e emission reductions from the RWE project activity (from Equation 26); t CO_2e

10.5.2 Estimation of uncertainty

(1) Uncertainty assessment aims to quantify the uncertainty in estimating greenhouse gas (GHG) emission reduction and removal projections for project carbon credits' credibility and accuracy.

- Purpose and scope: to calculate the precision level of a project and impose penalties on carbon credits if necessary after project implementation and monitoring due to insufficient precision, with a focus on the sources of uncertainty in baseline (base case) and project (scenario) estimates.
- Sources of uncertainty: the primary source of uncertainty arises from the estimation of carbon sinks and their changes, as well as the assessment of project emissions. Other factors causing uncertainty include project area or other activity data, carbon sinks, biomass growth rates, expansion coefficients, and other coefficients. These uncertainty information can be obtained from sources such as IPCC Guidelines (2006), IPCC GPG-LULUCF (2003), expert judgment, or based on comprehensive statistical sampling estimates. If the uncertainty value cannot be obtained or calculated, the project proponent may conservatively assume that the specific component's uncertainty is 0%.
- Uncertainty targets and penalty mechanism: the methodology sets precision targets that should have a 90% confidence interval equal to or less than 20% of the observed value, or a 95% confidence interval equal to or less than 30% of the observed value. If a project meets these precision targets, no penalties will be imposed for uncertainty. If the precision

exceeds the tolerable range, then a penalty will be imposed on the portion of the uncertainty that exceeds the tolerable level.

- Strategies to reduce uncertainty: project planning should clearly show consideration of uncertainty and include measures to minimize it. For example, stratified and sufficient sampling designs are crucial for ensuring low uncertainty in carbon sink estimates, which can ultimately lead to full certification.

(2) 3 Parts below the denominators of the equations must be expressed in absolute values.

(a) Part 1 – Uncertainty in baseline estimates

$$\text{Uncertain}_{\text{BSL,i}} = \frac{\sqrt{(U_{\text{BSL,SS1,i}} \times E_{\text{BSL,SS1,i}})^2 + (U_{\text{BSL,SS2,i}} \times E_{\text{BSL,SS2,i}})^2 \ldots + \cdots (U_{\text{BSL,SSn,i}} \times E_{\text{BSL,SSn,i}})^2}}{E_{\text{BSL,SS1,i}} + E_{\text{BSL,SS2,i}} \ldots + \cdots E_{\text{BSL,SSn,i}}} \quad (28)$$

Where:

$\text{Uncertain}_{\text{BSL,I}}$ = Percentage uncertainty in the combined carbon stocks and GHG sources in the baseline scenario in stratum i; %

$U_{\text{BSL,SS,I}}$ = Percentage uncertainty (expressed as 90% confidence interval as a percentage of the mean, where appropriate) for carbon stocks and GHG sources in the baseline scenario in stratum i (1,2…n represent different carbon pools and/or GHG sources); %

$E_{\text{BSL,SS,I}}$ = Carbon stock or GHG sources (e.g., trees, down dead wood) in stratum i (1,2…n represent different carbon pools and/or GHG sources) in the baseline scenario; t CO_2e

I = 1, 2, 3 …M_{BSL} strata in the baseline scenario

To assess uncertainty across combined strata, use the equation below:

$$\text{Uncertain}_{\text{BSL}} = \frac{\sqrt{(U_{BSL,2} \times A1)^2 + (U_{\text{BSL},2} \times A2)^2 \ldots + \cdots (U_{\text{BSL},M_{BSL}} \times A_{M_{BSL}})^2}}{A1 + A2 \ldots + \ldots A_{M_{BSL}}} \quad (29)$$

Where:

$\text{Uncertain}_{\text{BSL}}$ = Total uncertainty in baseline scenario; %

$U_{\text{BSL,I}}$ = Uncertainty in baseline scenario in stratum i; %

Ai = Area of stratum i; ha

i = 1, 2, 3 …M_{BSL} strata in the baseline scenario

(b) Part 2 – Uncertainty ex-post in the project scenario

$$\text{Uncertain}_{WPS,\text{i}} = \frac{\sqrt{\left(U_{WOS,\text{SS1,i}} \times E_{WPS,\text{SS1,i}}\right)^2 + \left(U_{WPS,\text{SS2,i}} \times E_{WPS,\text{SS2,i}}\right)^2 \ldots + \cdots \left(U_{WPS,\text{SSn,i}} \times E_{WPS,\text{SSn,i}}\right)^2}}{E_{WPS,\text{SS1,i}} + E_{WPS,\text{SS2,i}} \ldots + \cdots E_{WPS,\text{SSn,i}}} \quad (30)$$

Where:

$\text{Uncertain}_{WPS,i}$ = Percentage uncertainty in the combined carbon stocks and GHG sources in the project scenario in stratum i; %

$U_{WPS,SS,i}$ = Percentage uncertainty (expressed as 90% confidence interval as a percentage of the mean, where appropriate) for carbon stocks and GHG sources in the project scenario in stratum i (1,2…n represent different carbon pools and/or GHG sources); %

$E_{WPS,SS,i}$ = Carbon stock or GHG sources (e.g., trees, down dead wood, etc.) in stratum i (1,2…n represent different carbon pools and/or GHG sources) in the project scenario; t CO_2e

i = 1, 2, 3 …M_{WPS} strata in the project scenario

To assess uncertainty across combined strata, use the equation below:

$$\text{Uncertain}_{WPS} = \frac{\sqrt{\left(U_{WPS,2} \times A1\right)^2 + \left(U_{\text{WPS},2} \times A2\right)^2 \ldots + \cdots \left(U_{WPS,M_{WPS}} \times A_{M_{WPS}}\right)^2}}{A1 + A2 \ldots + \ldots A_{M_{WPS}}} \quad (31)$$

Where:

Uncertain_{WPS} = Total uncertainty in project scenario; %

$U_{WPS,I}$ = Uncertainty in project scenario in stratum i; %

Ai = Area of stratum i; ha

I = 1, 2, 3 …M_{WPS} strata in the project scenario

(c) Part 3 – Total error in project activity

$$NER_{\text{ERROR}} = \frac{\sqrt{\left(\text{Uncertain}_{BSL} \times GHG_{BSL}\right)^2 + \left(\text{Uncertain}_{WPS} \times GHG_{WPS}\right)^2}}{GHG_{BSL} + GHG_{WPS}} \quad (32)$$

Where:

NER_{ERROR} = Total uncertainty for project activity; %

Uncertain_{BSL} = Total uncertainty in baseline scenario; %

Uncertain_{WPS} = Total uncertainty in the project scenario; %

GHG_{BSL} = Net CO_2e emissions in the baseline scenario up to year t*; t CO_2e

GHG_{WPS} = Net CO_2e emissions in the project scenario up to year t*; t CO_2e

10.5.3 Calculation of carbon credits

The greater the change in carbon stocks, the more buffer credits may need to be deposited. This acts as a risk management mechanism to safeguard the permanence of emission reductions.

However, the percentage of buffer credits to be contributed to the AFOLU pooled buffer account must be determined using the latest version of the VCS AFOLU Non-Permanence Risk Tool.

The number of verified carbon units (VCUs) is calculated as:

$$VCU_{t2} = (adjusted_{NER\,t2} - adjusted_NER_{t1}) \times Bufferw_{t2} \quad (17)$$

Where:

VCU_{t2} = Number of VCUs in year t2

$adjusted_NER_{t1}$ = Total net GHG emission reductions from the project activity up to year t1 adjusted to account for uncertainty; t CO_2e

$adjusted_NER_{t2}$ = Total net GHG emission reductions from the project activity up to year t2 adjusted to account for uncertainty; t CO_2e

$Bufferw_{t2}$ = Number of buffer credits to be contributed to the AFOLU pooled buffer account in year t2

$$Buffer_{t2} = (NER_{stock,t2} - NER_{stock,t1}) \times Buffer\%_{t2} \quad (18)$$

Where:

$Bufferw_{t2}$ = Number of buffer credits to be contributed to the AFOLU pooled buffer account in year t2

$NER_{stock,\,t1}$ = Net GHG emission reductions from the project activity up to year t1, discarding non-CO_2 emissions from soil and biomass burning and emissions from fossil fuel use; t CO_2e

$NER_{stock,\,t2}$ = Net GHG emission reductions from the project activity up to year t2, discarding non-CO_2 emissions from soil and biomass burning and emissions from fossil fuel use; t CO2e

$Buffer\%_{t2}$ = Percentage of buffer credits to be contributed to the AFOLU pooled buffer account in year t2; %

10.6 Cost Efficiency Analysis

To assure the sustainability of emission reduction and removal quantity outcomes derived from project activities, the project developer will undertake an in-depth, project-specific non-reversal risk assessment to guarantee their continuity. This approach surpasses standard buffer pool contribution calculations by identifying and proactively mitigating crucial threats that could lead to carbon sink reversal.

Risk Categories and Mitigation

The project explicitly identifies four categories of non-reversal risk and details the corresponding management strategies:

1. Financial and Management Risk:

   This category addresses threats related to the long-term viability of the project and its management structure, including financial instability of the implementing organization, disputes over land tenure, or insufficient funding for continuous monitoring. To mitigate these risks, the project will secure land agreements by signing at least 20-year conservation easements or long-term contracts that legally restrict destructive land use. Furthermore, robust financial planning will establish a dedicated long-term monitoring and management reserve fund to ensure continuous financial support for project maintenance.

2. Natural Risk:

   These risks are associated with unpredictable or severe natural phenomena, such as extreme climate events (e.g., severe typhoons, heatwaves) leading to mass loss of carbon stocks, or accelerated sea-level rise causing permanent habitat inundation. Mitigation focuses on resilience: site selection will prioritize restoration areas with high resilience to climate change impacts. Engineering design will employ climate-smart restoration techniques, including incorporating accommodation space to allow for wetland migration and utilizing Nature-Based Solutions (NBS) for coastal protection.

3. Environmental Risk:

   This includes direct ecological threats to the restored habitats, such as outbreaks of invasive species, water quality pollution exceeding critical limits leading to vegetation mortality, or new diseases. The project will implement an adaptive management approach, establishing a regular and high-frequency monitoring program focused on key environmental indicators. A rapid response mechanism will be put in place to initiate immediate intervention measures (e.g., physical removal, hydrological adjustment) if monitoring data breaches established ecological thresholds.

4. Societal and Political Risk:

   These risks arise from external human factors, including disputes from local communities over resource use restrictions or abrupt, major policy or regulatory changes that could lead to the forced cessation of conservation activities. Mitigation relies heavily on sustained engagement: stakeholder engagement will be maintained through formal agreements and periodic consultation to ensure continuous support from local and indigenous communities. Additionally, policy tracking will provide an early warning system to anticipate and respond to potential shifts in the political landscape.

10.7 Documentation of Project Cost-Effectiveness and Efficiency

To align with the quantification of greenhouse gas emission reduction and removal, cost-benefit estimation, and operational efficiency while ensuring measures that demonstrate responsible allocation of resources and maximize climatic benefits per unit investment.

1. Estimated Cost per tCO_2e:

   The projected average cost per tonne of CO2 equivalent (tCO_2e) for the project is estimated to fall within the range of [$X to $Y per tCO_2e]. This figure is calculated by dividing the comprehensive project budget, which includes all phases from initial planning and restoration activities to long-term monitoring and management, by the total expected net GHG emission reductions and removals over the crediting period.

   This cost metric serves as a crucial indicator of the project's financial efficiency in delivering climate benefits. It will be regularly compared with industry benchmarks for blue carbon projects to ensure competitiveness and value.

2. Efficiency Measures and Optimization Strategies:

   This project emphasizes operational efficiency and implements several strategies to optimize resource allocation:

   - Optimization of Restoration Techniques:

     By selecting methods based on ecological effectiveness and cost-benefit analysis, with a priority for natural regeneration and minimum intervention when appropriate, labor and material costs can be reduced.

   - Integration of Monitoring Technology:

     Combining advanced remote sensing (satellite and unmanned aerial vehicle mapping) technology with ground truth survey marking significantly reduces the need for excessive on-site inspections, while maintaining high data quality and lowering monitoring expenses.

   - Community-Based Operations Management:

     Encouraging local community involvement in restoration and continuous operation management not only strengthens social benefits but also helps lower costs through the contribution of local professional knowledge and volunteer power.

   - Diversification of Strategic Funding:

     Actively seeking various funding sources to achieve financial support diversification, reduce dependence on carbon credit sales, and enhance long-term financial stability for the project.

11 MONITORING

11.1 Data and Parameters Available at Validation

Data / Parameter	$Depth_{peat,i,t0}$
Data unit	m
Description	Average organic soil depth above the drainage limit in stratum i at the project start date; m
Equations	1, 8, 9
Source of data	Existing peat depth maps and/or field assessment and/or in combination with remote sensing data. Literature involving the project area or similar areas.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Organic soil depths at the project start date may be derived from: Existing peat depth maps Surface height measurements relative to a fixed reference point in m a.s.l. (e.g., using poles fixed in the underlying mineral soil or rock) within the project area; where relevant in combination with gauge measurement of the water table to determine the drainage limit For the purpose of determining the PDT, where relevant, peat depth may be determined as the depth of the peat layer down to a level where no further oxidation or other losses occur (e.g., the average water table depth).
Purpose of data	Calculation of baseline emissions Calculation of the maximum quantity of GHG emission reductions that may be claimed by the project
Comments	Reassessed when baseline is reassessed In the absence of peer-reviewed data sources, the project proponent must justify that the data used are representative and that standard methods have been used.

Data / Parameter	$Rate_{peatloss\text{-}BSL,i}$
Data unit	m yr^{-1}
Description	Rate of organic soil loss due to subsidence and fire in the baseline scenario in stratum *i*; a conservative (high) value must be applied that remains constant over the time from $t = 0$ to PDT
Equations	1, 8, 14

Source of data	The rate of organic soil loss due to subsidence must be based on verifiable information and may be derived from: 1) Expert judgment, datasets and/or literature of historic subsidence involving the project or similar areas. Data must be based on surface height measurements relative to a fixed reference point in m asl, following methods described in Ballhorn et al. 2009 (e.g., using poles fixed in the underlying mineral soil or rock, or by remote sensing) or similar. Or 2) CO_2 emissions derived from GHG emission proxies (see Section 8.1.4.2.1 above) in combination with data on volumetric carbon content of the organic soil. Divide the annual CO_2 emission (t CO_2 ha^{-1}) by 44/12, then divide by volumetric carbon content (g C cm^{-3}) to obtain height loss in m. The average depth of burn scars may be derived from expert judgment, datasets and/or literature of historic burn depths involving the project or similar areas. Data must be based on surface height measurements, using field measurements or remote sensing (e.g., following methods described in Ballhorn et al. 2009). The areal extent of burn scars may be obtained from statistics and/or maps in official reports and/or field measurements or remote sensing data. For organic soil loss due to fire, based on the areal extent of burnt and non-burnt areas, a mean annualized burn depth must be calculated and applied to the entire project area. The project proponent must demonstrate, using expert judgment, datasets and/or scientific literature that the accuracy of the derived rate of organic soil loss is sufficient to fulfill the criteria in Section 5.2.2 (Stratification). Similarity of areas must be demonstrated (via direct measurements, literature resources, datasets or a combination of these) with respect to organic soil type, climatic conditions, land use (forestry, agriculture, peat extraction, or abandonment after these activities), and average annual water table depth (±20%). In case of dissimilarity, the project proponent must demonstrate that such difference gives a conservative result for the net GHG benefits of the project. Forecasting organic soil subsidence rates must be based on the conservative extrapolation of a historic trend, or conservative modeling of proxies such as water table depth and land use type.
Value applied	N/A
Justification of choice of data or description of measurement	See Source of data above

methods and procedures applied	
Purpose of data	Calculation of baseline emissions Calculation of the maximum quantity of GHG emission reductions that may be claimed by the project
Comments	In the absence of an accurate value for the determination of PDT, a conservative (high) value may be applied, while for the determination of the maximum quantity of GHG emission reductions which may be claimed from the soil carbon pool, a conservative (low) value may be applied that remains constant over time. The use of a relatively low value for a constant rate of organic soil loss may not be confused with a relatively high value when determining the need for stratification of organic soil depth. Reassessed when baseline is reassessed

Data / Parameter	$Rate_{peatloss\text{-}WPS,i,t}$
Data unit	m yr^{-1}
Description	Rate of organic soil loss due to subsidence in the project scenario in stratum i in year t
Equations	9
Source of data	The rate of organic soil loss due to subsidence must be based on verifiable information and may be derived from: 1) Expert judgment, datasets and/or literature of subsidence involving areas representing conditions similar to the project. Data must be based on surface height measurements relative to a fixed reference point in m asl, following methods described in Ballhorn et al. 2009 (e.g., using poles fixed in the underlying mineral soil or rock, or by remote sensing or similar). Or 2) CO_2 emissions derived from GHG emission proxies, see Section 8.1.4.2.1 above, in combination with data on volumetric carbon content of the organic soil. Divide the annual CO_2 emission (t CO_2 ha^{-1}) by 44/12, then divide by volumetric carbon content (g C cm^{-3}) to obtain height loss in m. The project proponent must demonstrate, using expert judgment, datasets and/or scientific literature that the accuracy of the derived rate of organic soil loss is sufficient to fulfill the criteria in Section 5.2.2 (Stratification). Similarity of areas must be demonstrated (by direct measurements, literature resources, datasets or a combination of these) with respect

	to organic soil type, climatic conditions, land use (forestry, agriculture, peat extraction, or abandonment after these activities), and average annual water table depth (±20%). In case of dissimilarity, the project proponent must demonstrate that such difference gives a conservative result for the net GHG benefits of the project.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	See Source of data above
Purpose of Data	Calculation of project emissions • Calculation of the maximum quantity of GHG emission reductions that may be claimed by the project
Comments	N/A

Data / Parameter	$Rate_{Closs\text{-}BSL,i,t}$
Data unit	t C ha^{-1} yr^{-1}
Description	Rate of organic carbon loss in mineral soil due to oxidation in the baseline scenario in stratum i in year t Rate of soil organic carbon loss due to oxidation in the baseline scenario in stratum i; a conservative (high) value must be applied that remains constant over the time from t = 0 to SDT
Equations	1, 1.0, 16
Source of data	May be estimated using published values (see Sections 8.1.4.1 and 8.1.4.2.2) or either historical data collected from the project site or chronosequence data collected at similar sites (see Sections 8.1.4.1 and 8.1.4.2.6). Alternatively, a conservative (low) value may be applied that remains constant over time.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Extrapolation of $Rate_{Closs\text{-}BSL,i}$ over the entire project crediting period for the quantification of the SDT must account for the possibility of a non-linear decrease of soil organic carbon over time, including the tendency of organic carbon concentrations to approach steady-state equilibrium (see Section Error! Reference source not found.). For this reason, a complete loss of soil organic carbon may not occur in mineral soils. This steady-state equilibrium must be determined conservatively.

Purpose of Data	Calculation of baseline emissions Calculation of the maximum quantity of GHG emission reductions that may be claimed by the project
Comments	In the absence of an accurate value for the determination of the SDT, a conservative (high) value may be applied, while for the determination of the maximum quantity of GHG emission reductions which may be claimed from the soil carbon pool, a conservative (low) value may be applied that remains constant over time. Reassessed when baseline is reassessed

Data / Parameter	$Rate_{Closs\text{-}WPS,i,t}$
Data unit	t C ha^{-1} yr^{-1}
Description	Rate of organic carbon loss in mineral soil due to oxidation in the project scenario in stratum i in year t
Equations	17
Source of data	N/A
Value applied	0
Justification of choice of data or description of measurement methods and procedures applied	This value is conservatively set to zero as loss rates are likely to be negative. The value must be reassessed when the baseline is reassessed. If at that event there is evidence that SOC has decreased, the calculation must be adjusted using the carbon loss rate to date, unless it can be justified that the carbon loss was temporary.
Purpose of Data	Calculation of project emissions Calculation of the maximum quantity of GHG emission reductions that may be claimed by the project
Comments	Reassessed when baseline is reassessed

Data / Parameter	$\Delta C_{TREE_BSL,t}$
Data unit	t CO_2-e yr^{-1}
Description	Change in carbon stock in baseline tree biomass within the project area in year t
Equations	24
Source of data	Derived from application of AR-Tool14

Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	N/A
Purpose of Data	Calculation of baseline emissions
Comments	Calculations are done for each stratum i Reassessed when baseline is reassessed

Data / Parameter	$Rate_{subs\text{-}BSL,i}$
Data unit	m yr^{-1}
Description	Rate of organic soil loss due to subsidence in the baseline scenario in stratum i
Equations	32
Source of data	The rate of organic soil loss due to subsidence must be based on verifiable information and may be derived from: 1) Expert judgment, datasets and/or literature of historic subsidence involving the project or similar areas. Data must be based on surface height measurements relative to a fixed reference point in m asl, following methods described in Ballhorn et al. 2009 (e.g., using poles fixed in the underlying mineral soil or rock, or by remote sensing) or similar. Or 2) CO_2 emissions derived from GHG emission proxies, see Section 8.1.4.2.1 above, in combination with data on volumetric carbon content of the organic soil. Divide the annual CO_2 emission (t CO_2 ha^{-1}) by 44/12, then divide by volumetric carbon content (g C cm^{-3}) to obtain height loss in m. The average depth of burn scars may be derived from expert judgment, datasets and/or literature of historic burn depths involving the project or similar areas. Data must be based on surface height measurements, using field measurements or remote sensing (e.g., following methods described in Ballhorn et al. 2009). The areal extent of burn scars may be obtained from statistics and/or maps in official reports and/or field measurements or remote sensing data. The project proponent must demonstrate, using expert judgment, datasets and/or scientific literature that the accuracy of the derived rate of organic soil loss is sufficient to fulfill the criteria in Section 5.2.2 (Stratification).

	Similarity of areas must be demonstrated (via direct measurements, literature resources, datasets or a combination of these) with respect to organic soil type, climatic conditions, land use (forestry, agriculture, peat extraction, or abandonment after these activities), and average annual water table depth (±20%). In case of dissimilarity, the project proponent must demonstrate that such difference gives a conservative result for the net GHG benefits of the project. Forecasting organic soil subsidence rates must be based on the conservative extrapolation of a historic trend, or conservative modeling of proxies such as water table depth and land use type.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	See Source of data above and Couwenberg & Hooijer (2013).
Purpose of Data	Calculation of baseline emissions
Comments	In the absence of an accurate value, for the determination of subsidence a conservative (low) value may be applied. Reassessed when baseline is reassessed

Data / Parameter	$C_{BSL\text{-}soil,i,t}$
Data unit	t C ha^{-1}
Description	Soil organic carbon stock in the baseline scenario in stratum i in year t
Equations	28, 29, (36)
Source of data	Estimated using methods described in Section 8.1.4.1 Soil coring may be used to generate a value of $C_{BSL\text{-}soil,i,t}$ as specified in Section 9.3.7
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	For the baseline scenario, soil cores must be collected within 2 years prior to the project start date. Where using an installed reference plane for the baseline scenario, it must have been installed at least 4 years prior to the baseline measurement, which is good practice to ensure that a reliable average accumulation rate is obtained.
Purpose of Data	Calculation of baseline emissions
Comments	Reassessed when baseline is reassessed

Data / Parameter	$Depth_{soil,i,t0}$
Data unit	m
Description	Mineral soil depth in stratum i at the project start date
Equations	12
Source of data	Direct measurements and/or literature involving the project area or similar areas
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Mineral soil depths at the project start date may be derived from direct measurements within the project area or literature involving the project area or similar areas
Purpose of Data	Calculation of baseline emissions Calculation of the maximum quantity of GHG emission reductions that may be claimed by the project
Comments	In the absence of peer-reviewed data sources, the project proponent must justify that the data used are representative and that standard methods have been used.

Data / Parameter	VC
Data unit	kg C m^{-3}
Description	Volumetric organic carbon content of organic or mineral soil
Equations	6, 7 12, 14 – 17, 32
Source of data	Direct measurements and/or literature involving the project area or similar areas
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Determined through procedures specified in Section 9.3.7
Purpose of Data	Calculation of baseline emissions Calculation of project emissions • Calculation of the maximum quantity of GHG emission reductions that may be claimed by the project
Comments	

Data / Parameter	$A_{BSL,i}$ (or $A_{i,t}$)
Data unit	ha
Description	Area of baseline stratum i (in year t)
Equations	4,13, 26, (79), 82, 83

Source of data	Delineation of strata is done preferably using a Geographical Information System (GIS), which allows for integrating data from different sources (including GPS coordinates and remote sensing data). Applied techniques must follow international standards of application or local standards as laid out in pertinent scientific literature or handbooks.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	See Source of data above
Purpose of Data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	$C_{BSL\text{-}herb,i,t}$
Data unit	t C ha^{-1}
Description	Carbon stock in herbaceous vegetation in the baseline scenario in stratum i in year t
Equations	25
Source of data	Direct measurements or default factor
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	A default factor[32] of 3 t C ha^{-1} may be applied for strata with 100% herbaceous cover. For areas with a vegetation cover <100%, a 1:1 relationship between vegetation cover and $C_{BSL,\text{-}herb,i,t}$ must be applied. The default may be claimed for one year only during the project crediting period as herbaceous biomass quickly reaches a steady state. Vegetation cover must be determined by commonly used techniques in field biology. Procedures for measuring carbons stocks in herbaceous vegetation are provided in Section 9.3.6 above.
Purpose of Data	Calculation of baseline emissions
Comments	Reassessed when baseline is reassessed

Data / Parameter	$GHG_{BSL\text{-}insitu\text{-}CO2,i,t}$
Data unit	t CO_2e ha^{-1} yr^{-1}
Description	CO_2 emissions from the SOC pool of in-situ soils in the baseline scenario in stratum i in year t
Equations	27, 28, 34, (37), 38

Source of data	Estimated using methods described in Section 8.1.4.2
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Calculation of baseline emissions
Purpose of Data	N/A
Comments	N/A

Data / Parameter	$C\%_{BSL\text{-}emitted,i,t}$
Data unit	%
Description	Organic carbon loss due to oxidation, as a percentage of C mass present in in-situ soil material in the baseline scenario in stratum i in year t (Section 8.1.4.2) Organic carbon loss due to oxidation, as a percentage of C mass present in eroded soil material in the baseline scenario in stratum i in year t (Section 8.1.4.3) Organic carbon loss due to oxidation, as a percentage of C mass present in excavated soil material in the baseline scenario in stratum i in year t (Section 8.1.4.4)
Equations	28, (48), (51)- (57)
Source of data	Estimated using methods described in Sections 8.1.4.2, 8.1.4.3 and 8.1.4.4
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	The default factors provided in Section 8.1.4.3.3 are the mean values for the specified CPDE, published in Figure 9 of Blair and Aller (2012).
Purpose of Data	Calculation of baseline emissions
Comments	$C\%_{BSL\text{-}emitted,i,t}$ and $Rate_{Closs\text{-}BSL,i,t}$ in Section 5.2.4 are different parameters with different units but relating to the same process of soil organic carbon loss.

Data / Parameter	$C\%_{BSL\text{-}soil,i,t}$
Data unit	%
Description	Percentage of carbon of in-situ soil material in stratum i in year t
Equations	29, 34
Source of data	Estimated using methods described in Sections 8.1.4.2, 8.1.4.3 and 8.1.4.4
Value applied	N/A

Justification of choice of data or description of measurement methods and procedures applied	N/A
Purpose of Data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	Depth_$i_{BSL,i,t}$
Data unit	m
Description	Depth of in-situ exposed soil in the baseline scenario in stratum i in year t
Equations	29
Source of data	Estimated using commonly accepted procedures by the scientific community and taking note of requirements in Section 8.1.4.2
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	See Source of data above
Purpose of Data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	Crown cover, vegetation cover
Data unit	%
Description	Proportion of an area covered by the herbaceous vegetation, shrubs, and/or the crowns of live trees
Equations	N/A
Source of data	For the baseline scenario, crown or vegetation covers must be based on a time series of vegetation composition.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	See Source of data above
Purpose of Data	Calculation of baseline emissions
Comments	Relevant for the application of the default factor in Section 8.1.4.2

Data / Parameter	%OM (or $\%OM_{soil}$)

Data unit	%
Description	Percentage of soil that is organic matter
Equations	41, (43), 45, 94 - 97
Source of data	Direct measurements based on loss-on-ignition or may be derived from direct measurements of soil carbon. These measurements may be made using samples collected in Section 9.3.7 or indirectly from the soil carbon percentage as described in Section 8.1.4.2.7.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Direct measurements based on loss-on-ignition or may be derived from direct measurements of soil carbon. These measurements may be made using samples collected in Section 9.3.7 or indirectly from the soil carbon percentage as described in Section 8.1.4.2.7.
Purpose of Data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	$\%C_{soil}$
Data unit	%
Description	Percentage of soil organic C
Equations	(39), (43), 45
Source of data	Direct measurements or may be derived from direct measurements of soil organic matter. These measurements may be made using samples collected in Section 9.3.7 or indirectly
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	See Source of data above
Purpose of Data	Calculation of baseline emissions Calculation of project emissions
Comments	N/A

Data / Parameter	BD
Data unit	kg m^{-3}
Description	Dry bulk density

Equations	29, (49),
Source of data	Direct measurements, or from a relationship with organic carbon content provided by the scientific literature.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Mass of soil material after drying per volume of soil material, based on commonly accepted procedures by the scientific community.
Purpose of Data	Calculation of baseline emissions Calculation of project emissions
Comments	N/A

Data / Parameter	$\%OM_{depsed}$
Data unit	%
Description	Percentage of deposited sediment that is organic matter
Equations	(40), 44, (46)
Source of data	May be estimated directly using loss-on-ignition (LOI) data, indirectly from soil carbon percentage as described in Section 8.1.4.2.7, or from the default value provided in Section 8.1.4.2.7. These measurements may be made using samples collected on sediment tiles or through collection and carbon analysis (see Section 9.3.7) of suspended sediments in tidal channels or sediments deposits in tidal flats.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	LOI may be assessed using standard laboratory procedures
Purpose of Data	Calculation of baseline emissions Calculation of project emissions
Comments	N/A

Data / Parameter	$\%C_{depsed}$
Data unit	%
Description	Percentage of deposited sediment that is organic C; %

Equations	44, (46), (47)
Source of data	May be estimated directly using loss-on-ignition (LOI) data or indirectly from soil carbon percentage as described in Section 8.1.4.2.7. These measurements may be made using samples collected on sediment tiles or through collection and carbon analysis (see Section 9.3.7) of suspended sediments in tidal channels or sediments deposits in tidal flats.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	The default factor is derived from the maximum value (conservative) provided by Mayer 1994 Figure 4
Purpose of Data	Calculation of baseline emissions Calculation of project emissions
Comments	N/A

Data / Parameter	SA
Data unit	m_2g^{-1}
Description	Average Surface Area of the sediment
Equations	(47)
Source of data	Laboratory procedures described in Mayer 1994
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	N/A
Purpose of Data	Calculation of baseline emissions Calculation of project emissions
Comments	N/A

Data / Parameter	$GHG_{BSL\text{-}eroded\text{-}CO2,i,t}$
Data unit	t CO_2e ha^{-1} yr^{-1}

Description	CO2 emissions from the eroded SOC pool in the baseline scenario in stratum i in year t
Equations	27, (48), (50)
Source of data	Estimated using methods described in Section 8.1.4.3
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	N/A
Purpose of Data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	$C_{BSL\text{-}eroded,i,t}$
Data unit	t C ha^{-1} yr^{-1}
Description	C mass present in eroded soil material in the baseline scenario in stratum i in year t
Equations	(48), (49)
Source of data	Estimated using methods described in Section 8.1.4.3
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	N/A
Purpose of Data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	$C\%_{BSL\text{-}eroded,i,t}$
Data unit	%
Description	Percentage of carbon of soil material eroded in the baseline scenario
Equations	(49)
Source of data	Estimated using methods described in Section 8.1.4.3
Value applied	N/A

Justification of choice of data or description of measurement methods and procedures applied	N/A
Purpose of Data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	Depth_$e_{BSL,i,t}$
Data unit	m
Description	Depth of the eroded area from the surface to the surface prior to erosion in the baseline scenario in stratum i in year t
Equations	(49)
Source of data	Estimated using methods described in Section 8.1.4.3
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	See Source of data above
Purpose of Data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	$GHG_{BSL\text{-}excav\text{-}CO2,i,t}$
Data unit	t CO_2e ha^{-1} yr^{-1}
Description	CO2 emissions from the SOC pool of tidal wetland soil exposed to an aerobic environment in the baseline scenario in stratum i in year t
Equations	27, (56),(58)
Source of data	Estimated using methods described in Section 8.1.4.4
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	N/A
Purpose of Data	Calculation of baseline emissions

Comments	N/A

Data / Parameter	$C_{BSL\text{-}excav,i,t}$
Data unit	t C ha^{-1} yr^{-1}
Description	Soil organic carbon stock in tidal wetland soil exposed to an aerobic environment through excavation in the baseline scenario in stratum i in year t
Equations	(56),(57)
Source of data	Estimated using methods described in Section 8.1.4.4
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	/A
Purpose of Data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	$C\%_{BSL\text{-}excav,i,t}$
Data unit	%
Description	Percentage of carbon of soil material excavated in the baseline scenario
Equations	(57)
Source of data	Estimated using methods described in Section 8.1.4.4
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	N/A
Purpose of Data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	$Depth_ex_{BSL,i,t}$
Data unit	m
Description	Depth of piled-up soil material due to excavation in the baseline scenario in stratum i in year t
Equations	(57)
Source of data	Estimated using methods described in Section 8.1.4.4
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	See Source of data above
Purpose of Data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	$EF_{N2O,burn}$
Data unit	g N_2O / kg dry biomass
Description	Emission factor for N_2O emissions from vegetation burning
Equations	82
Source of data	The project proponent may use factors that have been determined for grassland vegetation. A suitable EF_{N2O} value is 0.21, from Table 2.5 of the 2006 IPCC Guidelines for National Greenhouse Inventories.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Nitrous oxide emission factors for the combustion of herbaceous wetland vegetation are not currently available in scientific literature. However, these emissions are expected to be similar to those for grassland vegetation.
Purpose of Data	Calculation of project emissions
Comments	N/A

Data / Parameter	$EF_{CH4,burn}$
Data unit	g CH_4 / kg dry biomass
Description	Emission factor for CH_4 emissions from vegetation burning

Equations	83
Source of data	The project proponent may use factors that have been determined for grassland vegetation. A suitable EF_{CH4} value is 2.3, from Table 2.5 of the 2006 IPCC Guidelines for National Greenhouse Inventories.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Methane emission factors for the combustion of herbaceous wetland vegetation are not currently available in scientific literature. However, these emissions are expected to be similar to those for grassland vegetation.
Purpose of Data	Calculation of project emissions
Comments	N/A

Data / Parameter	allowable_uncert
Data unit	%
Description	Allowable uncertainty; 20% or 30% at a 90% or 95% confidence level, respectively
Equations	(93)
Source of data	N/A
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	N/A
Purpose of Data	Calculation of net GHG emissions reductions
Comments	N/A

Data / Parameter	$V_{ex,ty,i,t}$
Data unit	m^3
Description	Volume of timber extracted from within stratum i (does not include slash left onsite) by species j and wood product class ty in year t
Equations	103
Source of data	Data representing common practice in harvesting
Value applied	N/A

Justification of choice of data or description of measurement methods and procedures applied	This volume does not include logging slash left onsite. The project proponent should also make sure that extracted volumes are gross volumes removed (i.e., not already discounting for estimated wood waste). Assignment of volume extracted to wood product class(es), must be substantiated on the basis of participatory rural appraisal (PRA) findings or records of timber sales. Assignment of volume extracted to species, must be substantiated on the basis of either PRA findings, harvest records, or a commercial inventory.
Purpose of Data	Calculation of project emissions
Comments	N/A

Data / Parameter	D_j
Data unit	t d.m. m^{-3}
Description	Basic wood density in t d.m. m^{-3} for species j
Equations	103
Source of data	The source of data shall be chosen with priority from higher to lower preference as follows: (a) National species-specific or group of species-specific (e.g., from National GHG inventory); (b) Species-specific or group of species-specific from neighboring countries with similar conditions. Sometimes (b) may be preferable to (a); (c) Global species-specific or group of species-specific (e.g., IPCC 2006 INV GLs AFOLU Chapter 4 Tables 4.13 and 4.14). Species-specific wood densities may not always be available, and may be difficult to apply with certainty in the typically species rich forests of the humid tropics, hence it is acceptable practice to use wood densities developed for forest types or plant families or species groups.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Where using wood densities developed outside of the project country (cases (b) and (c) above under Source of data), wood densities must be validated with either limited destructive sampling or direct measurement of wood hardness (e.g., with a Pilodyn wood tester) in the field and correlating with wood density. Samples or measurements should be from 20-30 trees. For validation of mean forest type or species group wood densities, representation of species in the sample should be proportional to their occurrence in terms of basal area or volume in the project area (not abundance or stem

	density). Samples should provide representation across the length of the tree. Wood samples are cut in discs and thickness and diameter measured to calculate green volume. Samples are oven dried (105o C) to a constant weight in the laboratory, and density calculated as dry weight (g) per unit green volume (cm^3). If the density of the samples/measurements (or mean density in the case of forest type or species group means) is within ±10% of the selected density values, then the selected density values may be used. Otherwise, a new density value must be developed with more extensive sampling, using the validation samples as a base. Where new species are encountered in the course of monitoring, new wood density values must be sourced from the literature and validated, if necessary, as per requirements and procedures above.
Purpose of Data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	CFj
Data unit	t C t^{-1} d.m.
Description	Carbon fraction of dry matter in t C t-1 d.m. for species j
Equations	103
Source of data	Species- or family-specific values from the literature (e.g., IPCC 2006 INV GLs AFOLU Chapter 4 Table 4.3) shall be used if available, otherwise default value of 0.47 t C t^{-1} d.m. can be used.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	N/A
Purpose of Data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	SLF_{ty}
Data unit	Dimensionless

Description	Fraction of wood products that will be emitted to the atmosphere within 5 years of production by class of wood product ty
Equations	104
Source of data	The source of data is the published paper of Winjum et al. 1998[33]
Value applied	Winjum et al. 1998 give the following proportions for wood products with short-term (<5 yr) uses after which they are retired and oxidized (applicable internationally): Sawnwood 0.2 Woodbase panels 0.1 Other industrial roundwood 0.3 Paper and Paperboard 0.4 The methodology makes the assumption that all other classes of wood products, and where wood product class ty is unknown, are 100% oxidized within 5 years. Therefore SLF, by wood product class, is equal to

Wood Product Class	SLF
Sawnwood	0.2
Woodbase panels	0.1
Other industrial roundwood	0.3
Paper and paperboard	0.4
Other classes of wood products	1.0

Justification of choice of data or description of measurement methods and procedures applied	Parameter values to be updated if new empirically-based peer-reviewed findings become available.
Purpose of Data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	OF_{ty}
Data unit	Dimensionless
Description	OF = Fraction of wood products that will be emitted to the atmosphere between 5 and 100 years after production by class of wood product *ty*
Equations	104
Source of data	The source of data is the published paper of Winjum et al. 1998[34]
Value applied	Winjum et al. 1998 gives annual oxidation fractions for each class of wood products split by forest region (boreal, temperate and tropical). This methodology projects these fractions over 95 years to give the

	additional proportion (OF value) that is oxidized between the 5th and 100th years after initial harvest:

Wood Product Class	OF		
	Boreal	Temperate	Tropical
Sawnwood	0.36	0.60	0.84
Woodbase panels	0.60	0.84	0.97
Other industrial roundwood	0.84	0.97	0.99
Paper and paperboard	0.36	0.60	0.99

Justification of choice of data or description of measurement methods and procedures applied	Parameter values to be updated if new empirically-based peer-reviewed findings become available. Every 10 years, project proponents should review research findings to identify further refinements to the emission factors that are empirically-based and peer-reviewed.
Purpose of Data	Calculation of project emissions
Comments	N/A

Data / Parameter	BCEF
Data unit	Dimensionless
Description	Biomass conversion and expansion factor for conversion of commercial wood volume per unit area to total aboveground tree biomass per unit area; note that BCEF as defined here, and in most applications, is not applied on a per stem basis
Equations	104
Source of data	Equations must have been derived using a wide range of measured variables (commercial wood volume per unit area and total aboveground biomass per unit area) based on datasets that comprise at least 30 trees. Equations must be based on statistically significant regressions and must have an r2 that is ≥ 0.8. The source of data shall be chosen with priority from higher to lower preference as follows: (a) Existing local forest type-specific; (b) National forest type-specific or eco-region-specific (e.g., from national GHG inventory); (c) Forest type-specific or eco-region-specific from neighboring countries with similar conditions. Sometimes (c) might be preferable to (b);

	(d) Global forest type or eco-region-specific (e.g., IPCC 2006 INV GLs AFOLU Chapter 4 Table 4.5) The project volume data to which the selected BCEF is applied must conform to the data the BCEF was originally derived from, in particular, it must match forest type, stand structure, minimum DBH, and cover the range of potential independent variable values (commercial volumes) likely to be encountered in the project area. Care must be taken to ensure that the selected BCEF does not account for non-commercial species not represented in commercial volume estimates (i.e., is restricted to expanding merchantable volumes to account for only non-merchantable tree components).
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Alternatively, BCEF, where not directly available, can be calculated as wood density (t dry mass m-3 green volume) × BEF (Biomass Expansion Factor = ratio of aboveground biomass to biomass of the commercial volume). If using BCEFs developed outside the project country (cases (c) and (d) above under Source of data), it is necessary to validate the applicability of BCEFs used. Validation is performed by: 1. Limited Measurements Select at least 20 plots in the project area covering a wide range of commercial volumes. Obtain tree measurements (e.g. DBH, height to a 10 cm diameter top) from which to calculate commercial volume and total biomass. Calculate commercial volume per unit area (e.g. using Smalian's formula) and total biomass per unit area (using the biomass equation(s) selected for application in CP-AB) for each plot Calculate BCEF for each plot (biomass (t) / commercial volume (m^3) Graph the plot-level estimates of BCEF versus commercial volume along with the BCEF equation (predicted) to be validated. If the estimated BCEFs of the measured plots are distributed both above and below the predicted value the BCEF equation may be used. The BCEF equation may also be used if the measured plots have a BCEF consistently lower than that predicted. If graphing the BCEF of the measured plots indicates a systematic bias to overestimation of BCEF (>75% of the plots below the predicted value) then another BCEF equation must be selected or developed anew.
Purpose of Data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	$P_{comi,t}$
Data unit	Dimensionless
Description	Commercial volume as a percent of total aboveground volume in stratum i in year t
Equations	104
Source of data	The source of data shall be chosen with priority from higher to lower preference as follows: (a) Direct forest inventory of the project area, distinguishing commercially viable stocks on the basis of species and tree size, referencing local expert knowledge or a participatory rural assessment (PRA) of harvest practices and markets; (b) Forest inventory from a proxy area in the same region, representing the same forest type and age class, distinguishing commercially viable stocks on the basis of species and tree size, referencing local expert knowledge of harvest practices and markets National and forest type-specific or eco-region-specific (e.g., from National GHG inventory).
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	N/A
Purpose of Data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	CFj
Data unit	t C_{t-1} d.m.
Description	Carbon fraction of dry matter in t C_{t-1} d.m. for species j
Equations	103
Source of data	Species- or family-specific values from the literature (e.g., IPCC 2006 INV GLs AFOLU Chapter 4 Table 4.3) shall be used if available, otherwise default value of 0.47 t C_{t-1} d.m. can be used.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	N/A

Purpose of Data	Calculation of project emissions
Comments	N/A

Data / Parameter	CH4-GWP
Data unit	Dimensionless
Description	Global Warming Potential of CH_4
Equations	(59)– (61), 83, 101
Source of data	IPCC
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	N/A
Purpose of Data	Calculation of baseline emissions Calculation of project emissions
Comments	N/A

Data / Parameter	N_2O-GWP
Data unit	Dimensionless
Description	Global Warming Potential of N_2O
Equations	(62)- 68, 82, 102
Source of data	IPCC
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	N/A
Purpose of Data	Calculation of baseline emissions Calculation of project emissions
Comments	N/A

11.2 Data and Parameters Monitored

The rules for calculating and processing data related to “baseline emissions” and the ”project scenario” in a climate change or carbon reduction project (e.g., carbon credits, CDM, VCS, GHG programs).

- Substitution of “BSL” with “WPS”

  Typically, “BSL” refers to “baseline emissions”, while “WPS” may represent a specific project scenario or emissions under a certain methodology (e.g., With Project Scenario).
  This means that in all formulas originally used to calculate baseline emissions”, any variable that uses the subscript“BSL”must be replaced with“WPS”and the formula should be applied to the project scenario. This allows for a comparative analysis, such as estimating emission reductions.

- Monitoring Frequency of Data:

  For data that are required in both the baseline and project scenarios (e.g., energy consumption, fuel usage), and are also monitored during the actual implementation of the project, the data must be recorded for each monitoring period.

- QA/QC Procedures:

  All data must be subjected to “Quality Assurance and Quality Control (QA/QC)” procedures as specified in Section 9.3.2 of the document.

Data / Parameter	$Biomass_{i,t}$
Data unit	kg d.m. ha^{-1}
Description	Aboveground shrub biomass in stratum i in year t
Equations	81,82
Source of data	Measured using field collected data at time of burning or conservatively estimated from data collected during a period with greater biomass within year t
Description of measurement methods and procedures to be applied	This value may be obtained from $B_{SHRUB,i,t}$ in AR-Tool14 where $B_{SHRUB,i,t}$ (shrub biomass per hectare in shrub biomass stratum i at a given point of time in year t; t d.m. ha^{-1}) is quantified. Convert from t d.m. ha^{-1} to kg d.m. ha^{-1}.
Frequency of monitoring/recording	One-time measurement for each burn event
QA/QC procedures to be applied	See Section 9.3.2
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	N/A

Data / Parameter	$\Delta C_{TREE_PROi,t}$
Data unit	t CO_2-e yr^{-1}
Description	Change in carbon stock in tree biomass in the project scenario in year t
Equations	75)
Source of data	Derived from application of AR-Tool14
Value applied	See AR-Tool14
Justification of choice of data or description of measurement methods and procedures applied	See AR-Tool14
Purpose of data	See AR-Tool14
Comments	Calculation of project emissions

Data / Parameter	$\Delta C_{TREE_PROi,t}$
Data unit	t CO_2-e yr^{-1}
Description	Change in carbon stock in shrub biomass in the project scenario in year t
Equations	75)
Source of data	Derived from application of AR-Tool14
Value applied	See AR-Tool14
Justification of choice of data or description of measurement methods and procedures applied	See AR-Tool14
Purpose of data	See AR-Tool14
Comments	Calculation of project emissions

Data / Parameter	*CWPS-herb,i,t*
Data unit	t C ha^{-1}

Description	Carbon stock in herbaceous vegetation in the project scenario in stratum *i* in year *t*
Equations	(78)
Source of data	Direct measurements or default factor
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	A default factor of 3 t C ha^{-1} may be applied for strata with 100% herbaceous cover. For areas with a vegetation cover <100%, a 1:1 relationship between vegetation cover and $CWPS_{,\text{-herb},i,t}$ must be. The default factor may be claimed for one year only during the project crediting period as herbaceous biomass quickly reaches a steady state. Vegetation cover must be determined by commonly used techniques in field biology. Procedures for measuring carbons stocks in herbaceous vegetation are specified in Section 9.3.6.
Purpose of data	At each monitoring period
Comments	See Section 9.3.2

Data / Parameter	$A_{WPS,i}$ (or $A_{i,t}$)
Data unit	ha
Description	Area of project stratum i (in year t)
Equations	4, 13, 26, (79), 82, 83
Source of data	Delineation of strata must be done preferably using a Geographical Information System (GIS), which allows for integrating data from different sources (including GPS coordinates and Remote Sensing data)
Value applied	See Source of data above
Justification of choice of data or description of measurement methods and procedures applied	At each monitoring period
Purpose of data	See Section 9.3.2
Comments	Calculation of project emissions

Data / Parameter	$\%OM$ (or $\%OM_{soil}$)
Data unit	%
Description	Percentage of soil that is organic matter
Equations	34, 35, (37), (39), 76, 77, (79), (79)
Source of data	Direct measurements based on loss-on-ignition or may be derived from direct measurements of soil carbon. These measurements may be made using samples collected in Section 9.3.7 or indirectly from the soil carbon percentage as described in Section 8.1.4.2.7.
Value applied	The equations provided were developed for tidal marsh soils by Craft et al. 1991 and for mangrove soils by *Kauffman et al. 2011,* and for seagrass soils by *Fourqurean et al. 2012, as summarized in Howard et al. 2014*
Justification of choice of data or description of measurement methods and procedures applied	At each monitoring period
Purpose of data	See Section 9.3.2
Comments	Calculation of project emissions

Data / Parameter	$\%C_{soil}$
Data unit	%
Description	Percentage of soil organic C
Equations	33, (37), (39)
Source of data	Direct measurements or may be derived from direct measurements of soil organic matter. These measurements may be made using samples collected in Section 9.3.7 or indirectly from the soil organic matter percentage determined through loss-on-ignition as described in Section 9.3.6.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	See Source of data above
Purpose of data	At each monitoring period
Comments	See Section 9.3.2

Data / Parameter	Crown cover, vegetation cover
Data unit	%
Description	Proportion of an area covered by the herbaceous vegetation, shrubs, and/or the crowns of live trees
Equations	N/A
Source of data	For the project scenario, crown or vegetation cover mapping must be performed according to established methods in scientific literature.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	See Source of data above
Purpose of data	At each monitoring period
Comments	See Section 9.3.2

Data / Parameter	BD
Data unit	kg m^{-3}
Description	Dry bulk density
Equations	29, (49), (57), 100
Source of data	Direct measurements, or from a relationship with organic carbon content provided by the scientific literature.
Description of measurement methods and procedures to be applied	Mass of soil material after drying per volume of soil material, based on commonly accepted procedures by the scientific community.
Frequency of monitoring/recording	At each monitoring period
QA/QC procedures to be applied	See Section 9.3.2
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	Refer to procedures in *Sections 8.1.4.2.1 – 8.1.4.2.6. For all equations in these sections,* the subscript *BSL* must be substituted by *WPS* to make clear that the relevant values are

	being quantified for the project scenario.

Data / Parameter	*%OMdepsed*
Data unit	%
Description	Percentage of deposited sediment that is organic matter
Equations	(40), 44, (46)
Source of data	May be estimated directly using loss-on-ignition (LOI) data, indirectly from soil carbon percentage as described in Section 8.1.4.2.7, or from the default value provided in Section 8.1.4.2.7. These measurements may be made using samples collected on sediment tiles or through collection and carbon analysis (see Section 9.3.7) of suspended sediments in tidal channels or sediments deposits in tidal flats
Description of measurement methods and procedures to be applied	LOI may be assessed using standard laboratory procedures
Frequency of monitoring/recording	At each monitoring period
QA/QC procedures to be applied	See Section 9.3.2
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	Refer to procedures in Sections 8.1.4.2.1 – 8.1.4.2.6. For all equations in these sections, the subscript BSL must be substituted by WPS to make clear that the relevant values are being quantified for the project scenario.

Data / Parameter	$\%C_{depsed}$
Data unit	%
Description	Percentage of carbon in deposited sediment; %
Equations	44, (46), (47)
Source of data	May be estimated directly using loss-on-ignition (LOI) data or indirectly from soil carbon percentage as described in Section 8.1.4.2.7.

	These measurements may be made using samples collected on sediment tiles or through collection and carbon analysis (see Section 9.3.7) of suspended sediments in tidal channels or sediments deposits in tidal flats.
Description of measurement methods and procedures to be applied	The default factor is derived from the maximum value (conservative) provided by Mayer 1994 Figure 4
Frequency of monitoring/recording	At each monitoring period
QA/QC procedures to be applied	See Section 9.3.2
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	Refer to procedures in Sections 8.1.4.2.1 – 8.1.4.2.6. For all equations in these sections, the subscript *BSL* must be substituted by *WPS* to make clear that the relevant values are being quantified for the project scenario.

Data / Parameter	$ETFC_{,y}$
Data unit	t CO_2-e yr^{-1}
Description	CO_2 emissions from fossil fuel combustion during the year *y*; t CO_2 yr^{-1}
Equations	(65)
Source of data	Derived from application of CDM tool *AR-Tool05 Estimation of GHG emissions related to fossil fuel combustion in A/R CDM project activities*
Description of measurement methods and procedures to be applied	See *AR-Tool05*
Frequency of monitoring/recording	See *AR Tool05*
QA/QC procedures to be applied	See *AR Tool05*
Purpose of data	Calculation of project emissions
Calculation method	See AR Tool05
Comments	Calculations are done for each stratum i

Data / Parameter	NER_{ERROR}
Data unit	%
Description	Total uncertainty for project activity
Equations	72, 73
Source of data	N/A
Description of measurement methods and procedures to be applied	N/A
Frequency of monitoring/recording	At each monitoring period
QA/QC procedures to be applied	N/A
Purpose of data	Calculation of net GHG emission reductions
Calculation method	N/A
Comments	N/A

Data / Parameter	$V_{ex,ty,i,t}$
Data unit	m^3
Description	Volume of timber extracted from within stratum i (does not include slash left onsite) by species j and wood product class ty in year t
Equations	83
Source of data	Estimates derived from field measurements or remote assessments with aerial photography or satellite imagery.
Description of measurement methods and procedures to be applied	See Section 9.1
Frequency of monitoring/recording	At each monitoring period
QA/QC procedures to be applied	
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	$V_{ex,ty,i,t}$

11.3Description of the Monitoring Plan

The project will employ advanced and integrated monitoring technologies to ensure precise, systematic, and efficient tracking of carbon stocks, wetland area, vegetation health, and crucial environmental indicators within the project region. These technologies emphasize in-depth applications of current and historical aerial imagery, backed by thorough ground truthing:

1. High-Resolution Satellite/Aerial Imagery:

- Data Sources: Multi-spectral satellite imagery from publicly available sources such as Sentinel-2 and Landsat (e.g., Landsat 8/9) will be utilized, alongside higher-resolution aerial imagery from commercial providers (e.g., Maxar, Planet). Historical imagery will primarily draw from the Landsat archive and Google Earth Engine.
- Acquisition Frequency: Satellite imagery will be acquired at least quarterly to capture seasonal variations, while higher-resolution aerial imagery will be obtained at least annually, or additionally after significant events (e.g., major restoration efforts, extreme weather events), depending on project needs and budget.
- Application: This imagery will be used for precise mapping of changes in wetland area, seagrass coverage, vegetation types, and density, particularly for identifying and quantifying the expansion and success rate of restored areas. Time-series analysis will allow for tracking the dynamic evolution of the ecosystem over time.

2. Drone-Based Imagery and Mapping:

- Technology: For critical restoration zones or areas difficult to access by ground, drones equipped with high-resolution RGB and multi-spectral cameras will be deployed for periodic mapping.
- Frequency and Application: Drone flights will be conducted on a bi-annual or quarterly basis according to specific monitoring needs, providing highly detailed data on vegetation health indices (e.g., NDVI), topographical changes (e.g., tidal channel shifts), biomass estimation, and the early identification of invasive species.

3. Ground-Truthing and Field Sampling:

- Methodology: Remote sensing data will be calibrated and validated through systematic ground-truthing. This includes regular sampling plot surveys, vegetation species identification, soil sampling (for carbon density measurement), water quality parameter measurements (salinity, pH, dissolved oxygen), and tidal elevation data collection.
- Integration: Field data will be integrated with remote sensing data to improve model accuracy and to account for potential biases in image analysis.

By integrating these technologies, the project will establish a multi-layered monitoring system that provides comprehensive and reliable evidence of ecological conditions and carbon stock changes within the project area.

The monitoring plan includes continuous monitoring of changes in carbon stocks and GHG emissions, as well as estimation of the actual GHG reductions and removals achieved by the project based on the monitoring results.

Key components or technical elements of the monitoring plan are as follows:

(1) **Core Purpose of the Monitoring Plan**

- Reliably quantify carbon stocks and greenhouse gas (GHG) emissions within the project scenario throughout the certification period.
- Continuously monitor changes in carbon stocks and GHG emissions resulting from project activities.
- Conduct ex-post estimations of emission reductions and removals prior to each verification.

(2) **Technical Requirements and Monitoring Tasks**

A robust monitoring plan must specify the following:

- Parameters to be measured.
- Data collection methods and monitoring frequency.
- Quality Assurance (QA) and Quality Control (QC) procedures.
- Data archiving protocols.
- Team roles, responsibilities, and required capabilities.

(3) **Managing Data Quality and Uncertainty**

- Minimize uncertainty using internationally recognized best practices.
- Identify "key parameters" that significantly affect estimation accuracy.
- Prioritize local data from peer-reviewed literature, national inventories, or expert judgment.
- Apply conservative assumptions when uncertainties are significant—select data that may under-estimate benefits to avoid overstatement.

(4) **Standard Operating Procedures (SOPs) and QA/QC Measures**

- Document all field measurements in detail.
- Implement training programs for monitoring staff.
  To enhance the MRV capabilities of local teams, particularly in data collection and quality assurance/quality control (QA/QC), a rigorous training program must be implemented. This training should focus on standardized field measurement procedures such as soil sampling and vegetation assessment, ground truthing of remote sensing data, and error detection and outlier management protocols. All relevant training materials, attendance records, and competency assessment documents should be properly archived to ensure data reliability, transparency, and consistency.
- Regularly assess measurement accuracy.
- Archive data rigorously to ensure verifiability, transparency, and consistency.

(5) **Monitoring Project Implementation and Boundaries**

- Accurately record project boundaries and geolocation using GPS or georeferenced spatial data.
- Enforce restrictions:
  - Do not lower the water table unless required for project conversion.
  - Prohibit organic soil burning.
- Avoid use of nitrogen fertilizers in the project area.
- Allow stratification to improve precision and reduce cost, with flexibility to adjust during the crediting period due to disturbances or management changes.

(6) **Measuring Changes in Carbon Stocks**

- Use permanent sampling plots to measure changes in biomass (e.g., trees).
- Determine sampling size using CDM tool AR-Tool03.
- Target precision levels: ≤20% at 90% confidence or ≤30% at 95% confidence.

(7) **Monitoring Techniques for Carbon Pools and GHG Emissions**

- Herbaceous vegetation sampling.
- Soil carbon estimation through soil coring.
- Methane (CH_4) and nitrous oxide (N_2O) emissions via closed chambers or eddy covariance techniques.
- Soil subsidence monitoring and eroded soil depth estimation.

11.4 Stakeholder Transparency

The project places a strong emphasis on transparency with stakeholders, aiming to openly share updates on progress, performance, and relevant information through diverse and accessible channels. In addition to providing annual activity and implementation reports to partners and donors, we will actively employ the following mechanisms to ensure public disclosure:

1. A dedicated webpage will be established to serve as the primary public repository for all project-related information. This website will be regularly updated, with content published at least annually, including:

   - Annual Activity Summaries: Easily understandable overviews of the project's yearly achievements in ecological restoration, carbon emission reductions, and community engagement.
   - Summaries of Monitoring Reports: Concise data and trends on key ecological indicators, carbon stocks, and emission reductions/removals.
   - Financial Transparency Information: Summaries of funding sources and major expenditure categories (ensuring protection of sensitive commercial information).
   - Records of Stakeholder Engagement Activities: Including meeting minutes, outcomes of community consultations, and responses to feedback mechanisms.
   - Contact Information: Clear contact details for public inquiries or comments.

2. Local Community Bulletin Boards/Meetings:

- Physical bulletin boards will be maintained in community centers and local government offices within the project's area of influence. These will regularly display project progress summaries, upcoming activity plans, and important announcements, ensuring local residents without internet access can also obtain information.
- At least one to two public community meetings will be held annually, where the project team directly reports progress to local residents and provides a Q&A session to foster two-way communication.

3. Media Releases and Partnerships:

- Regular press releases or feature stories will be disseminated in collaboration with local and national media outlets to publicize project achievements and environmental benefits, raising public awareness.
- Partnerships with educational institutions or environmental organizations will be explored to collaboratively disseminate project research findings and environmental education materials.

4. VCS Project Registry:

- All verified VCS-related documents, including the Project Design Document (PDD), Monitoring Reports (MR), and Verification Reports (VR), will be publicly disclosed on Verra's public project registry, as per VCS standard requirements. This serves as a standardized public platform ensuring the highest level of transparency.

11.5 Integration of Co-benefits Monitoring and Reporting

The project adopts a comprehensive and holistic strategy, recognizing the importance of quantitative reporting and transparency on key biodiversity and social economic co-benefits, which are equally important to achieving the primary goal of carbon sequestration enhancement. Establishing a systematic framework for monitoring these integrated co-benefits and ensuring rigorous reporting is crucial for demonstrating the wider sustainable development impacts of the project and ensuring alignment with global biodiversity frameworks (such as the GBF), while showcasing true multi-faceted contributions to environmental and community well-being.

Key Co-Benefit Parameters to be Monitored:

1. Biodiversity/Ecological Metrics (GBF Targets 2, 3):

- Seagrass Cover: Percentage and area of restored/enhanced seagrass meadow coverage.
- Indicator Species Biomass/Population: Quantification (e.g., biomass, density, or species richness) of key ecological resources essential to local communities (e.g., commercially important fish, crabs, and shellfish stocks).

2. Socio-Economic Metrics (GBF Targets 9, 10):

- Community Resource Health Improvement: Metrics tracking the perceived or measured improvement in the stocks of fish and other resources by local stakeholders, gathered through participatory monitoring or resource surveys.
- Well-Being Indicators: Assessment of improvement in the multiple dimensions of human well-being of households within the landscape, as referenced in GBF possible indicators.

11.6 Data, Parameters, and Description of the Monitoring Plan to Practice the Strategy and Plan of Action 2023 -2030 of the International Partnership for the Satoyama Initiative

This monitoring plan is designed to reliably quantify carbon stocks and greenhouse gas (GHG) emissions within a project's context and to assess resulting emission reductions and removals. It closely aligns with the vision of the International Partnership for the Satoyama Initiative (IPSI) and its Strategy and Plan of Action 2023–2030, which seeks to promote societies in harmony with nature through the sustainable management of socio-ecological production landscapes and seascapes (SEPLS).

Integration of the Monitoring Plan with IPSI Strategic Objectives

The monitoring plan directly supports IPSI's goals, particularly in two key strategic areas:

- Knowledge Co-Production, Management, and Uptake
- Ecosystem Restoration

These contributions are realized through structured data practices, uncertainty management, restoration effectiveness assessments, and robust oversight of project implementation.

Advancing Knowledge Co-Production, Management, and Uptake

The monitoring plan enhances IPSI's ability to generate, manage, and disseminate credible environmental data.

Uncertainty Minimization

- Identification of key parameters that significantly influence data accuracy.
- Prioritization of locally relevant data sourced from peer-reviewed literature, national inventories, and expert insights.
- Use of conservative estimates in cases of high uncertainty, ensuring balanced and reliable assessments of climate benefits.

These practices result in transparent, reproducible knowledge products that support IPSI's mission of sharing information on SEPLS conservation and restoration.

Quality Assurance and Control (QA/QC)

A comprehensive QA/QC system is implemented, including:

- Standard Operating Procedures (SOPs) for all monitoring activities
- Full documentation of field data and measurement processes
- Formal training programs for personnel responsible for data collection and analysis
- Protocols for error detection, outlier treatment, and ensuring data consistency
- Secure systems for data archiving and backups

These measures reinforce the credibility and utility of IPSI's knowledge systems, particularly in integrating modern scientific and traditional ecological knowledge in SEPLS management.

Expert Integration

Expert judgment supports:

- Method selection and interpretation based on site-specific contexts
- Data gap filling and conservative assumption development

This integration helps blend scientific and local knowledge systems, a key value of IPSI's approach to landscape-scale sustainability.

Supporting Ecosystem Restoration

The monitoring plan plays a central role in assessing and guiding ecosystem restoration efforts by providing empirical data on environmental performance.

Quantifying Restoration Impacts

The following key indicators are monitored:

- Changes in carbon stocks in trees, shrubs, and herbaceous vegetation using permanent sample plots
- Soil Organic Carbon (SOC) levels tracked through soil coring and elevation reference planes
- Emissions of methane (CH_4) and nitrous oxide (N_2O) measured using direct methods such as closed chambers and eddy covariance systems
- Soil subsidence and erosion depth monitored to evaluate wetland condition and vulnerability

These data points serve as measurable outcomes of restoration effectiveness and support IPSI's objective of enhancing carbon sinks and building climate resilience.

Monitoring Project Conditions and Boundaries

To maintain ecological integrity, the monitoring framework includes:

- Restrictions on lowering the water table except for authorized project interventions
- Prohibitions on burning organic soils and applying nitrogen-based fertilizers
- Accurate mapping of project boundaries, buffer zones, and vegetation strata to account for sea level rise and wetland migration
- Continuous evaluation of hydrological connectivity to prevent GHG leakage to neighboring ecosystems

These elements support integrated landscape management, ensuring that project implementation adheres to ecological and policy guidelines endorsed by IPSI.

This monitoring plan provides a scientifically rigorous and result-oriented framework for tracking ecosystem restoration outcomes. Through strong data integrity protocols and alignment with IPSI's strategic directions, it enhances the conservation of SEPLS, supports global climate mitigation goals, and demonstrates the real-world environmental and social value of sustainable landscape management.

11.7 Data, Parameters, and Description of the Monitoring Plan to Practice the Kunming-Montreal Global Biodiversity Framework

A robust monitoring plan for tidal wetland and seagrass restoration methodologies is crucial for contributing to the ambitious goals of the Kunming-Montreal Global Biodiversity Framework (GBF). This plan is specifically designed to reliably quantify carbon stocks and Greenhouse Gas (GHG) emissions resulting from these restoration projects. By providing essential, verifiable data, it demonstrates how these vital ecosystem restoration efforts align with and implement the GBF's targets through a "landscape approach," which integrates diverse uses and users of a given area.

(1) Spatial Planning (GBF Target 1): The monitoring plan necessitates the precise definition and mapping of project geographic boundaries, including detailed coordinates and stratification based on critical environmental characteristics such as soil type, vegetation, and salinity. It also mandates the consideration of future conditions, notably relative sea level rise, when defining these boundaries. This rigorous collection of spatial data directly supports the GBF's emphasis on biodiversity-inclusive spatial planning. Landscape approaches inherently align with and are encouraged for this target, as they involve integrating multiple uses and users in a given area.

(2) Ecosystem Restoration (GBF Target 2): A central aim of the monitoring plan is the direct quantification of GHG emission reductions and removals achieved through restoration activities. This involves meticulously measuring changes in:

- Biomass carbon stocks, including trees, shrubs, and herbaceous vegetation.
- Soil organic carbon (SOC) accumulation and avoided loss.
- Reduced methane (CH4) and nitrous oxide (N2O) emissions that result from increased salinity or changes in land use.
- The quantification of a "Fire Reduction Premium" derived from rewetting activities . These quantitative metrics provide direct evidence of the project's effectiveness in restoring degraded ecosystems and enhancing their functions. The International Partnership for the Satoyama Initiative (IPSI) also strategically promotes ecosystem restoration within socio-ecological production landscapes and seascapes (SEPLS), directly contributing to GBF Target 2.

(3) Area-Based Conservation Measures (GBF Target 3): The rigorous monitoring framework ensures the accuracy and precision of carbon stock measurements, aiming for a high confidence interval (e.g., a 90% confidence interval of ≤20% of the recorded value) . This reliable data is instrumental

in supporting the recognition of restored tidal wetlands and seagrass meadows as effectively conserved areas. Such areas can potentially qualify as "other effective area-based conservation measures (OECMs)," integrating into wider landscapes and seascapes, a key aspect of GBF Target 3. IPSI's work also aligns with this, pushing for effective conservation and management through protected areas and OECMs integrated into wider landscapes.

(4) Climate Change Mitigation and Adaptation (GBF Target 8): By directly quantifying GHG emission reductions and removals, the monitoring plan offers tangible proof of the significant climate mitigation benefits derived from tidal wetland restoration. Furthermore, it explicitly integrates the consideration of sea level rise when defining project boundaries and assessing baseline conditions. It also leverages the VCS AFOLU Non-Permanence Risk Tool to account for climate-related risks to carbon stocks . This comprehensively supports nature-based solutions and ecosystem-based approaches for climate action, as outlined in GBF Target 8. SEPLS generally contribute to climate change mitigation and adaptation by enhancing carbon sinks and reservoirs.

(5) Knowledge Management (GBF Target 21): The methodology underscores the importance of high-quality data, information, and knowledge for effective biodiversity governance and management . This is achieved through stringent requirements for the monitoring plan, including:

- Establishing clear Standard Operating Procedures (SOPs) and Quality Assurance/Quality Control (QA/QC) procedures for all field measurements and data analysis.
- Mandating detailed documentation, staff training, and rigorous data archiving.
- Prioritizing data from peer-reviewed literature and national inventories, and requiring conservative estimates when uncertainty is high. This ensures the generation of reliable, verifiable, and transparent data, which is paramount for evidence-based decision-making and knowledge sharing. IPSI's strategic objective of "Knowledge Co-Production, Management, and Uptake" directly supports this by promoting the creation and sharing of knowledge, including synergies between modern science and traditional knowledge.

(6) Participation (GBF Target 22): While primarily a technical standard, the monitoring plan's inherent reliance on local data sources (e.g., for soil properties, vegetation composition, and historical land use) and its application within the broader "landscape approaches" framework fosters engagement with various stakeholders. "Landscape approaches" are defined by their meaningful involvement of multiple users and their prioritization of equitable participation. The "Landscape Approaches Manual" explicitly encourages stakeholder participation in the monitoring process to cultivate ownership and build capacity, thereby strengthening governance. This directly aligns with GBF Target 22's call for full, equitable, inclusive, and effective representation and participation of Indigenous Peoples and Local Communities (IPLCs), women, girls, children, youth, and persons with disabilities in biodiversity-related decision-making. IPSI's foundational principles also emphasize the full, effective, and equitable participation of IPLCs.

11.8 Key Performance Indicator

The Kunming-Montreal Global Biodiversity Framework has 23 action-oriented global targets for urgent action over the decade to 2030. The actions set out in each target need to be initiated immediately and completed by 2030. Together, the results will enable the achievement of the outcome-oriented goals for 2050. Actions to reach these targets should be implemented consistently and in harmony with the Convention on Biological Diversity and its Protocols and other relevant international obligations, considering national circumstances, priorities, and socioeconomic conditions.

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APPENDIX

Additional Resources or References

This appendix provides additional resources and references related to landscape approaches, National Biodiversity Strategies and Action Plans (NBSAPs), and associated biodiversity conservation and sustainable use efforts. These resources can assist policymakers, practitioners, and the public in gaining a deeper understanding and facilitating the implementation of the Kunming-Montreal Global Biodiversity Framework (GBF) targets.

Below is a list of recommended additional resources with their brief descriptions:

(1) The Kunming-Montreal Global Biodiversity Framework (GBF) and its 2030 Targets with Guidance Notes:

The GBF is a crucial global framework for biodiversity conservation, establishing 23 action-oriented global targets for urgent action over the decade to 2030, aiming to achieve the 2050 vision of "living in harmony with nature". Guidance material provided by the Secretariat offers an overview of each target, including key terms, implications for national target setting, key points, and guiding questions for consideration in national target-setting exercises. It also identifies adopted indicators for monitoring progress and resources to assist with national target setting and implementation.

(2) Integrated Spatial Planning Workbook (2022):

This is a United Nations Development Programme (UNDP) publication that demonstrates how countries can use integrated spatial planning to simultaneously achieve multiple nature-based goals. Through step-by-step explanations and case studies from 11 countries, it shows how nations can develop 'Maps of Hope' to indicate where ecosystems should be protected, managed, and restored to meet their unique goals.

(3) NBSAP Forum:

This is a community of practice aimed at supporting the implementation of the UN Biodiversity Convention and its policy and reporting mechanism. Led by a partnership between the Secretariat of the CBD, the United Nations Development Programme (UNDP), and UN Environment Programme (UNEP), its purpose is to help countries find the information they need to develop and implement

effective NBSAPs and prepare National Reports. NBSAPs are a central pathway for integrating landscape approaches.

(4) Convention on Biological Diversity (revised 2011-2012) NBSAP Capacity Building Modules:

This is a set of modules produced by the CBD outlining various aspects of NBSAPs, including mainstreaming, target setting, ensuring inclusive societal engagement, gaining political support, communication, subnational authorities, and gender. These modules are crucial for updating and revising NBSAPs in line with the Strategic Plan for Biodiversity 2011-2020 and the Aichi Biodiversity Targets.

(5) Satoyama Concept and its Landscape Approaches:

Landscape approaches are a key aspect of the Satoyama concept, which aims to establish mutually beneficial human-nature relationships, where the maintenance and development of socio-economic activities (including agriculture, fishing, and forestry) align with natural processes. It involves a range of activities such as expanding the body of knowledge, from both social and scientific perspectives, on how human-nature relationships should function in a wide variety of productive landscapes and seascapes. The International Partnership for the Satoyama Initiative (IPSI) is dedicated to promoting and supporting the sustainable management of socio-ecological production landscapes and seascapes (SEPLS) and facilitating their contribution to the GBF targets

(6) Local Biodiversity Outlooks 2 (2020):

Published by Forest Peoples Programme, this second iteration of the local biodiversity outlook complements the fifth edition of the Global Biodiversity Outlook issued by the CBD Secretariat. It presents the perspectives and experiences of Indigenous Peoples and Local Communities (IPLCs) on the current social-ecological crisis, and their contributions to the implementation of the Strategic Plan for Biodiversity 2011–2020 and to the renewal of nature and cultures. The full participation of IPLCs is crucial for the successful implementation of landscape approaches, as they are key custodians of land and resources.

(7) How Integrated Landscape Management can contribute to the CBD Post-2020 Biodiversity Framework: Recommendations for policymakers from African Landscape Leaders (2020):

This report presents the outcomes of a dialogue on African perspectives of biodiversity conservation, emphasizing policy support for locally led landscape partnerships, building 'green' landscape economies, and measuring landscape-level performance. This is closely related to efforts to integrate landscape approaches into GBF targets.

(8) Secretariat of the Convention on Biological Diversity Report on how to improve sustainable use of biodiversity in a landscape perspective (2011):

This is an official document of the Fifteenth meeting of the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA), providing a rationale for focusing on the landscape level and emphasizing the importance of landscape approaches in the sustainable use of biodiversity.

(9) Science-based ecosystem restoration for the 2020s and beyond (2021) by IUCN:

This is a "think piece" that presents recommendations for "specific actions to be undertaken by public and private stakeholders to sustain and restore the diverse and functioning ecosystems essential for human well-being and the preservation of biodiversity". This directly supports the GBF's targets on restoring degraded ecosystems.

(10) Making Protected Areas Relevant: A guide to integrating protected areas into wider landscapes, seascapes and sectoral plans and strategies. CBD Technical Series No. 44 (2010):

This guide provides conservation planners with a concrete set of steps to improve protected area integration, including how to begin, assess the broader context, develop and implement strategies, and monitor results. It also aims to inform and support others involved in land use planning to help them better understand and integrate conservation principles into their work. This aligns with GBF Target 3's requirement for integration into "wider landscapes, seascapes and the ocean".3

(11) Guidance on integrating human rights in National Biodiversity Strategy and Action Plans (NBSAPs):

This guidance aims to support UN Country Teams, States, policymakers, and stakeholders in integrating human rights into their National Biodiversity Strategy and Action Plans developed under the Convention on Biological Diversity. Respecting the rights of Indigenous Peoples and Local Communities is a fundamental principle in landscape approaches.

(12) Putting biodiversity at the centre of development: a checklist for reviewing the mainstreaming potential of a country's NBSAP (2015) by IIED and UNEP-WCMC:

This toolkit is for individuals who want to mainstream biodiversity concerns into development policy and planning, highlight how biodiversity contributes to nutrition and social development, or are involved in developing or revising an NBSAP. It guides users to better utilize NBSAP revision opportunities, understand the mainstreaming process, acquire and present evidence on the links between biodiversity and national development priorities, and develop communication strategies. Mainstreaming biodiversity is a core component of landscape approaches.

(13) Mobilizing Finance across Sectors and Projects to Achieve Sustainable Landscapes: Emerging Models (2020):

This is a publication on mobilizing finance to support the achievement of sustainable landscapes. The adequacy of financial resources is crucial for implementing landscape approaches and achieving biodiversity targets.

(14) Geographic Information System (GIS) software (e.g., QGIS and ArcGIS):

These are the most precise ways to map an area, essential for spatial planning and data visualization in landscape approaches.

(15) LandScale Initiative:

This is a framework developed for integrated impact monitoring at the landscape or seascape scale, including biodiversity, and provides a guide to landscape financing. This helps monitor and evaluate the effectiveness of landscape approach implementation.

(16) IPCC Guidelines (e.g., IPCC 2006 Guidelines, GPG-LULUCF 2003):

These guidelines provide important guidance on greenhouse gas accounting, uncertainty assessment, and the application of expert judgment. While primarily focused on climate change, their methodologies have broad applicability for integrated assessment and planning at the landscape level.

DOCUMENT HISTORY

Version	Date	Changes & Comment
v1.0	23 July 2025	

SATOYAMA INITIATIVE

Methodology

Me0006

Replacing Fossil-Fuel-Based Hydrogen Production (Blue Hydrogen) with Renewable-Based Green Hydrogen

Version 1.0
Published 05 January 2026
GBF 1-23

Version 1.0 of this methodology was developed by Prof. Jyh-Ming Ting (National Cheng Kung University).

Funder: National Science and Technology Council, Taiwan

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1 Source

Primary References:

1. AM0124: Hydrogen production from electrolysis of water --- Version 1.1
   - Used for:
     - Baseline emission factor calculations (Section 10.1)
     - Electrolyzer efficiency monitoring (Section 11.2)
   - Modifications:
     - Added grid-integration leakage assessment (VCS Section 4.5)
     - Excluded CDM's default additionality tool (replaced with VCS Tool 07.0)
2. ACM0002: Grid-connected electricity generation from renewable sources --- Version 22.0
   - Used for: Renewable electricity eligibility criteria (Section6.IV)
   - Modifications: Required REC retirement within 6 months (vs. CDM's 12 months)
3. M0191: Methodology for Alternative Low-Carbon Fuels for Shipping

Supporting References (Best Practices):

1. IEA Hydrogen Lifecycle Guidelines: Informs auxiliary emission factors (Section 10.2)
2. IPHE: Used for H_2 purity thresholds (Section 6.V)

2 Summary Description of the Methodology

Project activities are expected to generate GHG emission reductions and removals through the displacement of hydrogen produced from fossil-fuel-based processes (e.g., steam methane reforming or autothermal reforming) with hydrogen produced from renewable electricity-powered electrolysis systems.

This methodology provides the steps necessary for estimating the project's net GHG benefits, including the determination of baseline emissions, calculation of project emissions, and assessment of leakage. These are represented by the relevant equations and data monitoring procedures described in subsequent sections. This methodology quantifies GHG emission reductions achieved by replacing hydrogen produced from fossil fuels (e.g., SMR, ATR) with hydrogen produced using renewable energy-powered electrolysis. The methodology accommodates various electrolysis technologies (AEMWE, PEM, ALK, SOEC) and considers flexible project boundaries to capture on-site and off-site renewable integration.

3 Relation to Strategy and Plan of Action 2023 -2030 of the International Partnership for the Satoyama Initiative

This methodology supports the Satoyama Initiative's Strategy and Plan of Action 2023–2030 by promoting low-carbon hydrogen as an industrial and urban solution that enhances socio-ecological resilience. Specifically:

- Target 8 (Climate Change Mitigation): Avoids GHG emissions by substituting fossil-based hydrogen with renewable hydrogen.
- Target 10 (Sustainable Infrastructure): Encourages deployment of renewable-powered technologies and circular energy systems in local production landscapes.
- Target 14 (Mainstreaming Biodiversity): Reduces environmental degradation associated with fossil extraction, indirectly protecting surrounding ecosystems.

By accelerating the adoption of green hydrogen, the methodology enables local communities and industrial regions to participate in climate action while reducing ecological footprints. This methodology supports sustainable production practices and climate-resilient infrastructure in industrial regions, aligning with Targets 8 (climate change mitigation), 10 (sustainable industry), and 14 (integration of biodiversity in decision-making).

4 Relation to Kunming-Montreal Global Biodiversity Framework (GBF)

The vision of the Kunming-Montreal Global Biodiversity Framework is a world of living in harmony with nature where "by 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people."

4.1 Description

By phasing out fossil-derived hydrogen and replacing it with renewable hydrogen, the methodology supports the following GBF targets:

- Target 7 – Pollution reduction: Minimizes air, water, and soil pollution from fossil fuel extraction and combustion, benefiting terrestrial and aquatic biodiversity.
- Target 8 – Climate mitigation: Directly contributes to climate stabilization by reducing GHG emissions, addressing one of the primary drivers of biodiversity loss.
- Target 15 – Sustainable practices: Encourages industries to shift toward environmentally responsible models that account for ecological risks and dependencies.

4.2 Basic Information

Table 1 Basic Information

Rationale
Green hydrogen displaces high-emission energy pathways and alleviates ecological pressure caused by fossil fuel operations, such as habitat destruction, contamination, and climate destabilization.
Objectives
Support global biodiversity targets by embedding low-carbon hydrogen solutions into industrial systems, contributing to both emissions reductions and environmental protection.
Activities and/or practices employed
Deploy renewable-powered electrolyzers and associated infrastructure to replace fossil-derived hydrogen across various sectors.
Monitoring methodology
Monitoring follows a landscape-based and integrative approach aligned with the Strategy and Plan of Action 2023–2030 of the Satoyama Initiative and the Kunming–Montreal Global Biodiversity Framework (GBF). It includes both technical and ecological indicators: • Technical indicators: tracking hydrogen output, renewable electricity use, and operational efficiency through real-time metering and digital logs. • Ecological indicators: optional monitoring of co-benefits such as reductions in pollutant loads or land use impacts, especially in projects near sensitive ecosystems or community co-managed areas.

This integrated monitoring structure ensures environmental integrity, supports biodiversity goals, and reflects principles of adaptive, community-inclusive project evaluation. GHG reductions are measured through baseline–project comparisons, while renewable energy use and hydrogen output are continuously tracked to ensure environmental integrity.

4.3 Landscape & Seascape Approaches

Table 2 Specifically, biochar contributes to the following targets

1. Reducing threats to biodiversity
TARGET 1: Plan and Manage all Areas To Reduce Biodiversity Loss
Possible landscape & seascape -related indicators
Number of green H_2 projects outside key biodiversity areas (KBAs)
TARGET 2: Restore 30% of all Degraded Ecosystems
Possible landscape & seascape -related indicators
Area of fossil-H_2 industrial land converted or avoided (ha)
TARGET 3: Conserve 30% of Land, Waters and Seas
Possible landscape & seascape -related indicators
Number of projects complying with regional protected area regulations
TARGET 4: Halt Species Extinction, Protect Genetic Diversity, and Manage Human-Wildlife Conflicts
Possible landscape & seascape -related indicators
Air/water quality metrics near threatened species habitats
TARGET 5: Ensure Sustainable, Safe and Legal Harvesting and Trade of Wild Species
Possible landscape & seascape -related indicators
Change in emissions near migration corridors or buffer zones
TARGET 6: Reduce the Introduction of Invasive Alien Species by 50% and Minimize Their Impact
Possible landscape & seascape -related indicators
Area of natural habitat conserved through siting policy
TARGET 7: Reduce Pollution to Levels That Are Not Harmful to Biodiversity
Possible landscape & seascape -related indicators
Tons of air pollutants avoided per year per region
TARGET 8: Minimize the Impacts of Climate Change on Biodiversity and Build Resilience
Possible landscape & seascape -related indicators

Annual GHG reduction (tCO_2e) from displaced fossil hydrogen
2. Meeting people's needs through sustainable use and benefit-sharing
TARGET 9: Manage Wild Species Sustainably To Benefit People
Possible landscape & seascape -related indicators
Number of H_2 sourced locally; # of invasive events near sites
TARGET 10: Enhance Biodiversity and Sustainability in Agriculture, Aquaculture, Fisheries, and Forestry
Possible landscape & seascape -related indicators
Number of green H_2 used in biodiversity-sensitive sectors
TARGET 11: Restore, Maintain and Enhance Nature's Contributions to People
Possible landscape & seascape -related indicators
Surveyed co-benefits (clean air/water) among nearby residents
TARGET 12: Enhance Green Spaces and Urban Planning for Human Well-Being and Biodiversity
Possible landscape & seascape -related indicators
Number of urban deployments; PM concentration change in cities
TARGET 13: Increase the Sharing of Benefits From Genetic Resources, Digital Sequence Information and Traditional Knowledge
Possible landscape & seascape -related indicators
Number of training programs on biodiversity-safe H_2 implementation
3. Tools and solutions for implementation and mainstreaming
TARGET 14: Integrate Biodiversity in Decision-Making at Every Level
Possible landscape & seascape -related indicators
Number of EIA/SEA reports including biodiversity safeguards
TARGET 15: Businesses Assess, Disclose and Reduce Biodiversity-Related Risks and Negative Impacts
Possible landscape & seascape -related indicators
Number of companies adopting biodiversity reporting for H_2 projects
TARGET 16: Enable Sustainable Consumption Choices To Reduce Waste and Overconsumption
Possible landscape & seascape -related indicators
Volume of green H_2 sold under certified eco-labels
TARGET 17: Strengthen Biosafety and Distribute the Benefits of Biotechnology
Possible landscape & seascape -related indicators

Use of landscape-level biodiversity monitoring with H_2 rollout
TARGET 18: Reduce Harmful Incentives by at Least $500 Billion per Year, and Scale Up Positive Incentives for Biodiversity
Possible landscape & seascape -related indicators
Number of incentive programs rewarding biodiversity-conscious H_2 use
TARGET 19: Mobilize $200 Billion per Year for Biodiversity From all Sources, Including $30 Billion Through International Finance
Possible landscape & seascape -related indicators
Money invested in biodiversity-compliant H_2 infrastructure
TARGET 20: Strengthen Capacity-Building, Technology Transfer, and Scientific and Technical Cooperation for Biodiversity
Possible landscape & seascape -related indicators
Number of inclusive stakeholder consultations by landscape region
TARGET 21: Ensure That Knowledge Is Available and Accessible To Guide Biodiversity Action
Possible landscape & seascape -related indicators
Number of projects co-designed with Indigenous/local land users
TARGET 22: Ensure Participation in Decision-Making and Access to Justice and Information Related to Biodiversity for all
Possible landscape & seascape -related indicators
Number of women-led or community-led green H_2 installations
TARGET 23: Ensure Gender Equality and a Gender-Responsive Approach for Biodiversity Action
Possible landscape & seascape -related indicators
Availability of project-level biodiversity and GHG metrics

5 DEFINITIONS

Baseline Scenario

The situation where hydrogen is produced from fossil-fuel-based technologies (e.g., steam methane reforming, autothermal reforming), resulting in significant greenhouse gas (GHG) emissions. Used as the reference for calculating emission reductions.

Project Scenario

The condition in which hydrogen is produced using renewable energy sources (e.g., solar, wind, hydro) via electrolysis technologies, displacing the baseline hydrogen production method.

Electrolysis

A process that uses electricity to split water into hydrogen and oxygen. When powered by renewable electricity, it produces zero-emission hydrogen.

Green Hydrogen

Hydrogen generated through electrolysis powered by 100% renewable electricity sources, resulting in minimal lifecycle GHG emissions.

Blue Hydrogen

Hydrogen produced from fossil fuels (primarily natural gas) using reforming methods (e.g., SMR, ATR), typically coupled with carbon capture and storage (CCS) to reduce direct emissions.

Emission Factor (EF)

A coefficient expressing the amount of GHG emissions produced per unit of activity, such as per kg of hydrogen produced. Used in both baseline and project emission calculations.

Additionality

The demonstration that the proposed green hydrogen project would not occur in the absence of carbon finance, typically due to economic, regulatory, or technological barriers.

Leakage

GHG emissions that occur outside the project boundary as a result of project activities. In this methodology, leakage is generally negligible.

Renewable Energy Certificate (REC) / Guarantee of Origin (GoO)

Instruments used to verify that electricity consumed in a project is derived from renewable sources.

Landscape and Seascape Indicators

Metrics derived from biodiversity, ecological, or socio-environmental parameters to assess the broader impacts of green hydrogen deployment, in line with the Satoyama Initiative and GBF Targets.

Fossil Hydrogen Emission Intensity

The amount of CO2 emitted per kg of hydrogen produced from fossil fuels. Typically ranges from 9–12 kg CO2/kg H2 depending on source and efficiency.

Crediting Period

The timeframe over which verified GHG emission reductions are eligible for issuance of credits. Defined in this methodology as 7-10 years, renewable upon reassessment.

System Boundary

The physical and temporal scope of emissions and activities considered within a project, including hydrogen production, electricity sourcing, water use, and optional distribution.

Hydrogen Purity

A quality standard (typically >99.9%) required for hydrogen to be considered suitable for industrial, mobility, or energy sector applications.

GHG Accounting Tools

Methodological and computational frameworks used to quantify emissions, including CDM tools, ISO 14064 standards, and national GHG inventories.

Carbon Intensity (CI)

The GHG emissions associated with producing one unit of product (e.g., g CO2e/MJ or kg CO2/kg H2), used to compare baseline and green hydrogen performance.

6 APPLICABILITY CONDITIONS

This methodology applies to project activities that reduce GHG emissions by replacing fossil-derived hydrogen with green hydrogen produced via electrolysis powered by renewable energy. The following applicability conditions must be met:

1. General Eligibility

This methodology shall apply to project activities that meet all of the following criteria:

- The activity is located in a jurisdiction where fossil-based hydrogen is in active or planned use;
- The hydrogen production facility is either new or involves the retrofit of an existing fossil hydrogen plant;
- The hydrogen is used in one or more of the following sectors: industry, energy generation, transport, refining, or ammonia/fertilizer production.

2. Permissible Configurations

Eligible project activities may include one or more of the following configurations:

- On-site hydrogen production via electrolysis powered by co-located renewable energy (e.g., solar, wind);
- Grid-connected electrolysis facilities drawing certified renewable electricity;
- Centralized or distributed hydrogen generation systems delivering to off-site consumers;
- Green hydrogen use in sectoral blending, displacement, or full substitution applications.

3. Conditions Prior to Project Start Date

Prior to the project start date, the following conditions must be true:

- No irreversible investment (financial closure, equipment procurement) related to green hydrogen has occurred;
- The baseline hydrogen source is fossil-derived and verifiable;
- The project proponent has not claimed emissions reductions or renewable energy benefits under any other crediting scheme.

4. Renewable Electricity Requirements

- Electricity used for hydrogen production must be sourced entirely from renewable generation.
- Evidence shall include PPAs, RECs, GoOs, or on-site generation data traceable to certified renewable energy assets.
- Projects using grid electricity must demonstrate additionality of renewable share and exclude double counting.

5. Hydrogen Quality and End Use

- Produced hydrogen must meet the technical purity and delivery standards of its designated

application.

- Temporary storage, flaring, or non-displacing uses (e.g., backup-only) are not eligible unless they replace fossil hydrogen in practice.

6. System Boundary & Monitoring Readiness

- The project boundary shall include all relevant energy and emissions flows: electrolysis, electricity input, water input, compression, storage, transport (if applicable), and auxiliary systems.
- Projects must implement systems for real-time monitoring, secure data logging, and emissions accounting consistent with methodology requirements.

7. Additionality and Environmental Integrity

- The project must demonstrate that it would not proceed in the absence of carbon finance, due to economic, technological, or regulatory barriers.
- Emission reductions must not be claimed under any other policy mechanism, carbon market, or voluntary program.

7 PROJECT BOUNDARY

7.1 Temporal Boundaries

The temporal boundary refers to the duration during which the project generates eligible emission reductions. It includes:

- Project Start Date: The date at which the project begins material implementation (e.g., installation of electrolyzers or renewable power infrastructure).
- Crediting Period: Typically 7-10 years per cycle, with the possibility of renewal upon successful validation.
- Project End Date: The final date of the crediting period or the project's operational phase.

Projects must demonstrate continuous data collection and reporting throughout the crediting period.

7.2 Geographic Boundaries

The geographic boundary defines the spatial extent within which project activities, infrastructure deployment, and environmental assessments occur. It includes the areas where renewable electricity is generated or procured, where electrolysis-based green hydrogen production takes place, and where the produced hydrogen is stored, distributed, or consumed.

This boundary encompasses all physical sites where measurable greenhouse gas emissions, removals, or leakage may occur throughout the project lifecycle. It may consist of multiple discrete locations, such as:

- On-site or off-site renewable energy generation facilities (e.g., solar farms, wind parks),
- Electrolyzer installations and associated equipment (e.g., compressors, purification systems),
- Water intake or treatment infrastructure (if applicable),
- Hydrogen distribution corridors (pipelines, trucking routes),
- End-use facilities in industrial, mobility, or energy applications.

This geographic boundary ensures that all direct and indirect emissions are monitored within a consistent and verifiable spatial framework, enabling transparent GHG accounting and sustainability assessments across the hydrogen value chain.

7.3 Carbon Pools

While traditional carbon pools (e.g., biomass, soil) are not the primary focus of this methodology, the following are acknowledged:

- Energy-related carbon pools: Emissions associated with hydrogen production, electricity use, and fossil displacement.
- Infrastructure-related carbon (optional): Embedded emissions in electrolyzer units, renewable systems, and ancillary equipment, if quantified.

Carbon stocks in vegetation or soil are excluded unless the project explicitly includes land-use components (e.g., biomass-integrated hydrogen production).

7.4 Sources of Greenhouse Gases (GHGs)

The methodology includes the following GHG sources within its accounting boundary:

- Baseline Scenario (Fossil Hydrogen):
  - CO_2 emissions from natural gas reforming (e.g., SMR or ATR).
  - CH_4 leakage in the natural gas supply chain.
  - CO_2 emissions from electricity used in conventional hydrogen production (if applicable).
- Project Scenario (Green Hydrogen):
  - CO_2 emissions from electricity use (if not 100% renewable or grid-integrated).
  - Emissions from compression, purification, or storage systems (auxiliary energy use).
  - CH_4 or other trace GHGs from water treatment or equipment operation (usually negligible).

Upstream emissions from equipment manufacturing may be optionally included if consistent with lifecycle analysis protocols but are not mandatory under this methodology.

8 BASELINE SCENARIOS

8.1 Determination of the Most Plausible Baseline Scenario

The baseline scenario represents the most likely situation in the absence of project activity. For this methodology, the most plausible baseline is the continued production and consumption of hydrogen derived from fossil fuels, predominantly through:

- Steam Methane Reforming (SMR), or
- Autothermal Reforming (ATR) of natural gas.

This determination is justified based on the following:

- Market prevalence: Fossil-based hydrogen currently dominates global and regional hydrogen supply.
- Economic viability: Without carbon finance or regulatory incentives, green hydrogen remains less competitive in many markets.
- Infrastructure lock-in: Existing fossil hydrogen infrastructure (pipelines, refineries, ammonia plants) continues to drive demand for fossil-based supply.
- Policy inertia: In many jurisdictions, there is an absence of enforceable mandates for low-carbon hydrogen adoption.

Project proponents must provide verifiable evidence that fossil hydrogen would have remained the dominant pathway in the absence of the project. This may include national statistics, facility production records, or documented purchase agreements for fossil hydrogen.

Baseline emission factors must reflect the actual or representative fossil hydrogen production process in the host country or region and may be sourced from:

- IPCC default values,
- Verified national GHG inventories, or
- Peer-reviewed industry datasets.

If multiple fossil hydrogen production pathways exist, the most emission-intensive or the most commonly used process shall be adopted for conservative estimation.

8.2 Reassessment of the Baseline Scenario

The baseline scenario must be reassessed under the following conditions:

- At the start of each new crediting period (typically every 7–10 years), to ensure continued conservativeness and relevance;
- If material changes occur in the regulatory, technological, or market landscape, such as:
  - Introduction of carbon pricing that significantly alters hydrogen economics;
  - Large-scale adoption of alternative low-carbon hydrogen technologies in the same sector;

- Changes in national or regional grid electricity carbon intensity (for grid-connected fossil hydrogen plants);
- Shifts in fuel supply chains that affect upstream emissions (e.g., increased LNG imports, methane leakage rates).

The reassessment process must include updated justification of the baseline condition and revised emission factor documentation. All changes must be transparently documented and submitted for third-party validation.

9 ADDITIONALITY

This section establishes the procedures and rationale for demonstrating that the project activity is additional—that is, it would not have occurred in the absence of carbon finance.

1. General Principle

A project is deemed additional if it faces significant barriers or lacks sufficient incentives to proceed under a business-as-usual (BAU) scenario. In the context of this methodology, the production of green hydrogen via electrolysis is generally not the most economically or institutionally favored option when compared to fossil-based hydrogen (e.g., SMR or ATR), especially in jurisdictions without strong regulatory mandates or carbon pricing.
The following approach must be used to demonstrate additionality, consistent with Verra's VCS Standard and CDM Tool for the Demonstration and Assessment of Additionality (Version 7.0 or later).

2. Steps for Demonstrating Additionality

- Step 1: Identification of Alternatives
  The project proponent shall identify realistic and credible alternative scenarios to the proposed project, such as:
  - Continued production of hydrogen from fossil fuels (e.g., SMR/ATR);
  - Importation of fossil-derived hydrogen;
  - Deferred investment in hydrogen infrastructure;
  - Production of green hydrogen without carbon finance (to test financial viability).

- Step 2: Investment Analysis
  An investment analysis must demonstrate that, in the absence of carbon revenues, the project is either:
  - Not economically or financially viable (e.g., negative net present value, unattractive internal rate of return), or
  - Less attractive than one or more fossil-based alternatives.

  The analysis should include all capital and operational costs, expected revenues, and any available subsidies. Where possible, sensitivity analyses shall be provided.

- Step 3: Barrier Analysis (optional but recommended)
  Project proponents may demonstrate the existence of one or more of the following barriers:
  - Economic barriers: High capital costs of electrolyzers and renewable infrastructure.
  - Technological barriers: Limited access to reliable electrolyzer supply chains or grid interconnection.
  - Institutional or policy barriers: Lack of mandates for green hydrogen procurement; regulatory uncertainty.
  - Market barriers: Weak offtake demand; lack of long-term purchase agreements; high cost of RECs or GoOs.

If using this step, qualitative evidence must be supported by documentation (e.g., government reports, feasibility studies, market assessments).

- Step 4: Common Practice Analysis
  Demonstrate that green hydrogen deployment remains uncommon or marginal in the host country or applicable sector. This includes:
  - Market share of green hydrogen versus fossil hydrogen;
  - Number and scale of existing green hydrogen projects;
  - Status of enabling policies or national hydrogen strategies.

  If green hydrogen is not yet widely implemented without carbon finance or mandates, the project is considered additional.

3. Documentation Requirements

To satisfy the additionality test, the following must be submitted:

- A list of alternatives considered (Step 1)
- Detailed investment analysis and assumptions (Step 2)
- Evidence of barriers, if applicable (Step 3)
- Market analysis and common practice justification (Step 4)
- Sensitivity analyses and third-party validation (if available)

Projects making use of external funding mechanisms (e.g., green hydrogen subsidies, innovation grants) must disclose all sources of support to avoid double counting. Such support does not automatically negate additionality but must be assessed for material impact.

9.1 Methodological Novelty and Need for a New Approach

Existing methodologies such as AMS-III.F and VM0042 do not cover rapid-cycle enzymatic and multi-stage biological treatments (e.g., TTT technology) capable of converting organic waste into stable fertilizer within hours. This methodology fills that gap by integrating methane avoidance with soil carbon enhancement. Therefore, the methodology is required to cover advanced resource-processing pathways not supported in existing protocols.

10 QUANTIFICATION OF GREENHOUSE GAS EMISSION REDUCTIONS AND REMOVALS

10.1 Baseline Emissions

Baseline emissions refer to GHGs that would have occurred from the continued production of fossil-based hydrogen (e.g., SMR or ATR).

$$BE_{year,y} = H_y \times EF_{fossil\ H_2}$$

Where:

$BE_{year,y}$ = Baseline emissions in year y (tCO_2e)
H_y = Amount of hydrogen (in kg) displaced by the project in year y
$EF_{fossil\ H2}$ = Emission factor for fossil hydrogen production (kg CO_2e/kg H_2)

Emission factors shall be based on IPCC defaults, national databases, or validated life-cycle models (e.g., GREET, ecoinvent).

10.2 Project Emissions

Project emissions include GHGs from electricity consumption (if not 100% renewable), ancillary systems, and minor operational emissions.

$$PE_{year,y} = E_y \times EF_{elec} + PE_{aux}$$

Where:

E_y = Electricity used for hydrogen production (kWh/year)
EF_{elec} = Emission factor for electricity (kg CO_2e/kWh)
PE_{aux} = Emissions from auxiliary systems (e.g., water treatment, compression), estimated conservatively or via monitoring

If electricity is fully derived from renewable sources with proper documentation (e.g., RECs, PPAs), project emissions may be negligible.

10.3 Emission reductions due to rewetting and fire management (Fire Reduction Premium)

Not applicable to this methodology. This subsection is intentionally left blank as no rewetting or fire-related activity is included in the green hydrogen project boundary.

10.4Leakage

Leakage refers to emissions outside the project boundary resulting from the project activity.

10.4.1 Activity-shifting leakage and market leakage

Leakage from displaced fossil hydrogen production is not counted, as the project does not suppress overall hydrogen demand but rather substitutes production technology. However, in cases where fossil hydrogen production shifts to a different location or end-use market, proponents must assess potential impacts qualitatively.

10.4.2 Market Leakage

Not applicable. The project does not involve land-use conversion, biomass harvesting, or ecological displacement.

10.5 Net GHG Emission Reductions and Removals

10.5.1 Calculation of net GHG emissions reductions

$$ER_y = BE_y - PE_y - LE_y$$

Where:
ER_y = Emission reductions in year y
BE_y = Baseline emissions (from avoided fossil hydrogen production)
PE_y = Project emissions
LE_y = Leakage emissions in year y
Net reductions are considered valid if ERy > 0 and verifiable under ISO 14064 or Verra VCS standards.

10.5.2 Estimation of uncertainty

All parameter estimates must incorporate uncertainty analysis, especially:

- Hydrogen production quantity and quality
- Electricity consumption (monitored or modeled)
- Grid emission factor (if used)
- Fossil hydrogen emission factor

Where uncertainty exceeds 10%, conservative default values or discount factors may be applied in line with Verra guidelines.

10.5.3 Calculation of carbon credits

The number of Verified Carbon Units (VCUs) issued is equal to the net emission reductions after discounting for any uncertainty, leakage, or temporary buffer (if applicable):

$$VCU_y = ER_y \times (1 - U_y)$$

Where:
LE_y = Leakage emissions in year y (tCO_2e)
VCU_y = Carbon credits issued in year y (tCO2e)
U_y = Uncertainty discount rate (if applicable)

10.6 Cost Efficiency Analysis

Methane avoidance will be permanent when organic fertilizer is applied under aerobic conditions. To safeguard benefits in line with ISO 14064-2, the project will:

(1) Verify soil aeration and drainage during application.
(2) Maintain a 10–20% buffer pool against reversals.
(3) Conduct SOC sampling every 3–5 years.
(4) Apply corrective measures if SOC declines or anaerobic risks arise.
(5) Document soil management practices for transparency and verification.

This ensures both methane avoidance and soil carbon gains remain durable and verifiable.

11 MONITORING

11.1 Data and Parameters Available at Validation

Table 3 Data and Parameters Available at Validation

Parameter	Description	Source	Units
$EF_{fossil\ H2}$	Emission factor for fossil hydrogen production	IPCC, national inventory, GREET	kg CO_2e/kg H_2
Project location coordinates	Geographic boundary of project sites	GIS files, local registry	-
Design capacity of electrolyzer	Maximum annual H_2 output	Manufacturer specs	kg/year
Renewable electricity source	Type and certification (e.g. REC, PPA)	Utility contracts, registry	-
Hydrogen purity requirement	End-use specification threshold	National standard, user agreement	%

11.2 Data and Parameters Monitored

Table 4 Data and Parameters Monitored

Parameter	Description	Frequency	Method
Hy	Amount of green hydrogen produced	Continuous (metered)	H_2 flow meters, gas chromatography
Ey	Electricity consumed	Continuous	Energy meters, SCADA
Water usage	Water input per unit H_2	Monthly	Flow meters
Emissions from auxiliary systems	Energy for compression, storage	Monthly	Power logs, emission factor
Operational uptime	System runtime	Monthly	SCADA logs
Grid connection data (if any)	Emission factor of imported electricity	Monthly	Utility records

11.3 Description of the Monitoring Plan

The monitoring plan includes:

- Installation of calibrated metering devices for hydrogen output and electricity input;
- Data collection via automated logging systems with manual backup;
- Quality assurance procedures to ensure data integrity;
- Annual verification of electricity source (RECs, GoOs);
- Periodic review of system efficiency and auxiliary energy demand;
- Secure archiving of all records for at least two crediting periods;
- Independent third-party verification at each credit issuance cycle.

11.4 Data, Parameters, and Description of the Monitoring Plan to Practice the Strategy and Plan of Action 2023 -2030 of the International Partnership for the Satoyama Initiative

The monitoring system aligns with the Satoyama Initiative's goal of integrating socio-ecological production landscapes and seascapes (SEPLS) into low-carbon transitions.

- Projects must assess the interaction between hydrogen infrastructure and local land uses.
- Qualitative and spatial indicators should monitor:
  - Land use stability around generation and electrolysis sites;
  - Protection of traditional land management by Indigenous and local communities;
  - Avoidance of ecosystem disruption.

11.5 Data, Parameters, and Description of the Monitoring Plan to Practice the Kunming-Montreal Global Biodiversity Framework

In accordance with GBF Targets 1, 8, 15, and 18:

- The project must report landscape integrity metrics at least once every two years.
- Geospatial analysis should verify:
  - No encroachment into key biodiversity areas;
  - No harm to ecosystem services (e.g., water cycles);
  - Net-positive impact if vegetation is restored (e.g., solar sites with pollinator habitats).

Monitoring results shall be linked to the reporting framework under the GBF and local NBSAPs (National Biodiversity Strategies and Action Plans)

11.6 Key Performance Indicator

The Kunming-Montreal Global Biodiversity Framework has 23 action-oriented global targets for urgent action over the decade to 2030. The actions set out in each target need to be initiated immediately and completed by 2030. Together, the results will enable the achievement of the outcome-oriented goals for 2050. Actions to reach these targets should be implemented consistently and in harmony with the Convention on Biological Diversity and its Protocols and other relevant international obligations, considering national circumstances, priorities, and socioeconomic conditions.

12 REFERENCES

APPENDIX

DOCUMENT HISTORY

Version	Date	Changes & Comment
v1.0	05 January 2026	

SATOYAMA INITIATIVE

Module

Mo0001

Module for Estimation of Carbon Capture Storage using Indoor Plants

Version 1.0
Published 05 January 2026

Version 1.0 of this methodology was developed by Ph.D Amit Kumar Sharma & Prof. Yen-Hsun Su (National Cheng Kung University).

Funder: National Cheng Kung University, Taiwan.

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DOCUMENT HISTORY **13**

1 SOURCE

- VMD0022 Estimation of Carbon Stocks in Living Plant Biomass
- VT0008 Additionality Assessment
- Determination of Total, Organic, Inorganic Carbon and Total Nitrogen in Biological Cultures and Liquid Fraction Process Samples

2 SUMMARY DESCRIPTION OF THE MODULE

This module provides the methods and framework to estimate, calculate and validate carbon sequestration using indoor plants to quantify carbon credits for greenhouse use.

3 DEFINITIONS

Total Carbon

The sum of the organic and inorganic carbon including elemental carbon.

Total Organic Carbon (TOC)

The measure of the carbon stored in the organic material of the plants, derived from dry biomass after water removal.

Total Inorganic Carbon (TIC)

The measure of the carbon that is not covalently bound in the organic molecules, such as carbonate, bicarbonate and dissolved carbon dioxide.

Dissolved Organic Carbon (DOC)

Organic carbon that remains in the sample after filtration of the solution.

Living biomass

The mass of the living plant material, including above ground biomass (stem, leaves, branches) and below ground biomass (roots).

Woody biomass

The mass of organic material in stems and branches, primarily in the form of lignified tissues.

Biomass expansion factor

The ratio of the total above ground biomass (stem, leaves, branches) to total living biomass of the plant.

Project area

The area of the land on which the project proponent will undertake the project activities.

Wood density

The mass per unit volume of the dry wood of a given species.

Volatile Organic Carbon (VOC)

The sum of organic carbon that is not converted to carbon dioxide.

4 APPLICABILITY CONDITIONS

4.1 Introduction

Indoor plants mainly absorb ambient carbon dioxide from their surroundings through photosynthesis, incorporating the captured carbon into their biomass, including stem, leaves and roots. By estimating the living biomass, the amount of carbon stored in the organic material of these plants and its contribution to mitigating carbon levels in the vicinity can be determined.

Indoor plant species with high biomass accumulation potential can be selected in planting arrangements like vertical walls or pots that provide optimal growth and spatial efficiency, consequently facilitating high carbon dioxide sequestration. For plants with woody vegetation, the amount of above-ground biomass should be calculated.

Based on the preliminary stratification, the size of the plant species can be estimated. For indoor plants typically placed in small pots, measure:

- Height: measure from the base of the plant to the tallest leaf using a measuring tape
- Diameter: measure the width of the largest stem or the plant canopy at its widest point
- Growth rate: monitor changes in height, diameter or leaf count over a defined period.

4.2 Living Biomass calculations

The above ground biomass and below ground biomass in each plant can be estimated either using Allometric equations method.

The following steps can be followed:

a. Measure the diameter of the height (H) of the plant and the diameter (D) of the largest stem at its widest point. The variation in H and D may depend on the plant species and the weather conditions in the vicinity of the project area.
b. Establishing and applying appropriate allometric equations

Above-Ground Biomass calculations:

$$\text{Above-Ground Biomass (AGB) (kg)} = D \times H \qquad (1)$$

Verification must be undertaken by destructively harvesting 5 branches or stems of the species or species group to which the equation is to be applied within the project area. The biomass of these plants must be measured and compared to the results derived from the equation. If the biomass measured from the harvested plant is not more than 10% less than that predicted by the Allometric equation, it can be assumed the selected equation is suitable for the project.

If this is not the case, it is recommended to develop local allometric equations for the project. In order to develop the equations, a sample of indoor plants, representing different size classes, is destructively harvested, and the total dry biomass of each plant is determined. The number of plants to be

destructively harvested and measured depends on the range of size classes and number of species—the greater the heterogeneity the more plants are required. Finally, allometric equations are constructed relating the biomass with values from easily measured variables, such as the D and H.

Below-Ground Biomass calculations:

$$\text{Below-Ground Biomass (BGB) (kg)} = \text{AGB} \times \text{R} \quad (2)$$

where, R is root-to-shoot ratio.

4.3 Calculation of the Total Biomass

Total Biomass comprises of smaller woody and non-woody vegetation, for which a destructive sampling method must be used. The steps in sampling and calculating biomass for smaller woody and non woody biomass are:

Step 1. Stratification and determination of distribution

Additionally, stratification of the project area, where more than one variety of indoor plants are available within the leakage belt or reference region, must be undertaken using the methods specified in VMD0018 Methods to Determine Stratification. During stratification, necessary attention must be given to the species and spatial distribution and ecological and management dynamics of the indoor plant and woody species.

Step 2. Sampling

Destructive sampling entails the collection of all aboveground material within the plant pot. As such, plant pots are typically relatively small, to avoid the necessity of collecting large amounts of material. Square pots of 1 m × 1 m are acceptable where the material is relatively evenly distributed at the individual plant level. Where more heterogeneous distributions are found, larger plant pots may be considered.

Step 3. Measurement of Biomass

Within the project area, all biomass is weighed, oven dried, and weighed again, to give both green and dry weights. Ideally the biomass is oven dried, to achieve “bone dry” conditions. However, drying in direct sun may also be used. In case biomass samples are weighed after sun drying, small representative subsamples need to be taken from the larger sample, weighed, oven dried as described above, and weighed again to determine the level of residual moisture in the weighed sample. The dry weights of the samples must then be adjusted accordingly, to provide an estimated oven dry weight of the biomass.

Step 4. Testing Statistical Confidence

Calculations to test the statistical confidence of the mean must be carried out on the total above ground biomass per plant. The error of the mean must not be greater than 10%, at a 90% confidence level. In the case of small project size and a minimum of 10 pots per project are

installed, project proponents may proceed with sampling before the project commencement to determine the baseline as follows:

$$B_s = B_s \times (1 + (c_i - 0.1)) \quad (3)$$

where,

B_s = Total biomass including small woody and non-woody biomass living vegetation per stratum

c_i = The calculated confidence interval at 90% confidence

Step 5. Calculation of Total Biomass

Total Biomass small woody and non-woody biomass per stratum is then calculated using the following equation:

$$B_s = \sum_s^w b_s \times 10^2 \times A_s^{-1} \times A \times (1 + R) \quad (4)$$

where,

B_s = Total biomass including small woody and non-woody biomass living vegetation per stratum

s = small biomass plants

w = number of small biomass plants

b_s = biomass of the collected small woody and non-woody vegetation in each plant (kg)

A_s = Area of small biomass plant (m^2)

A = Area of the stratum (m^2)

R = Root-to-shoot ratio for small woody and non-woody biomass

4.4 Calculations for Total Organic Carbon (TOC)

TOC in the whole suspended plant biomass and in cell free supernatant can be determined by calculating the Total Carbon (TC) and subtracting the Total Inorganic Carbon (TIC), to avoid negative or inaccurate results and establishing a baseline. High concentrations of TIC can interfere with the absolute concentrations of TOC owing to the buffering capacity of carbonate and bicarbonate ions. Care should be taken to dry the living biomass by heat treatment. The amount of volatile organic carbon (VOC) must be determined accurately and removed from the solution by purging with VOC free gas to avoid interference with the absolute carbon dioxide stored in the living biomass.

Step 1. Sampling

The living biomass such as must be collected precisely in unused glass. The biomass may be heat-treated to ensure the removal of water. Post-heat treatment, the biomass must lose structural integrity and fall into pieces upon evaluation with a spatula. The weight of the sample must be recorded accurately, and mark as Dry Biomass.

Step 2. Calculation of TOC

TOC can be calculated using the following methods:

1. Samples with moisture or unknown Total Biomass:

$$\text{TOC} = \text{Total Biomass (kg)} \times (1 - \text{Moisture Content}) \quad (5)$$

where,
Moisture content in living biomass is typically 70%.
Additionally, the project proponents must evaluate the moisture content of living biomass in case Total Biomass calculations could not be employed.

2. Sample with known Total Biomass (calculated as per equation 3)

$$\text{TOC} = \text{Total Biomass} \times 0.5 \quad (6)$$

where,
0.5 is the most widely employed carbon content in plants
This equation can also be employed for samples prepared as per Step 3 of Section 4.3, replacing Total Biomass with the calculated Dry Biomass.

4.5 Calculations for the amount of Carbon Dioxide Stored in the plant

TOC determined from equation 5 can be used to calculate the amount of carbon dioxide stored in the plant, consequently determining the amount of carbon sequestered through the indoor plant. The ratio of the molecular weight of carbon dioxide to carbon can be multiplied with the calculated TOC to determine the accurate carbon sequestered using the plant.

$$Mass\ of\ CO_2\ sequestered\ (kg) = TOC\ (kg) \times \frac{Molecular\ weight\ of\ CO_2}{Mass\ of\ Carbon} \quad (7)$$

5 PARAMETERS

Data Unit/Parameter	b_s
Data unit	kg
Description	Average of the Total Biomass including small woody and non-woody biomass living vegetation per stratum
Source data	Estimation from ground sampling
Justification of choice of data or description of measurement methods and procedures applied	Single indoor plants are identified and randomly chosen using standard mensuration methods given in the methodology

Data Unit/Parameter	A_s
Data unit	m^2
Description	Area of the small biomass plant
Source data	Measured
Justification of choice of data or description of measurement methods and procedures applied	Measured manually

Data Unit/Parameter	A
Data unit	m^2
Description	Area of stratum
Source data	Measured
Justification of choice of data or description of measurement methods and procedures applied	Measured manually

Data Unit/Parameter	R
Data unit	Dimensionless
Description	Root-to-shoot ratio for the given plant species
Source data	Measured
Justification of choice of data or description of measurement methods and procedures applied	Derived from measured data where appropriate data is recorded. In some cases, destructive sampling may be required to determine this ratio

6 PARAMETERS

All carbon stock measurement data, calibration certificates, photographs, and calculation sheets shall be compiled in standardized formats and retained for a minimum of 10 years after credit issuance. An updated measurement report must be re-submitted for assessment by an independent expert. Project proponents must detail the procedures for collecting and reporting all data and parameters. All instruments that are used through this module must be calibrated annually by an accredited laboratory or institution. A minimum of 10% of the project area shall be independently re-sampled for quality assurance and quality control purposes. Project proponents must provide auditors with full access to all indoor plant installations and maintenance records at all reported locations. Auditors may use this module to perform random remeasurements to validate and verify. Summary data tables and raw measurements collected using this module must be provided in electronic format to project auditors upon request.

7 REFERENCES

ISO 18400-204:2017 - Soil quality — Sampling. Available at: https://www.iso.org/standard/65224.html

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APPENDIX

None

DOCUMENT HISTORY

Version	Date	Changes & Comment
v1.0	21 July 2025	Initial version release.

SATOYAMA INITIATIVE

Module

Mo0002

Module for Estimation of Carbon Stocks Changes and Greenhouse Gas Emissions from Biodiversity Ecosystem via System-of-Systems Solution in Monitoring, Validation, and Verification

Version 1.0
Published 05 January 2026

Version 1.0 of this methodology was developed by Assoc. Prof. Tsung-Sheng Cheng, Assoc. Prof. Li-Hsueh Chang, Ph.D. Li-Yu Chang (Taiwan Space Agency) & Ph.D. Ya-Hui Chang, Ph.D. Amit Kumar Sharma, Prof. Yen-Hsun Su (National Cheng Kung University).

Funder: Taiwan Space Agency.

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1 Source

- VMD0001 Estimation of carbon stocks in the above- and belowground biomass in live tree and non-tree pools (CP-AB), v1.2
- VMD0007 Estimation of baseline carbon stock changes and greenhouse gas emissions from unplanned deforestation and unplanned wetland degradation (BL-UP), v3.3
- Qualitative illustration of how different technological solutions for quantifying field-level carbon outcomes fit in the accuracy and cost diagram. (Ref: Earth-Science Reviews 243, 104462 (2023))
- Determination of Total, Organic, Inorganic Carbon and Total Nitrogen in Biological Cultures and Liquid Fraction Process Samples

2 SUMMARY DESCRIPTION OF THE MODULE

This module provides the system-of-systems solution for the methods and framework to estimate, calculate and validate carbon stocks changes and greenhouse gas emissions from biodiversity ecosystems.

Climate actions initiated under agreements like the Paris Agreement, the Kyoto Protocol, and the Convention on Biological Diversity (CBD) will determine whether the world achieves the long-term goals of the Paris Agreement. These actions must rapidly peak global greenhouse gas (GHG) emissions and then undertake steep reductions, following the best available science, to achieve a balance between anthropogenic emissions and removals by sinks. At the same time, climate actions must align with the spirit of the International Partnership for the Satoyama Initiative (IPSI) and the Kunming-Montreal Global Biodiversity Framework (KMGBF). Biodiversity is fundamental to human well-being, a healthy planet, and economic prosperity of the local communities, allowing people to live well in balance and harmony with Mother Earth.

The KMGBF is a global agreement of the 15th Conference of the Parties to the Convention on Biological Diversity (CBD COP15). The KMGBF has four long-term goals related to the 2050 Vision for biodiversity. GOAL A: Protect and Restore; GOAL B: Prosper with Nature; GOAL C: Share Benefits Fairly; and GOAL D: Invest and Collaborate. Most areas consist of multifunctional landscapes and seascapes, and their coastal waters consist mostly of multifunctional seascapes. These landscapes and seascapes may cross national and regional boundaries. Due to the high management demand on the operator, landscape approaches cannot be implemented everywhere immediately.

The KMGBF directly addresses the lack of financial resources to achieve the five goals of the Aichi Targets. A set of 20 global targets was set in 2010 by the Parties to the CBD, as a part of the Strategic Plan for Biodiversity 2011-2020. These targets are grouped in five strategic goals:

1. Strategic Goal A: Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society;
2. Strategic Goal B: Reduce the direct pressures on biodiversity and promote sustainable use;
3. Strategic Goal C: To improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity;
4. Strategic Goal D: Enhance the benefits to all from biodiversity and ecosystem services;
5. and Strategic Goal E: Enhance implementation through participatory planning, knowledge management and capacity building. The KMGBF is best understood as the global community's course correction following the partial achievement of the Aichi Targets.

Actions of monitoring the Geographic Information System to reach these targets should be implemented consistently and in harmony with the Convention on Biological Diversity and its Protocols and other relevant international obligations, taking into account national circumstances, priorities, and socioeconomic conditions. Recognizing the efforts of local proponents of landscape approaches encourages them to continue and expand their work. Using the carbon credit program as a public model can further amplify this impact and guide others. SEPLS carbon credit regional revitalization approaches are tools and solutions for implementation and mainstreaming. SEPLS

carbon credit regional revitalization approaches in carbon credit programs not only reduce threats to biodiversity but also meet people's needs through sustainable use and benefit-sharing by designing and shaping the implementation, corresponding to Kunming-Montreal Global Biodiversity Framework (KMGBF).

Biodiversity carbon reduction technologies offer several benefits for local communities, including:

1. Enhanced Ecosystem Services: These technologies help in restoring and maintaining ecosystems, which provide essential services such as clean water, air purification, and soil fertility. Healthy ecosystems contribute to better agricultural productivity and food security.
2. Climate Resilience: By promoting biodiversity, these technologies can enhance the resilience of local communities to climate change impacts. Diverse ecosystems are better able to withstand environmental stress and recover from disturbances.
3. Economic Opportunities: Implementing carbon reduction technologies can create new job opportunities in areas such as sustainable agriculture, ecotourism, and conservation. Local communities can benefit from initiatives that promote sustainable practices and generate income.
4. Community Engagement and Empowerment: Involving local communities in biodiversity conservation and carbon reduction efforts fosters a sense of ownership and responsibility. This engagement can strengthen community ties and promote collaborative efforts for environmental stewardship.
5. Cultural and Social Benefits: Biodiversity is often linked to cultural identity and heritage. Protecting and enhancing local ecosystems can help preserve traditional knowledge, practices, and cultural landscapes, contributing to community well-being.
6. Improved Health Outcomes: Cleaner environments resulting from healthy ecosystems can lead to better public health outcomes. Reduced pollution and enhanced natural spaces promote physical and mental well-being.
7. Access to Funding and Resources: Participation in biodiversity carbon reduction initiatives can provide local communities with access to funding from governmental and non-governmental organizations focused on climate action and conservation.
8. Sustainable Resource Management: These technologies encourage the sustainable use of natural resources, reduce overexploitation and ensure that resources are available for future generations.

Biodiversity carbon reduction technologies contribute to environmental sustainability and support local communities' socio-economic development.

A foundational and scalable framework to quantify field-level carbon outcomes for farmland, which is based on the holistic carbon balance of the agroecosystem (Guan et al., 2023):

$$\text{Agroecosystem Carbon Outcomes} = \text{Environment (E)} \times \text{Management (M)} \times \text{Crop (C)}$$

When the referred aspect considers the ecosystem, the quantification of field-level carbon outcomes can be placed on the holistic carbon balance of the ecosystem, such as:

$$\text{Ecosystem Carbon Outcomes} = \text{Environment (E)} \times \text{Management (M)} \times \text{Chloroplastida (C)}$$

In terms of Management (M), incorporating GBF, the IPSI Strategy, and IPSI Plan of Action into management actions will enable a more effective achievement of the GBF 2050 goals and the UNFCCC 2050 goals.

Different technological solutions for quantifying field-level carbon outcomes have many advantages and disadvantages (as shown in Figure 1 illustration). An integration of a more viable path, including sampling, sensing, and modeling is a novel aspect for quantification of field-level carbon outcomes, called "System-of-Systems" solution. The integration of a more viable path is also excellent tool for quantification of field-level monitor for climate change issues on all targeted fields for SEPLS to strengthen sustainable value chain development. The integration with the accurate simulation results of different GHGs and organic carbon in the NIR range to NIR identification within the frame of the above-mentioned system can become a milestone to understand organic carbon, CO_2, CH_4, and N_2O in the carbon cycle, which can save sampling time and cost. By establishing the correlation between organic carbon changes and CO_2, CH_4, and N_2O, we can also accurately calculate the dynamic exchange/release/storage status of CO_2, CH_4, and N_2O. Therefore, we introduce a system-of-systems frame based on the artificial intelligence (AI) data-driven: simulation/sampling/satellite. Alternatively, simulation models can be developed using the knowledge of dynamic physical interactions within ecosystems and between human or social systems without AI assistance.

Furthermore, United Nations Environment Program (UNEP) recently proposed that wetlands (including aquatic plants, coral reefs, and mangroves) have the largest carbon storage capacity (Howard et al, 2017). Satellite technology remote sensing can make up for the difficulties in sampling. However, in satellite technology, if NIR is used, it has high reflectivity at the water/air interface and low penetration in the water body. In recent years, microwave remote sensing technology has also been developed. L-band microwave (300-150 mm wavelength) radiometry can be used to observe the physical changes of surface plants and water bodies. Active or passive microwave remote sensing is used to indirectly estimate the total organic carbon in the soil (Soil Organic Carbon, SOC) and the dynamics of organic carbon below the surface of the water body or under the phytoplankton layer, using the indirect physical response of microwave signals to make inferences. The microwave monitoring range covers P, L, S, and C bands (1300 mm- 300 mm, 300-150 mm, 150-75 mm, and 75-37.5 mm in wavelength). If the GHGs and organic carbon spectrum simulation and satellite telemetry information in the microwave band can be further considered, the accuracy can be improved, and the original measurement of yellow carbon (soil carbon sink) can be extended to plant carbon sink (green carbon) and water carbon sink (blue carbon).

3 DEFINITIONS

All terms in the following module are used inline with Satoyama Mace GHG program definitions.

Normalized Difference Water Index (NDWI)

A dimensionless index that detects and monitors surface water features by quantifying the difference in reflectance between green and near-infrared spectral bands.

Normalized Difference Vegetation Index (NDVI)

A dimensionless index derived from remote sensing measurements, representing vegetation greenness and health by quantifying the difference in reflectance between near-infrared and red wavelengths.

Sentinel-1 Synthetic Aperture Radar (SAR)

Synthetic Aperture Radar (SAR) from Sentinel-1 satellites uses microwave pulses, making it immune to cloud cover and lighting conditions, operating in C-band frequency to provide high-resolution day and night imagery for monitoring land use, crop rotation, forest cover, soil moisture, and wetlands.

Soil Moisture Active Passive (SMAP) Microwave

SMAP Microwave refers to satellite-derived soil moisture measurements utilizing L-band microwave radiometry and radar. SMAP is a NASA mission that combines passive microwave radiometer observations and active (radar) measurements to generate global, high-resolution maps of surface soil moisture and its freeze/thaw status.

Soil Organic Carbon (SOC)

The organic component contained within the mineral and organic fractions of soil (including peat), quantified based on the mass of organic carbon per unit area for a defined stratum and depth.

4 APPLICABILITY CONDITIONS

This module is applicable to all ecosystem types and age classes.

5 PROCEDURES

5.1 Introduction

The complex problem of quantifying environmental factors in an ecosystem cannot be solved by using a single sensor or a model alone. The complex problem can only be solved by effectively integrating various approaches, which includes satellite remote sensing (System 1: Satellite/telemetry systems), sampling (sampling, ground sensing, and airborne for System 2: Field survey system), spectrum simulation of GHGs and organic carbon in the NIR and microwave regions (System 3: Simulation system), a process-based model and data driven model (System 4: Machine Learning Modeling System). The above integration, as the "cross-scale sensing" approaches, reaches the goal of quantification of field-level monitoring for climate change issues to be applied in System 5: Management and Decision-making System.

5.2 Biomass calculations

Sample design example for forest soil organic carbon & mangrove water total organic carbon:

1. Sample number setting

   1.1 Forest SOC

   - Set up at least 3 to 5 sampling points for every 10 hectares
   - Samples must cover different terrains (ridges, slopes, valleys, plains)
   - Stratified sampling: random sampling after grouping by NDVI or vegetation type
   - Soil depth should be consistent throughout the measurements, e.g. 0-30 cm to predict SOC

   1.2 Mangrove TOC

   - One sampling point is set every 500 meters in each waterway
   - Contains different flooding frequency areas in the intertidal zone (high frequency flooding, medium frequency, low frequency)
   - Stratified sampling: Sampling is divided into layers according to NDWI, water depth, and salinity gradient

2. Sample Design Process

Figure 1 Flowchart of Sample Design Process

3. Add system to systems design

3.1 Upstream systems (System 1: Satellite/telemetry systems)

- SMAP Microwave
- MODIS vegetation index
- Sentinel-1 SAR
- Sentinel-2 Water Color/Vegetation
- Auxiliary data from satellite/telemetry systems and so on…..

Provides large-scale background fields (forest/water body spatial heterogeneity)

3.2 Ground system (System 2: Field survey system)

- Soil carbon measurement
- Dissolved carbon measurement in water
- Environmental conditions records
- Provide basic point data as a basis for model training/verification

3.3 Theoretical system (System 3: Simulation system)

- Soil carbon and GHGs simulation in NIR
- Soil carbon and GHGs simulation in Microwave
- Soil carbon and GHGs simulation in spectrum

Provide basic point data as a basis for model training/verification

3.4 Estimation System (System 4: Machine Learning Modeling System)

- Generative AI 2.0 model
- Reinforcement learning model
- Deep Learning model
- Other machine learning or geostatistical estimation methods

Build a regional estimation model by linking system 1, system 2, and system 3 data

3.5 Application System (System 5: Management and Decision-making System)

- SOC/TOC map generation
- Identification of hotspots (high carbon and low carbon areas)

- Long-term change monitoring

The results support forest carbon sink assessment, water ecological management, and carbon rights market application in biodiversity.

5.3 Frequency of measurement for dynamic baseline

Measurements of initial stocks employed in the baseline must take place within the period of the project start date, for simplicity referred to here as stocks at t=0. Biomass stock estimates are valid in the baseline (i.e. treated as constant) for period, after which they must be re-estimated from new field measurements.

Option 1: In general, for each stratum, where the re-measured estimate is within the 90% confidence interval of the t=0 estimate, the t=0 stock estimate takes precedence and is re-employed, and where the remeasured estimate is outside (i.e. greater than or less than) the 90% confidence interval of the t=0 estimate, the new stock estimate takes precedence and is used for the subsequent period.

Option 2: In accordance with scientific measurements and the public welfare and justice of the indigenous people, the setting of dynamic baseline is also able to be selected. For dynamic baseline, the new stock estimate takes precedence and is used for the subsequent period.

5.4 Calculations for Total Organic Carbon (TOC)

After the TOC map of the different definition types at time t is generated using a system-of-systems approach, it is then considered based on the different definition types (land above ground, land below ground, water above water, water within water above ground, water within water below ground, etc.) and area, and the TOC for each definition type is generated. The TOC for each definition type is then summed to obtain the total TOC at time t.

$$\mathrm{C} = \sum_{i}\sum_{m}(\mathrm{C}_{\mathrm{TOC,m,i,t}} - \mathrm{C}_{\mathrm{TOC,m,i,t-1}}) \times A_{m,i}$$

where

C = total TOC

i = 1, 2, 3 …. the definition types (land above ground, land below ground, water above water, water within water above ground, water within water below ground, etc.)

m. = 1, 2, 3….. the index of area

$C_{TOC,m,i,t}$ = TOC of the i definition types in the m index of area at time t in $A_{m,i}$

$A_{m,i}$ = The m index of Area for the i definition types at time t

The ratio of the molecular weight of carbon dioxide to carbon can be multiplied with the calculated TOC to determine the accurate carbon sequestered using the plant.

$$Mass\ of\ CO_2\ sequestered\ (ton) = TOC\ (ton) \times \frac{Molecular\ weight\ of\ CO_2}{Atomic\ Weight\ of\ Carbon}$$

6 PARAMETERS

Data Unit/Parameter	$C_{TOC,m,i,t}$
Data unit	ton
Description	TOC of the i definition types in the m index of area at time t
Source data	Estimation from system-of-systems methods
Justification of choice of data or description of measurement methods and procedures applied	Estimation from system-of-systems methods

Data Unit/Parameter	A_m
Data unit	m^2
Description	Area for the i definition types at time t
Source data	Measured
Justification of choice of data or description of measurement methods and procedures applied	Measured manually

7 REFERENCES

VMD0001 Estimation of carbon stocks in the above- and belowground biomass in live tree and non-tree pools (CP-AB), v1.2 Available at: https://verra.org/methodologies/vmd0001-estimation-of-carbon-stocks-in-the-above-and-belowground-biomass-in-live-tree-and-non-tree-pools-cp-ab-v1-1/

VMD0007 Estimation of baseline carbon stock changes and greenhouse gas emissions from unplanned deforestation and unplanned wetland degradation (BL-UP), v3.3 Available at: https://verra.org/methodologies/vmd0006-estimation-baseline-carbon-stock-changes-greenhouse-gas-emissions-from-planned-deforestation-planned-degradation-blpl-v1-4/

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APPENDIX

None

DOCUMENT HISTORY

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v1.0	21 July 2025	Initial version release.

SATOYAMA INITIATIVE

Module

Mo0003

Methods for Soil Sampling, Preservation and TOC, CH4, N2O Analyses

Version 1.0
Published 05 January 2026

Version 1.0 of this methodology was developed by Asst. Prof. Cheng-Han Lee & Prof. Yen-Hsun Su (National Cheng Kung University).

Funder: National Cheng Kung University, Taiwan.

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7 REFERENCES **10**

APPENDIX **11**

DOCUMENT HISTORY **11**

1 Source

- ISO 18400-204:2017 - Soil quality — Sampling
- ISO 20951:2019 - Soil Quality — Guidance on methods for measuring greenhouse gases (CO_2, N_2O, CH_4) and ammonia (NH_3) fluxes between soils and the atmosphere
- ISO 10694:1995 Soil quality — Determination of organic and total carbon after dry combustion (elementary analysis)
- NIEA S102.64B Soil sampling methods（土壤採樣方法）
- NIEA S103.60C General principles of soil testing methods（土壤檢測方法總則）
- TARI S201.1B
- Determination of Total, Organic, Inorganic Carbon and Total Nitrogen in Biological Cultures and Liquid Fraction Process Samples

2 SUMMARY DESCRIPTION OF THE MODULE

This module details methods for quantifying total organic carbon (TOC), methane (CH_4), and nitrous oxide (N_2O) in soils, encompassing procedures for sampling, preservation, and analysis. The methodology is consistent with the Paris Agreement, the Kyoto Protocol, and the calls to action of the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP26), thereby supporting global climate objectives. It provides a rigorous foundation for carbon-emission accounting and for assessing the mitigation potential of activities in agriculture, land use, and related sectors.

2.1 Soil GHG Dynamics

Net-Zero Emissions does not mean the complete absence of greenhouse gas output. Instead, the goal is to reduce anthropogenic emissions while deploying negative-emissions technologies (NETs) and expanding carbon sinks in forests, oceans, and soils. The Agricultural Net-Zero agenda is structured around four pillars—reduction, sink enhancement, circularity, and green transition. Within the reduction pillar, the essential first step is to detect current greenhouse gas sources of soil and to quantitatively benchmark emissions under conventional practices versus mitigation interventions. These data underpin the design of mitigation strategies and the assessment of both mitigation capacity and outcomes.

2.2Analysis of TOC, CH_4, and N_2O In Soil: Sampling × Analyses

We propose a technological solution for TOC, CH_4, and N_2O outcome measurement:

- Sampling: Ground-truth field collection
- Preservation: Set up a sample preservation method
- Analysis: Develop the analytical process of TOC, CH_4, and N_2O in soil

This integrated approach supports:

- Cost-effective monitoring of organic carbon and GHGs
- Real-time understanding of TOC, CH_4, and N_2O fluxes
- Enhanced visibility into soil-based (yellow carbon) sink

3 DEFINITIONS

All terms in the following module are used in line with the Satoyama Macs GHG program definitions.

4 APPLICABILITY CONDITIONS

This module is applicable to all ecosystem types and age classes.

5 PROCEDURES

5.1 Introduction

In crop production, TOC, CH_4, and N_2O are the principal greenhouse gases associated with soils. Soil both sequesters and releases carbon; net carbon exchange is governed by the balance between photosynthetic carbon fixation and carbon released via plant and microbial respiration and the decomposition of plant residues. CH_4 emissions arise mainly from the anaerobic decomposition of organic matter, whereas N_2O emissions arise from fertilizer-induced nitrogen losses—volatilization, leaching, and runoff. Emission magnitudes vary with plant type, regional edaphic and climatic conditions, and cultivation and management practices.

5.2 Soil Sampling

- For the target analytes currently under investigation, soil shall be collected with a thin-walled tube sampler to a depth of at least 30 cm. During coring, rotational drilling is to be avoided; instead, apply axial pressure to drive soil into the hollow sampling tube so as to prevent and minimize disturbance. For analysis, separate topsoil (0–15 cm below ground surface) and subsoil (15–30 cm below ground surface) and analyze them independently.
- Thin-walled tube sampler: Typical specifications for outside diameter / wall thickness / tube length are as follows: 50.8 mm / 1.24 mm / 91 cm, 76.2 mm / 1.65 mm / 91 cm, and 127 mm / 3.05 mm / 145 cm. The sampler shall be connected to the sampler adaptor and pusher of either manual augering equipment or a mechanized power drilling rig. When the tube diameter is at least six times the maximum particle size of the soil, the sampler yields a relatively undisturbed specimen that preserves the soil's structure, bulk density, porosity, water content, and other physical and mechanical properties.
- Because the analytes are CH_4 and N_2O, grab sampling shall be used; composite sampling is not permitted.
- Contamination control. Soil samples shall be protected from contact with ambient air and external contamination (e.g., direct hand contact) to prevent microbial activity from altering the results.
- Set up at least 3 to 5 sampling points for every 10 hectares
- Samples must cover different terrains (ridges, slopes, valleys).

5.3 Sample Preservation

- Sample container: Immediately after collection, place each soil specimen in a 250 mL straight-sided, wide-mouth glass jar with a PTFE-lined screw cap. Record the sampling time, location, and depth. The sealed jar may be double-bagged in plastic to prevent contact with ambient air.
- Cold storage: Refrigerate at 4 ± 2 °C and transport to the laboratory as soon as possible. Analyses should preferably be completed within 24 h of sampling to minimize microbial activity and changes in gas release.
- Labeling: All collected and preserved samples shall bear a label including at least: (1) sample ID; (2) sampler's name and affiliation; (3) date and time of collection; (4) sampling location; (5) analytical targets/items; and (6) preservation/holding conditions.

5.4 Sampling and Analysis of TOC, CH_4 and N_2O In Soil

Pre-analysis processing: Sieve the soil to remove debris, then subject it to low-temperature drying (40–60 °C) to reduce moisture content.

5.4.1 TOC Analysis

- TIC (total inorganic carbon) removal (acidification pretreatment): Prior to analysis, the sample is treated with 4M HCl under the liquid to solid ratio of 10 mL/g to convert inorganic carbonates to CO_2. During a drying step lasting several hours with gradual temperature elevation, the evolved CO_2 is released/vented, thereby eliminating TIC and allowing selective determination of TOC.
- TOC determination: After acidification to remove TIC, TOC is measured by high-temperature combustion at ≥900 °C. Under oxygen-rich conditions, carbon in the sample is oxidized to CO_2, which is subsequently quantified using analytical instrumentation.
- This procedure is routinely applied to soils, where combustion at temperatures above 900 °C ensures complete oxidation of carbonaceous matter.
- Analytical instrumentation: Gas chromatography (GC), cavity ring-down spectroscopy (CRDS; laser-based absorption), or Fourier transform infrared spectroscopy (FTIR) may be used to quantify gas concentrations.

5.4.2 CH_4 and N_2O Analyses

- Closed chamber: The principle is to place a sealed enclosure over the soil surface to create an airtight headspace.
- Dynamic headspace sampling (purge-and-trap): A gas-phase extraction technique for volatile and semi-volatile analytes. After enclosing the soil to form a sealed headspace, an inert carrier gas (e.g., N_2) is passed through to purge target compounds from the matrix, and the purge stream is subsequently analyzed by gas chromatography or other instruments.
- Soil-gas extraction: Using a miniature vacuum pump to withdraw pore gas directly from within the sealed enclosure; the slight negative pressure facilitates the release of CH_4 and N_2O from the soil. The extracted gas is then introduced to the analyzer.
- Analytical instrumentation: Gas chromatography (GC), cavity ring-down spectroscopy (CRDS; laser-based absorption), or Fourier transform infrared spectroscopy (FTIR) may be used to quantify gas concentrations.

6 PARAMETERS

Data Unit/Parameter	TOC, CH_4, and N_2O
Data unit	mg/L
Description	The concentration of TOC, CH_4, and N_2O in soil
Source data	From Analytical instrumentation
Justification of choice of data or description of measurement methods and procedures applied	Gas chromatography (GC), cavity ring-down spectroscopy (CRDS; laser-based absorption), or Fourier transform infrared spectroscopy (FTIR) are used for justification of choice of data

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APPENDIX

None

DOCUMENT HISTORY

Version	Date	Changes & Comment
v1.0	15 August 2025	Initial version release.

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About the Cover
Integrating satellite imagery with environmental governance, this design uses remote sensing and global networks to symbolize precision ecological monitoring from space. By implementing carbon mitigation through transparent data, it represents a tangible contribution to the KMGBF framework and a shared commitment to a sustainable future. (The cover story is designed and supported by Taiwan Space Agency (TASA).)