Scaling soil organic carbon sequestration for climate change mitigation

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ABOUT CCAFS

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COVER PHOTO

Rice paddy in the Mekong River Delta in Vietnam. Credit: 2013 V. Meadu (CCAFS)

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Executive Summary

Moving towards net zero GHG emissions by 2050 is likely a pre-condition for avoiding global warming higher than 1.5° C by the end of the century. The land-use and agriculture sector can provide close to one third of this global commitment while ensuring food security, farmer resilience, and sustainable development. Protecting soil organic carbon (SOC) and sequestering carbon in organic matter-depleted soils might cost-effectively provide close to 15% of this target and support another 15% from large-scale restoration and implementation of best agronomic practices.

Major players across food systems have recognized SOC's potential and are setting up SOC sequestration-based targets to reduce corporate GHG emissions. However, farmer incentives, consumer education for informed choices, and transparent, accurate, consistent, and comparable methods for measurement, reporting, and verification (MRV) of changes in SOC stocks are lagging behind and preventing large-scale SOC protection and sequestration from fully taking off. Improvements in SOC MRV could be achieved notably through deploying new technologies and enabling standardized protocols at low transaction costs.

The development of cost-effective SOC MRV would therefore help to unlock carbon assets and implementation of best agronomic practices at scale. This is especially applicable to developing countries where most of the opportunities to implement improved practices are found. Broadly speaking, developing countries are characterized by limitations in data availability and a lack of technical capacity and infrastructure for implementing and running a robust SOC MRV. In this context, the private sector and international development organizations – such as multilateral development banks (MDBs) – can play a crucial role given their global reach and investment capacity.

By reviewing existing SOC MRV protocols and lessons learned from carbon projects that view SOC as a climate benefit and testing them against other projects, this report provides strategic recommendations to the World Bank Group's (WBG) Carbon Markets and Innovation team (CMI) and Agriculture and Food Global Practice (GP) division. The recommendations provide guidance for implementing cost-effective SOC MRV of the WBG's agricultural investments while improving the standardization of processes for creating carbon assets – with the potential to scale across multilateral and international development agencies and governments.

Findings

Several protocols, tools, and standards exist for accounting and monitoring SOC changes in agricultural systems. These existing SOC MRV systems rely on similar indicators (e.g., soil characteristics and management), but vary in input data details, thus, providing a rational structure that can be implemented in various contexts and improve the accuracy of estimates over time.

Practice-based (or activity-based) accounting and monitoring is a pillar of existing SOC MRV systems in local and regional projects and programs. By tracking practices (less expensive) rather than direct soil measurements (more expensive), practice-based approaches are a cost-effective way of estimating SOC changes and are more robust when accompanied by process-based models combined with strategic soil measurement for deriving rates of SOC sequestration, which is the main approach recommended and used in voluntary carbon market (VCM) methodologies.

However, since it is recommended that model calibration and continuous improvement be conducted against field measurements to reduce uncertainties, this condition may impose limitations for specific countries and contexts in the short run. In such cases, the use of basic accounting approaches (e.g., IPCC-Tier 1) is a good starting point. Furthermore, recent innovations and applicability of remote sensing techniques and soil databases will soon play a key role in improving data availability, reducing costs, and improving accuracy in estimating SOC changes.

Major features of implemented MRV of SOC

Principles	Features of successful implementation of MRV of soil carbon
SOC accounting and monitoring	▪ Use of practice-based accounting and monitoring for cost-effective SOC MRV ▪ Adoption of model-informed look-up tables for reducing cost and complexity of SOC accounting and monitoring ▪ Process-based models continuously improved and calibrated against field measurements for accuracy ▪ Building datasets to fill data gaps (e.g., field surveys and climate stations) ▪ Discounts are applied for conservativeness, based on SOC accounting uncertainties and permanence as well as project leakage and realization
Emerging innovations	▪ The major innovations relate to remote-sensing, especially for gathering activity data and estimating SOC changes when coupled with models. ▪ Soil probes, portable analyzers, and artificial intelligence are promising innovations for lowering costs and increasing the speed of direct SOC measurements.
Supporting actions for SOC MRV implementation (institutional arrangement and stakeholder engagement)	▪ Establishing a decision-making body composed of policy-makers, academia, project implementers, and farmers ▪ Participatory planning and monitoring and evaluation (M&E) of a farmer-led implementation system ▪ Getting community stakeholders on board to ensure the permanence of the project after an intensive development phase ▪ Providing farmers with substantial technical assistance and meaningful eligible practices to enhance productivity, generate extra revenue, and improve resilience

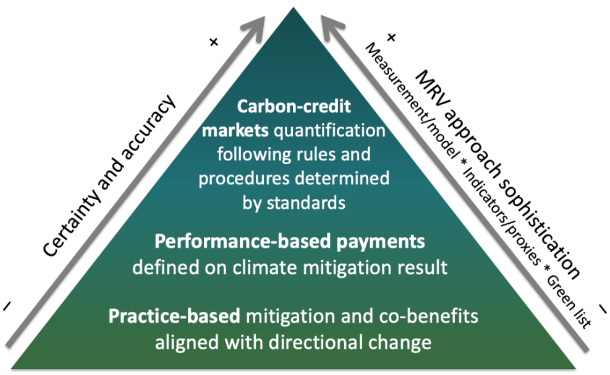
- Researchers to develop robust scientific methodologies with rigorous peer review. Practitioners to review protocols and ensure practicality. Value-chain actors to understand potential and evaluate investments.
- Inter-ministerial coordination, including between central and local government, building linkages with complementary land-planning and environmental programs.
- Alignment with country-level GHG inventories and communications with the UNFCCC

In addition, this report identifies major measures to support SOC MRV implementation that can be broadly categorized as: (1) decision-making bodies composed of policy makers, academia, project implementers, and farmers; (2) measures in the early stages of involving farmers, practitioners, and non-state actors (e.g., consulting companies and NGOs); (3) capacity-building activities to support the implementation of meaningful eligible practices by farmers. It is important to point out that, although this work is focused on the agriculture sector, findings can be also applied to forestry and other land-use-based projects.

Recommendations

To choose an SOC accounting protocol, it is important that projects clearly define their objectives and evaluate current capacity for adopting available resources for SOC MRV. Going through this process will help project developers plan for MRV implementation.

Given the WBG's global reach and presence in various countries – in diverse contexts and capacities – and to achieve improved standardization of processes for creating carbon assets, this study recommends an initial development of model-informed look-up tables with SOC variation factors. This approach can significantly reduce SOC MRV implementation and operationalization costs and verification complexity by permitting practice-based accounting and monitoring with known uncertainties and providing a rational structure capable of being implemented in various contexts and improved as better data is available and generated over time. Recent and upcoming developments in remote sensing techniques and large-scale soil databases, especially for data retrieval, will increase cost-effectiveness and facilitate the implementation of SOC MRV in the coming years.



Fit-for-purpose MRV of soil carbon

The required level of certainty and accuracy in an SOC MRV system depends on its purpose. While a high level of certainty is required in order to be able to issue carbon credits in the voluntary carbon market, a coarser estimate of SOC change is sufficient for reporting in other circumstances. Generally, the higher the targeted certainty and accuracy, the more sophisticated and resource-intensive the MRV system.

For WBG projects intended for monitoring SOC, an adequate SOC MRV system should always be guided by the purpose for SOC monitoring and the available resources to establish such an MRV. To ensure the implementation of fit-for purpose, efficient MRV systems, it is important to have incentive structures in place that encourage fulfilment of the necessary tasks by the stakeholders involved. This report presents a set of principles that encourage successful uptake of SOC MRV systems based on practical experiences and expert opinions:

- **The MRV system is based on existing institutional structures that provide appropriate accountability to the project or national context:** This principle requires a thorough assessment of any existing MRV structures, in particular of the agriculture sector, to identify ways of integrating SOC monitoring. This includes an understanding of the institutional and regulatory environment and the available structures and arrangements for collection of farm-based data.
- **Aligning the system with farmers' interests through a bottom-up activity-based approach:** To be relevant to farmers, emphasis should be placed on collecting farm-level data they would find useful, but would also be used for soil carbon and GHG emission calculation. Such data relate primarily to monitoring the productivity of the farming system. Therefore, when engaging farmers in the design and implementation of the proposed data system, emphasis should be placed on using the data collection system to monitor farm productivity, its relation to farm practices, and their long-term impact on productivity. This is meant to align data collection closely with farmers' data interests and engage them in farm-level data collection so they can relate to their farm management.
- **Activity-based MRV approach is designed to achieve multiple benefits:** The collection of farm activity data should ideally serve the assessment of multiple indicators. Ideally, MRV systems for all categories should focus on multiple benefits, and particularly on providing incentives for maintaining the system over time. Above all, the system should be transparent for farmers who are actively involved in the implementation of practices related to SOC sequestration. This includes identifying specific training needs and priority interventions for extension services. Activity monitoring engages the farmer, provides crucial information to improve extension and self-learning structures, and creates an environment conducive to committing the farmers to the relevant adaptation or mitigation activities.

- **The quantified climate benefits are real, accurately quantified with known uncertainties:** For all categories of SOC MRV systems, it is important to represent the actual situation on the ground and not simply to be artifacts of incomplete or inaccurate monitoring. In addition, it is important to apply the logical theory of change for performance-based and carbon crediting schemes where changes and benefits of SOC can be attributed to the impacts of the particular activities being promoted and are not a result of other factors, including climate change. For carbon crediting schemes, MRV systems in place must accurately quantify the uncertainties involved. Therefore, these projects usually require a statistical sampling approach for their activity-based MRV system to collect relevant parameters at the farm or household level. For projects where SOC represents an indicator for the assessment of transformational or directional change, the uncertainties of the applied MRV system should be assessed more descriptively way by acknowledging the gaps and potential sources of uncertainties without quantification.
- **The system includes provision for quality control and quality assurance (QC/QA):** One of the key gaps in many existing data collection systems is inadequate (if any) QC/QA procedures. Setting clear standards is essential for ensuring integrity across all MRV categories – carbon crediting schemes and other performance-based programs are a higher priority. This means all procedures required by an MRV system (data recording, survey activities, data processing, analysis, and data archiving and reporting) are encoded in explicit rules that are transparently communicated, taught, and verified.
- **Cost-effective MRV design:** Any MRV system monitoring the performance of SOC mitigation activities needs to be cost-efficient. However, for MRV categories with set rules and requirements in terms of uncertainty and verifiable results, there is a trade-off between certainty and cost, which often leads to demanding MRV systems including in terms of costs. Important points to consider to reduce costs are linking the system to existing national monitoring and evaluation (M&E) institutional structures and using many parameters already monitored regularly as part of any existing system; using existing available datasets from global, regional or national sources. These data are needed to establish a relationship between the activity-based farm data and other important conditions (e.g., climate, soil conditions, available GIS data and databases, etc.); developing easy-to-use digital data collection solutions and web-based analysis tools for data aggregation, automatic processing and reporting.

Putting recommendations into practice. By assessing three specific WBG projects, this report provides a first set of recommendations regarding the design options of SOC MRV. The *Niger Community Action Project for Climate Resilience (Niger CAPCR)*, for example, represents a case in its final stages of implementation of various Sustainable Land and Water Management (SLWM) practices in Niger. The current MRV design does not represent a project or activity-based approach, rather a wholesale approach for reporting SLWM financing on a national scale. The ambition of a SOC MRV system taken from this program as a general case would be to establish a national low-cost, low transaction but robust results-based SLWM financing approach. A "Benchmarking SOC Monitoring System" could be established by using SOC as a proxy indicator for the implementation of Nationally Determined Contribution (NDC) targeted activities such as SLWM in Niger with multiple programs and projects all contributing to the performance on a national level.

This means that, on a national level, the performance efforts of various projects and programs targeting the implementation of different SLWM practices are measured over time by introducing a SOC mitigation score, for instance, from 1 (= low performance) to 5 (=maximum, optimal performance). This allows a comparison of different projects and programs implemented within different agro-ecological conditions and land-uses and aggregate project/program level performance to a national SOC mitigation score, comparing it to the national benchmark (e.g., in the NDC). The benchmarking must be done on a national level and ideally on each project/program level to represent the maximum mitigation potential. This reflects an optimal ex-ante estimation in tCO_2 sequestered per year in the soil, which requires defining a baseline scenario.

The monitoring of a project/program should take place annually and capture the following minimum data in order to then derive the SOC mitigation score for a particular year compared to the benchmark:

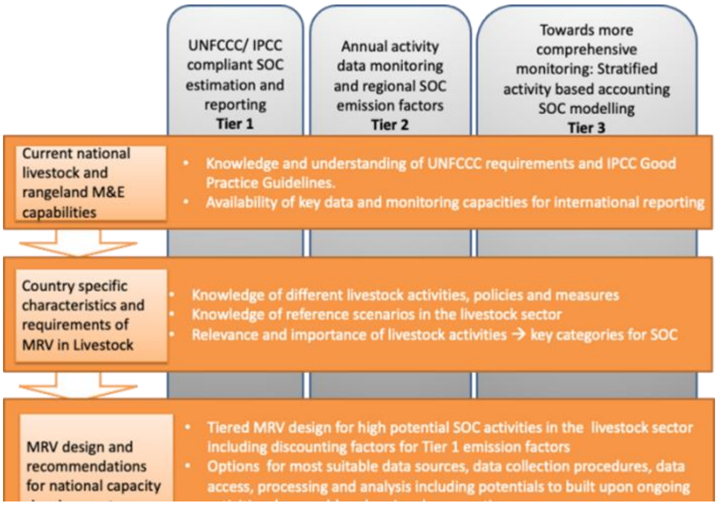
1. Georeferenced areas of implementation. The level at which this is reported can vary from project to project or program.
2. Assessment of adoption areas (ha or % of total) for each relevant and implemented SLWM practice, ideally for each identified level of implementation.
3. Yield of target crops (kg/ha) ideally for each assigned level of implementation.
4. Livestock type and number ideally for each assigned level of implementation.

A quality control system should be established to verify the data in an efficient way (e.g., through a system of control farmers). If data are collected on the field or farm level, then a statistical survey design (simple random or stratified random sampling) should be implemented.

The *Kazakhstan Sustainable Livestock Development Program* will be implemented from 2021 to 2025 to support the development of environmentally sustainable, inclusive, and competitive beef production in Kazakhstan. The Program is estimated to contribute to the net mitigation of GHG emissions from the livestock sector in Kazakhstan by 5.6 million tons CO_2e over five years, partly achieved by SOC sequestration through the adoption of improved grazing management practices.

The Program will support the development of a specific MRV system for the livestock sector that will allow monitoring emissions and sequestration throughout implementation as part of the M&E plan. The data and monitoring system to demonstrate net mitigation of the Program will further form the basis on which to update the NDC.

Against this background, a SOC MRV system should be developed as an integral part of a wider national livestock MRV system with at least an IPCC Tier 2 approach. Given the need for establishing this system in the context of the emerging national carbon market to provide also financial incentives for farmers to continue the improved grassland management practices beyond the Program's lifetime, the MRV system should be developed as a transitional results-based payment and NDC reporting to carbon credit production system moving over time from Tier 1 to at least a combined Tier 2/3 system.



The general sequence of steps towards the MRV design and implementation (from top to bottom) while ideally moving over time from Tier 1 to Tier 3.

Moving forward to establish such a system requires a thorough assessment of the incentive and design principles for the adoption of MRV systems outlined above. The graph above summarizes the general sequence of steps towards the MRV design and implementation (from top to bottom), while ideally moving from Tier 1 to Tier 3 over time. Conceptually, the SOC MRV system could be initially established using the ex-ante benchmarking approach outlined under the Niger Case Study.

When moving towards higher IPCC Tier levels requirements with the potential to certify SOC carbon credits and other emission reductions under the national carbon market or any international voluntary market, an MRV system should be designed in line with accepted (verified) carbon market standards and methodologies.

The *Burkina Faso Agricultural Carbon Project (BUFACAP)* is a national program that contributes to climate mitigation and adaptation efforts set out in the country's NDC in the Agriculture, Forestry and Other Land-use (AFOLU) sector. It promotes sustainable agricultural land management for smallholders and is implemented across the Sudanian and Sudano-Sahelian Agro-Ecological Zones (AEZs). The program is currently being developed under the Verra - VCS Carbon Standard using a specific soil carbon accounting methodology (VM0017) to be certified and produce carbon credits. Therefore, the SOC accounting and monitoring system is developed in line with the specific methodological requirements.

In the frame of this carbon project, a digital platform is conceptualized, allowing different project implementers in the country to register under the Verra - VCS BUFACP Project. The platform allows registration and management of different SALM projects under one carbon project, leading to lower transactions costs and transparent and standardized use of operating procedures to register farmers, monitor emission reductions and removals (especially soil organic carbon), and transparently report issued carbon credits in the context of a national accounting system. This SALM platform will be the basis to develop a wider digital platform for including other emission reduction activities in the AFOLU sector, in particular livestock, forest conservation, and afforestation and tree restoration activities monitored on a project level and ideally integrated into a national AFOLU MRV system.

The project uses a participatory group approach to register participating community members, provide training and other support, and undertake monitoring. The participating farmers are organized into groups (or exist as members of established groups), and the members receive training and capacity building for implementing the project activities on their land. The system includes two types of monitoring, permanent farm monitoring (PFM) and Farmer Group Monitoring (FGM). The main distinction between the two is that the PFM is implemented entirely by the project staff (field extension and M&E unit) on a representative sample of farms, representing the entire project area. The FGM is a farmer-self assessment – where each contracted farmer group records all data annually by themselves and reports the data to the field extension staff. The PFM is used to establish the project baseline and compare it with the FGM data as a quality control measure. The FGM data are used to quantify the project's climate mitigation outcomes (tCO_2e) in line with carbon standard (Verra - VCS) requirements for certification.

Unlocking climate change mitigation through SOC sequestration can be supported by developing a standardized low-cost SOC MRV system. This could affect wide-ranging impacts across the WBG portfolio, as well as that of other multilateral development organizations. This report points to opportunities to improve the standardization of processes for creating carbon assets through SOC MRV and, ultimately, to help reduce future climate change impacts.

Keywords

Agriculture; climate change; food systems; food security; soil carbon sequestration; soil organic carbon; MRV.

Contents

Acronyms

C	Carbon
CCAFS	CGIAR Research Program on Climate Change, Agriculture and Food Security
CERs	Certified emissions reductions
CO2e	Carbon dioxide equivalents, a standard for aggregating gases according to the global warming potential, using CO_2 as a reference unit
CSA	Climate -mart agriculture
ETS	Emission trading scheme
GHG	Greenhouse gas
Gt	Gigaton or billion tons
GWP	Global warming potential
Ha	Hectare
INDC	Intended nationally determined contribution
IPCC	Intergovernmental Panel on Climate Change
LAC	Latin America and the Caribbean
M&E	Monitoring and evaluation
MRV	Monitoring, reporting, and verification
MDB	Multilateral development banks
Mt	Megaton, equal to 1 billion kilograms (109 kg)
NDC	Nationally determined contribution
SOC	Soil organic carbon
t	Tons
WBG	World Bank Group
VCM	Voluntary carbon market
y	Year

1 Introduction

The global soil organic carbon (SOC) pool at two-meter depth (~2500 Gt) is about three times greater than in the atmosphere (~800 Gt C) (Smith et al. 2007; Lal et al. 2004). However, lack of land planning and inappropriate agricultural practices have already depleted nearly 150 Pg C from soils (top two-meter) (Sanderman et al. 2017).

Soil rich in organic carbon is associated with enhanced agricultural productivity and environmental services (e.g., rich biodiversity and water cycling) (Pries et al. 2017; Sanderman et al. 2017). Therefore, SOC restoration and protection have been increasingly recognized as part of the solution to major global problems, such as climate change and food security (Bossio et al. 2020; Vermeulen et al. 2019).

Recent estimates show that restoration and protection of SOC globally represents 25% of the mitigation potential estimated for all natural (land-based) climate solutions (~24 Gt of CO_2e per year), 40% through protection of existing SOC and 60% through rebuilding SOC-depleted areas. If half of this land-based potential could be realized, it would represent 30% of the mitigation needed by 2030 to keep global temperature increases under 2°C (Bossio et al. 2020). In grasslands and agriculture areas, close to 50% of the total potential mitigation (2.3 $GtCO_2$e/yr) would come from SOC protection and sequestration, while 20% relates to other greenhouse gases (GHGs) involved with the implementation of improved soil management practices (Bossio et al. 2020).

In addition, management practices that maintain and increase SOC are largely low in cost compared to alternative GHG abatement (Smith et al. 2007). Global implementation of crop and livestock interventions that allegedly accumulate carbon in soil is estimated to provide 21-40% of cost-effective (<20 USD/tCO_2e) climate change mitigation needed in the sector through 2030 to limit warming to 2°C (Wollenberg et al. 2016) while offering increasing resilience through improved soil health and water storage capacity, buffering temperature change, and protecting biodiversity and natural habitats.

In recent years, most of the major players across the agriculture value chain and food systems have recognized the potential that SOC has in attenuating climate change and have set targets for reducing emissions based on SOC sequestration (e.g., Bayer, Rabobank, PepsiCo). Yet investments and actions to foster SOC gains at scale are slower than needed. The three top-ranked priorities for leveraging global commitment on SOC relate to: (i) an overarching case and vision for action, (ii) more robust business cases and track-records of success among public and private investors, and (iii) a compelling value proposition for farmers and land managers (Vermeulen et al. 2019).

In this context, one major constraint has been the need for transparent, accurate, consistent and comparable methods for measurement, reporting and verification (MRV) of changes in SOC stocks, notably through new technologies and enabling standardized verification protocols at low transaction costs. While sampling designed long-term experiments is straightforward, field sampling campaigns to affordably measure SOC stocks with reasonable certainty levels require development of the necessary analytical infrastructure and technical capacity to estimate SOC and evaluate mitigation options, especially in the developing world. Promising approaches combine practical, user-friendly tools with site-specific modeling and the use of geospatial data sources and technology (Costa Jr. et al. 2020).

1.1 Objective

The objective of this report is to provide strategic recommendations to the World Bank's Carbon Markets and Innovation (CMI) and the Agriculture and Food Global Practice (GP) divisions to implement cost-effective MRV systems for SOC in the World Bank Group's (WBG) agricultural investments and improve the standardization of processes for creating carbon assets – with the potential to scale across multilateral and international development agencies and governments.

1.2 SOC accounting: framing principles

SOC is the carbon component of soil organic matter (SOM). SOM represents 2–10% of the soil and is composed mainly of carbon, hydrogen, and oxygen, but also contains small amounts of other elements (e.g., nitrogen, phosphorus, sulfur, potassium, calcium, and magnesium). SOM contributes to nutrient retention and turnover, soil structure, moisture retention and availability, degradation of pollutants, and carbon sequestration.

The level of SOM results from the long-term input and output of carbon to and from the soil, especially from cropping residues and other organic amendments. SOC composition and decomposition balance are dependent on biophysical factors (e.g., soil texture and climate), while the amount and type of biomass (carbon) added to the soil are dependent on land-use (e.g., crop type) and management (e.g., tillage and fertilizer use). Thus, changes in land-use and agriculture practices affect the level of SOC. If the amount of biomass produced by a land-use option is low, the practice will reduce input to the soil from organic residues, leading to soil degradation. On the other hand, land-use options and land management practices leading to high crop residue inputs may maintain or increase SOC over time, resulting in a phenomenon commonly referred to as soil carbon sequestration.

SOC is measured as a stock, which is the quantity of SOC in a given soil layer corrected for differences caused by land-use changes in soil density (e.g., Ellert & Bettany 1995). In carbon projects, SOC sequestration is usually estimated against a counterfactual baseline scenario. Baselines can be defined as the common or conventional practice in the project region, the historical (before implementing the policy or project) or future (projected or expected) practice on the farm or in the region.

Technically, the amount of SOC that can be stored in soil and the duration of that accrual remains unclear. Under the Intergovernmental Panel on Climate Change (IPCC) guidelines, 20 years is assumed to be the default period for SOC accrual during which SOC stocks are approaching a new steady state, enabling comparison of results between regions and countries and with other estimation methods (IPCC, 2006; 2019). Nevertheless, a meta-analysis of field studies has suggested that in some cases significant SOC sequestration can continue for over 40 years before reaching new equilibriums (Minasny et al. 2017).

Furthermore, implementing practices leading to SOC increases may also alter emissions of GHG (e.g., methane (CH_4) and nitrous oxide (N_2O)) (Hijbeek et al. 2019). For example, SOC can be increased with the use of nitrogen fertilizers, through higher crop biomass production, but at a certain point, driven by the levels of fertilization and crop yield, associated N_2O emissions may outweigh the GHG mitigation from SOC sequestration (Gao et al. 2018; Lugato et al. 2018). Therefore, SOC sequestration tradeoffs with CH_4 and N_2O emissions must be assessed and taken into account to calculate the total net GHG reductions provided by a given project.

Although aspects related to the SOC sequestration equilibrium and the full net GHG emissions assessment are critical to evaluating the climate benefits of projects, this report focuses exclusively on aspects related to SOC accounting and monitoring and supporting actions to implement SOC MRV systems.

1.3 Organization of the report

The report is organized as follows:

1. **Case studies on SOC MRV**: This section identifies existing SOC MRV systems and provides a synthesis of case studies, including a description of practices, innovations, technical demands, and aptitude to support SOC MRV systems to advance towards standardization of processes for creating carbon assets. It also highlights key parameters that lead to successful MRV implementations and describes innovations that may enhance SOC accounting and monitoring cost-effectiveness.
2. **Incentive structures that can enhance adoption of MRV systems**: This section provides guidance for broad SOC MRV uptake and use by WBG projects and investments, including: project selection of methods; cost-effective methods, metrics and indicators; sequence for progressive improvement towards "market grade" methodologies; and conditions for WBG projects to meet applicability of MRV protocols, and links to resources.
3. **Design features of WBG projects**: This section outlines features for implementing soil carbon MRV in three selected projects in the WBG pipeline following key elements of recommendations made in previous sections.

Supporting data and further analysis are provided in the annexes.

2 Soil organic carbon MRV systems

2.1 Existing SOC MRV systems

Several resources for accounting and monitoring SOC in the agricultural sector have been developed in recent years. Today, there are at least three dedicated guidance frameworks and protocols (Table 1), several GHG calculators (Colomb et al. 2013) (Table 2) and at least 11 registered voluntary carbon market (VCM) methodologies supporting SOC MRV for various agricultural conditions (Table 3). It is important to point out that, although these resources are focused on the agriculture sector, principles can be also applied to forestry and other land-use based projects and initiatives.

However, to choose a SOC accounting protocol it is important that projects define their objectives clearly and evaluate current capacity for adopting available resources for SOC MRV. Going through this process will help project developers plan for MRV implementation.

The main difference between these resources relates to the level of accuracy and sophistication in accounting and monitoring SOC changes. However, identified approaches share common data requirements and procedures that make them interchangeable and evolvable within SOC MRV systems.

The IPCC guidelines (IPCC 2006; 2019) lay out procedures for countries to estimate GHG emissions and removals, including SOC, which are periodically reported to the UNFCCC. The IPCC guidelines provide a three-tiered methodology for accounting and monitoring SOC and net GHG emissions (IPCC 2006; 2019).

The IPCC-Tier 1 approach, or default approach, uses average emission factors for large eco-regions globally. Tier 2 is similar but uses country- or region-specific emission factors, with superior accuracy, which are usually based on field measurements. Tier 3, the most demanding approach, is more detailed, usually including process-based models, which rely on agricultural management data and SOC analysis for model validation and calibration.

Several Excel- or web-based GHG calculators have been developed on the IPCC premises in order to facilitate the process of going through activity data requirements and collection, especially to perform SOC changes and net GHG emission calculations (Colomb et al. 2013). For example, GHG calculators have been used for ex-ante estimates and monitoring of the World Bank Green Climate Fund (GCF) and Global Environmental Facility (GEF) investments and to support impact investing (e.g., Mirova) and private-sector commitments (e.g., Bayer, Rabobank, PepsiCo).

Table 1. Supporting resources for technical guidance on SOC measurements and the implementation of MRV for soil carbon

Resource	Core feature
FAO GSOC MRV Protocol	Protocol on SOC MRV, including soil sampling and analysis, use of empirical and process-based models, as well as good reporting and verification practices
CCAFS SAMPLES	Guidance on SOC and GHG emissions measurements, including soil sampling and analysis, use of empirical and process-based models and design of mitigation actions
IPCC Guidelines	Guidance on GHG emissions and SOC change estimates using default data, providing options for improving accuracy of estimates according to local-specific data availability

Box 1. IPCC good practice guidance (GPG) for SOC change in land-use, land-use change and forestry (LULUCF).

The IPCC GPG provides two major approaches to estimate SOC, namely the stock-change approach and the gain-loss approach.

With the **stock-change approach**, mean annual emissions are estimated as the ratio of difference in stock estimates at two points in time and the number of intervening years. The stock-change approach is fairly easy to implement for countries with well-established sampling programs and would be similar for aboveground carbon of trees and for monitoring SOC over time. Therefore, this approach refers to the implementation of time series of stock changes as a result of changes in land management practices.

However, in countries without established sampling programs, the use of the **gain-loss approach** is more common. With this approach, emissions are estimated as the product of the areas of classes of land-use change, characterized as activity data, and the responses of carbon stocks for those classes, characterized as emission factors. The Verra's SALM Methodology (VM0017), developed by the World Bank, reflects the lack of consistent sampling programs in terms of SOC monitoring and applies the gain-loss approach only for those practices that a project or programs implements additional to the ones already resent in the baseline or reference scenario. This means that the absolute SOC stocks at the beginning of the project or the increase of stocks over time do not need to be known. The accounting works by modeling an emission factor for the identified common baseline practices (which could be a SOC gain or loss factor) and each year under the adoption of project practices (which should represent a SOC gain factor).

The trade-off of this approach is that absolute SOC stock changes within a project are not known. This could potentially mean that a project is losing SOC but less compared to the baseline. SOC is still being sequestered, which can be accounted for and even certified, but still lower than the loss.

Table 2. Major GHG calculators used for SOC accounting in agriculture projects

System	SOC accounting system
Carbon Benefits Project (CBP)	CBP provides web-based tools for estimating the carbon balance of projects in the land-use sector. In the CBP, the impact on the carbon balance of a given project can be assessed using three approaches: 'Simple Assessment,' 'Detailed Assessment,' and 'Dynamic Modeling Option,' reflecting the three tiers provided by the IPCC guidelines, which vary in terms of accuracy and data input demands. The tool also provides the Drivers-Pressures-States-Impacts-Responses (DPSIR) Framework, which allows social and cost-benefit project analysis. Colorado State University, partner universities (East Anglia and Leicester) and UN-Environment developed the CBP and its platform that produces a framework that can be used by the Global Environment Facility (GEF) projects.
Cool Farm Tool	Developed by the University of Aberdeen in partnership with Unilever Corp., the Cool Farm Tool is a GHG calculator designed for full accounting (GHG emissions and carbon sequestration) at the farm level. Originally an Excel-based tool, the CFT is now an online tool. It aims to help farmers evaluate farming management options for improving their carbon balance performance over time. Carbon balance estimates are conducted using IPCC methods and empirical research.
EX-ACT	This Excel™-based tool, developed by the FAO, provides *ex-ante* carbon balance estimates of development projects in the agriculture and forestry sectors. The tool compares, against a baseline scenario, the carbon emitted or removed as a result of project implementation. The EX-ACT tool uses IPCC Tier 1 values and allows input of specific coefficients (Tier 2). While the tool is typically used for on-farm analysis, users can also estimate GHG emissions occurring beyond the farm gate, such as from fertilizer production and fuel associated with the transport of products. The EX-ACT tools for value chains (EX-ACT VC) and biodiversity (B-INTACT) have also been developed.

The most frequently used GHG calculators are the Cool Farm Tool, EX-ACT-FAO, and the Carbon Benefit Project (CBP) (Table 2). These GHG calculators are equipped with embedded Tier 1 default factors and allow for project developers to update them with Tier 2 factors based on data availability (i.e., scientific literature and direct measurements). In addition, GHG calculators have been valuable tools for understanding the potential SOC and GHG emissions impacts and mitigation options of projects, as well as evaluating demands for data collection and monitoring climate impacts. Although significant uncertainties may apply, GHG calculators are a low-cost and straightforward accounting and monitoring option for SOC.

Soil sampling, however, is key to enhancing project capabilities to estimate SOC changes more accurately. CCAFS-SAMPLES and FAO-SOC-MRV are examples of guidelines providing a set of requirements, recommendations and options for planning and designing direct field measurements to quantify SOC and GHG emissions, in addition to aspects related to SOC MRV (Table 1). These guidelines also provide supporting information and examples of the likely effect of climate (e.g., annual rainfall) and farm management (e.g., soil tillage and fertilizing) on SOC stocks, as well as resources to evaluate mitigation options.

The content outlined by these guidance tools is beneficial for building technical capacity and improving the accuracy of SOC accounting with particular attention to developing and validating process-based models, which is the most commonly used approach for SOC accounting and monitoring by VCM standards (Table 3).

Table 3. Main features of existing land-use and agriculture methodologies in the voluntary carbon market including soil carbon

Standard	Focus area	Primary SOC accounting method
Verra - VCS (VM0017) - Adoption of Sustainable Agricultural Land Management	Cropland, agroforestry, and grassland	Modeling
Verra - VCS (VM0021) - Soil carbon quantification methodology	Crop- and grassland	Measuring and modeling
Verra - VCS (VM0026) - Sustainable Grasslands Management	Grassland and agroforestry	Measuring and modeling
Verra - VCS (VM0032) - Adoption of Sustainable Grasslands through Adjustment of Fire and Grazing	Grassland and livestock	Measuring and modeling
Verra - VCS (VM0042) - Improved agriculture management	Crop- and grassland	Measuring and modeling
Nori - Soil C sequestration in croplands	Cropland	Modeling
Gold Standard - Soil C sequestration in croplands and grasslands	Crop- and grassland	Measuring, modeling, peer-reviewed publication, or Tier 1/2 IPCC approach
Plan Vivo - Ecosystem restoration and rehabilitation, improved land management	Crop- and grassland, agroforestry, and livestock	Modeling
CAR - Soil enrichment	Crop- and grassland	Measuring and modeling
CAR – Avoided grassland conversion	Grassland	Modeling
ACR - Avoided GHG emissions and soil C losses from preventing the conversion of shrubland/grassland to cropland	Grassland	Modeling
ACR - Compost additions to grazed grasslands	Grassland	Measuring and modeling
CDFA - California's Health Soils Program	Orchard	Modeling

The main reason for the predominance of modeling in VCM standards is that this approach is considered credible and cost-effective for accounting of SOC changes, especially for large regions, when combined with validation and periodically confirmed or adjusted through soil measurement. In brief, two types of models have been used to predict SOC: empirical models (i.e., based on statistical relationships built on direct field observations); and process-based models (i.e., mathematical representation of biogeochemical processes comprising the functions of an agroecosystem, embedding the interactions of management and environmental factors with those processes leading to GHG and SOC changes).

Process-based models, however, are considered more suitable for extrapolation and representation of agricultural conditions that might not be well represented in the observational data (Paustian et al. 2019; Olander & Haugen-Kozrya 2011). Once validated, process-based models can deliver fairly accurate results at local and regional levels, reducing the need for expensive direct measurements and permitting monitoring and verification based on agricultural practices or model inputs (usually called "practice-based monitoring") rather than measurements.

Modeling eligibility under VCM requires the use of internationally recognized process-based models that have been validated for the scope and conditions of the target project or region. RothC, Century and DeNitrification-DeComposition (DNDC) are the most used and cited process-based models in identified VCM methodologies (Table 4) – although several other process-based models (Denef et al. 2012) could also be used once validated and calibrated for the target condition. Model validation and calibration, however, may demand investments in measuring field-level data (e.g., soil chemistry and physical characteristics) and supporting information (e.g., climate and agricultural management data), a robust system of data monitoring, and technical capacity and infrastructure (e.g., laboratory, practitioners, and modelers). Although they do provide an accurate SOC estimate, the implementation of these in VCM standards, therefore, may be costly compared to IPCC Tier 1/2-based approaches.

Table 4. Description of major process-based models used for SOC accounting in VCM projects

Model	Definition	Key input data required
Century/ DayCent	The Century model simulates carbon and nitrogen fluxes and interactions in the atmosphere, vegetation, and soil. DAYCENT is the daily time-step version of the CENTURY biogeochemical model.	▪ Climate (precipitation and temperature daily/monthly basis) ▪ Use of farming inputs (e.g., timing and amount of N-fertilizer used); ▪ Soil characteristics (e.g., density, texture, and pH) ▪ Soil management (e.g., no-tillage)
DNDC	The DeNitrification-DeComposition model (DNDC) is a family of models for predicting plant growth, soil C sequestration, GHG emissions and nutrient fluxes for cropland, pasture, forest, wetland, and livestock operation systems.	
Roth-C	Models the turnover of SOC in topsoil, allowing for the effects of soil (i.e., type, temperature, moisture), plant and agriculture management characteristics during the turnover process.	

2.2 Indicators for monitoring SOC

The leading indicators used for accounting and monitoring GHG emissions and SOC in agricultural production systems are shown in Table 5. These indicators correspond to activity data requirements for primary sources of emissions and are estimated in the baseline and monitored in the project scenario.

Although SOC monitoring indicators differ in accuracy and sophistication, any approach, requires similar data inputs. The core difference pertains to the level of data detail, making the application of different approaches interchangeable and evolvable. For example, soil tillage type is an item of input information necessary for GHG calculators and modeling (e.g., no-tillage), but modeling further requires physical and chemical soil characteristics (e.g., bulk density and pH) from the location where this no-tillage practice is implemented (Table 5).

Table 5. Key indicators to support GHG and SOC accounting and monitoring in agricultural systems using GHG calculators and process-based models.

Scope	Indicators (Tier 1)	Additional indicators for improving accuracy (Tier 2) and supporting modeling approaches (Tier 2/3)
General	▪ Total area ▪ % of the area under improved practice ▪ Previous land-use	▪ Chemical and physical soil characteristics (e.g., pH, texture, density, and organic matter) ▪ SOC content ▪ Climate data (e.g., daily precipitation and temperature on a daily basis)
Soil management	▪ Tillage method ▪ N-fertilizer use (i.e., synthetic, and organic sources)	▪ Type, quantity, and application method
Cropping management	▪ % of the cultivated area under cover cropping or avoided burning of residues ▪ Total crop production	▪ Quantity and carbon content of crop returned to soil
Agroforestry	▪ Total agroforestry production	▪ Number and species of trees planted ▪ Quantity and carbon content of woody biomass returned to soil (e.g., from pruning)
Livestock	▪ Stocking rate ▪ Manure management ▪ Total milk or meat production	▪ Livestock population by age, sex, productive use, live weight, and live weight gain ▪ Typical animal diet by animal population ▪ Feed composition and quality

2.3 Evidence for implementation of MRV of soil carbon

2.3.1 Carbon projects encompassing SOC as a climate benefit

As SOC sequestration potential gains momentum, there have been several projects in developed and developing countries that have considered SOC as a climate benefit. These projects provide examples of national, subnational and project-scale SOC MRV that have been (or are in the process of being) credited within compliance and VCMs

Of the more than 25 identified carbon projects and initiatives, two are related to compliance markets (Alberta and Australia) and eight are located in developing countries. All these projects operate under six standards and use three types of SOC accounting and monitoring approaches: direct soil measurements, modeling, and a mix of the two (Figure 1; Annex 1). Globally, these projects aim to increase SOC levels in carbon-depleted lands, whereas in the US, most projects concentrate on avoiding SOC loss from grassland conversion to croplands.

Interestingly, some other identified projects that could have potentially considered SOC, but did not, reported risks of using available data and the costs related to soil sampling as major barriers. For example, developers of a Plan Vivo project in Burkina Faso reported that the extrapolation of data from literature to project-specific sites would involve risks and be open to criticism within the context of the VCM due to specifics of SOC changes in regenerated soils in the Sahel. This case would require new soil sampling, and, for “practical” reasons, project developers decided not to consider potential SOC sequestration benefits as a function of project activities.

Key features of the case studies described below are further examined in the next sections, focusing on lessons learned, illustrating key aspects of the diverse ways in which SOC accounting has been conducted, and actions supporting project development and uptake.

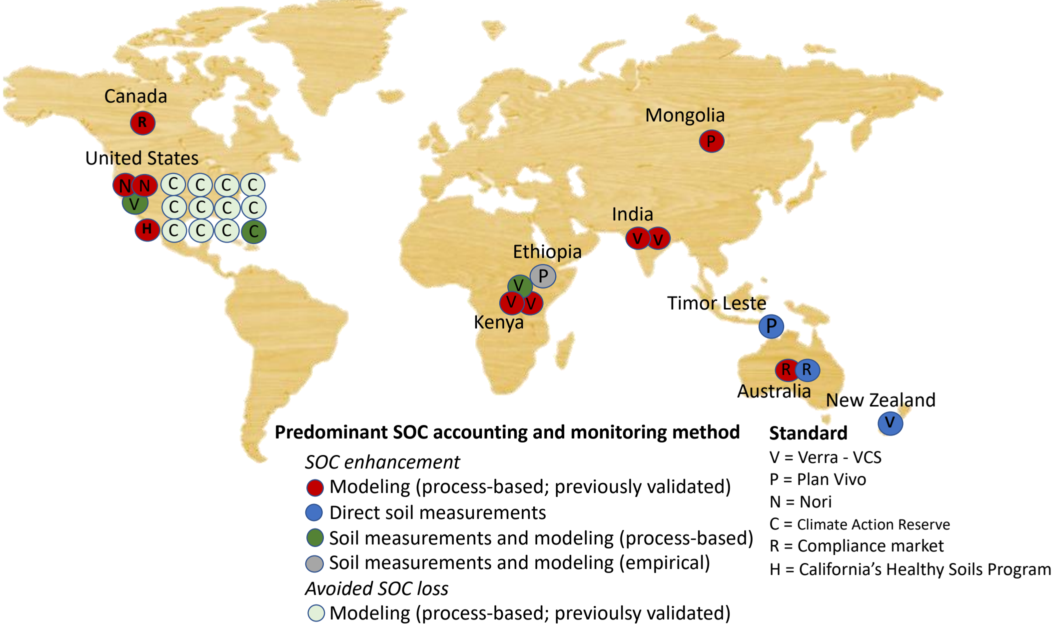


Figure 1. Agriculture and land-use carbon projects in the compliance and voluntary markets which include soil organic carbon (SOC) as project climate benefits, and their respective primary method of SOC accounting and monitoring.

2.3.2 SOC accounting and monitoring

The use of practice-based (or activity-based) SOC accounting and monitoring is a key element in MRV implementation of most projects identified here (Figure 1; Annex 1). Since the cost of direct measurements of SOC across project areas is likely to be prohibitive for many projects and initiatives, the practice-based approach provides a cost-effective method even at long time intervals.

The practice-based approach requires collecting and reporting information directly relevant to the project activities, used in models for accounting SOC changes after implementing eligible practices – especially process-based models previously validated for the target region. Thus, practice-based monitoring is focused on tracking the implementation of project-eligible practices (or model inputs) rather than direct field measurements of SOC. Practice monitoring is still required when using direct SOC field measurements.

In this context, the use of look-up tables has been particularly successful, especially for SOC MRV at scale. For example, the Alberta Carbon Offset System, a model (Century) calibrated and validated with SOC field measurements (Annex 1), was used to generate look-up tables of net GHG emission reductions from the implementation of reduced tillage and summer fallow (i.e., eligible practices) for the different climate and soil conditions of the Alberta province. The estimated factors were used for accounting emission reductions based on monitoring of the adoption and maintenance of the eligible practices. The monitoring system was complemented with remote sensing for assessing the total area of adoption.

Similarly, the California Department of Food and Agriculture Office of Environmental Farming and Innovation (CDFA) and the California Air Resources Board (CARB) validated the DNDC model against field trial data from California's counties for SOC and GHG emissions from whole orchard recycling (WOR) (Annex 1) – a practice in which orchard trees are chipped and incorporated back into the soil. The model was then used to develop county-specific look-up tables with estimated SOC sequestration rates and GHG emissions based on their climate, soil, and orchard management data. These tables were then used for MRV of California's WOR projects (Wolff et al. 2020).

Analogously, Climate Action Reserve adopted a modeled approach (using the DAYCENT model) to determine the SOC loss avoided by preventing the conversion of grasslands into croplands in the USA (Annex 1). By establishing a standardized baseline, utilizing various national databases, the methodology does not require project proponents to execute complex process-based models for estimating SOC changes. Instead, SOC changes can be determined using composite emission rates derived from the modeling approach utilizing conditions of the project area (e.g., climate, soil and cropping system types).

On the one hand, pre-determining SOC variation factors have several important advantages, especially in reducing project costs and verification complexity, compared with an alternative method in which project proponents would be responsible for detailed documenting of their project activities and performing modeling exercises (DuBuisson & Zavariz 2020). On the other hand, this approach may entail greater uncertainty at the project level due to its more general consideration of the project variables influencing SOC.

Other carbon projects in the VCM have followed a similar SOC accounting and monitoring principle to those described above, except that they periodically run process-based models for estimating SOC variation using site-specific data from the place where the project activities are being implemented. In the Kenya Agriculture Carbon Project (KACP) and Halo Verde Project, field surveys are carried out to record and report land management practices annually via a data aggregation system. The data gathered are used as (i) input values to run the RothC and SHAMBA models, which have been validated for the target region, to derive local SOC emission factors and (ii) to determine the practices' adoption rate (Figure 2; 3; Table 6).

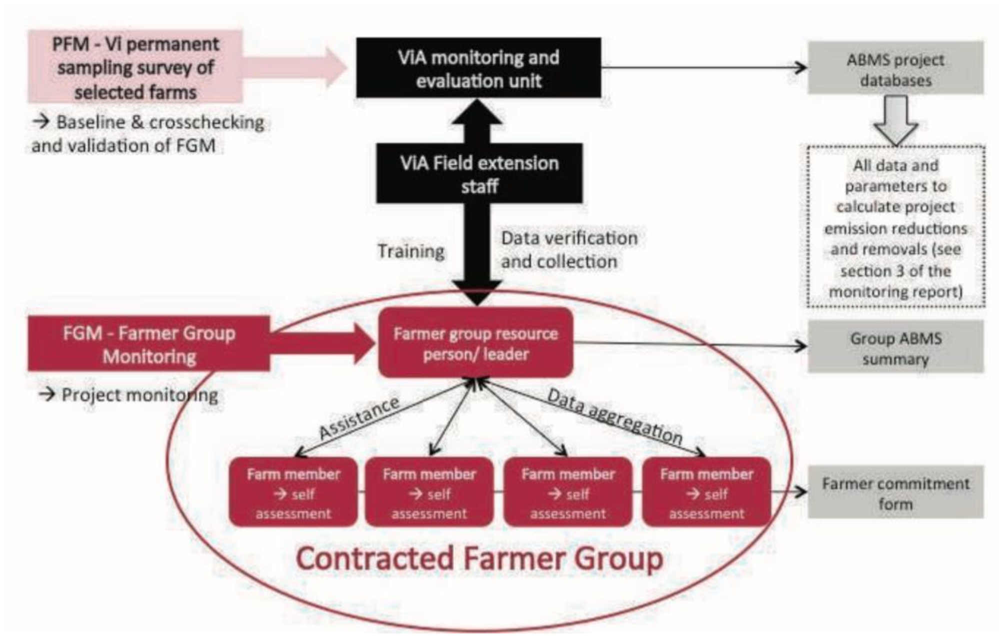


Figure 2. Simplified structure of the KACP's SOC monitoring system (Source: Tennigkeit et al. 2012)

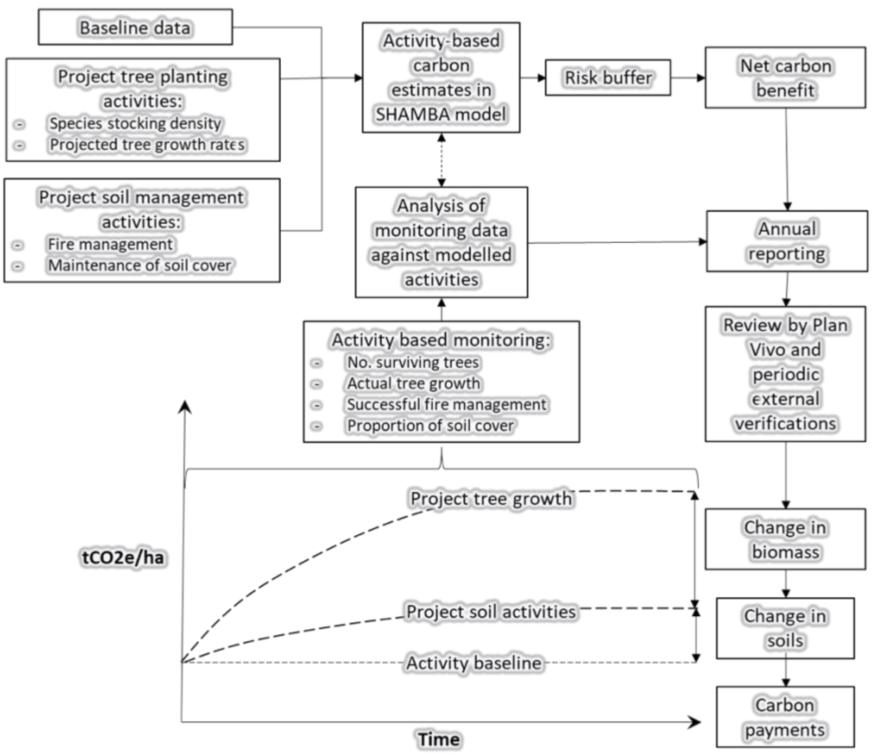


Figure 3. Simplified structure of the Hallo Verde project activity-based monitoring of modelled carbon benefits (Source: Plan Vivo)

Table 6. Examples of Roth-C modelled local SOC sequestration rates developed in KACP (Tennigkeit et al. 2012)

Sustainable Agriculture and Land Management (SALM) practices	SOC sequestration factor (tCO_2e/ha/year)	
	Kisumu region	Kitale region
Residue management Maize		
1st season / 2nd season	0.31 / 0.22	0.58 / 0.64
Residue management Beans		
1st season / 2nd season	0.20 / 0.14	0.35 / 0.50
Residue management Sorghum		
1st season / 2nd season	0.22 / 0.16	0.30 / 0.42
Composted manure		
1st season / 2nd season	0.19 / 0.21	0.20 / 0.21
Agroforestry (soil fertility trees)		
1st season / 2nd season	0.05 / 0.02	0.19 / 0.10

The Pastures, Conservation, Climate Action – Mongolia (PCC-Mongolia) project used the Century model to run ex-ante SOC sequestration rates based on the project's implementation plan (i.e., improved grazing management) over the commitment period (e.g., 2015-2019), using local climate, soil, and vegetation data (Annex 1). The model had previously been validated for two of the project's three areas based on extensive soil and biomass sampling and analyses. The model was further applied to the third project site, which was not included in the original validation, by considering a risk factor to safeguard estimates. At the end of each commitment period, SOC changes may be assessed using limited sampling of soils to determine the accuracy of model predictions. Furthermore, a practice-based approach was used to collect data, which was self-reported by project members and subject to biannual confirmation by project developers and demonstrated whether the project was on track to achieving the expected benefits.

In the USA and Kenya, the Northern Great Plains Regenerative Grazing and the Northern Kenya Grassland Carbon projects proposed a practice-based modeled data approach where baseline SOC stocks are estimated using direct field measurements and the SNAP model is used to monitor SOC changes (Annex 1). The model uses the following parameters, which will be collected for the baseline and monitored throughout the project development: grazing intensity (using Normalized Difference Vegetation Index - NDVI), the percentage of lignin and cellulose content of aboveground biomass, percentage of the soil comprised of sand; mean annual precipitation, mean annual temperature and the frequency of fire. The project plans to re-measure SOC after crediting periods long enough to detect SOC changes at sampling stations to revalidate and recalibrate the model.

The Australia Carbon Farming Initiative has also considered the modeling approach (FullCAM) for accounting and monitoring SOC changes (Annex 1). Initially designed to be more conservative, this approach did not generate enough credits to pay back transaction costs, whereas direct soil measurements often did. However, the measurement costs are prohibitive to gaining scale (only four projects have been developed to date under the Australian scheme). Since 2018, Australia has been improving modeling validation across eligible zones (through soil measurements) to increase accuracy and, consequently, the methodology's cost-effectiveness and attractiveness.

The EthioTrees project is an exception among the projects identified by this work. It has decided not to use the climate benefit accounting model recommended by Plan Vivo (Shamba model, which uses RothC for estimating SOC changes), but an empirical model that was developed for the project region (Annex 1). The project developers reported that their management techniques focused on soil and water conservation–rather than only on tree planting, agroforestry, or conservation agriculture–and the soils in the project area are less than 30 cm deep. Consequently, EthioTrees decided to follow a data-driven approach based on existing peer-reviewed published soil measurements (used as the baseline) in the region (e.g., Assefa et al. 2017; Mekuria et al. 2011). One of these assessments (Mekuria et al. 2011) measured soil and above-ground carbon dynamics until they reached the maximum carbon stock and developed an empirical model, which was used to estimate the project's carbon sequestration. Even so, EthioTrees follows a strict checklist (with ten conditions) where the project sites could use this empirical model, which also serves to identify candidate sites for expanding the project. The project, therefore, plans to re-assess SOC and above-ground biomass every five years using field measurements.

2.3.4 SOC accounting uncertainty

Although relying on models and practice-based monitoring can significantly reduce the cost and complexity of SOC MRV, they may also increase the uncertainty associated with SOC estimates compared to direct SOC measurements only. The main reason for this is that the accuracy of determining SOC changes using practice-based and modeling approaches is dependent on the quality of data used. In this case, errors may also occur if the data collected are inaccurate.

Therefore, assessing the uncertainties of modeling and monitoring input data is necessary. For cases where uncertainty is exceptionally high relative to the magnitude of the potential emission reductions, discount factors have been used to increase the level of confidence and avoid over-estimation of mitigation outcomes.

In Australia, discounts applied to measured values were a function of the variance of measured soil carbon stock values determined by statistical approaches (i.e., level of SOC sequestration associated with a probability of exceedance equal to 60%). In addition, credits were reduced by 50% in the first temporal measurement to avoid initial over-crediting resulting from unknown SOC long-term trend characteristics. For uncertainties associated with activity data and modeling, Monte Carlo analysis was used in conjunction with the propagation of error method as described in the IPCC inventory guidelines (IPCC 2006).

The KACP project estimates uncertainties based on the model inputs and outputs, and project GHG removals are adjusted if the modeling uncertainty is above 15%. With regard to the uncertainty of the RothC model outputs, the SALM methodology recommends calculating the soil model response using the model input parameters with the upper and lower confidence levels. The RothC model automatically calculates the overall uncertainty of the baseline as well as the project input values.

In the PCC-Mongolia project, if the uncertainty of SOC modeling was greater than 50% of the mean value, the project proponents were required to increase the sample size of the input parameters until the soil model uncertainty was better than ± 50%. Further adjustments were applied, with an increased risk factor of 20% for sites for which the model was not originally calibrated.

For example, if the uncertainty of the model output was up to 15% of the mean value, then the project proponents could use the estimated value without any deduction for conservativeness. For uncertainties of 15-30% and 30-50% a SOC sequestration deduction of 15% and 25%, respectively, were applied.

2.3.5 Leakage and permanence

An essential requirement of carbon projects is that they are additional, do not result in leakage of emissions, and ensure that emission reductions or GHG removals from the atmosphere occur and are permanent. The leakage and permanence assessments are usually also deducted from the SOC sequestered as a result of the project.

For example, in the KACP project, any increases in chemical fertilizer-related GHG emissions resulting from the project activities are captured in the monitoring system and deducted from the SOC (and biomass carbon) sequestered. KACP also applies a Verra - VCS non-permanence risk tool to assess the risk of non-permanence, which rated the project as low, subsequent to which 10%

of the credits were placed in Verra - VCS's risk buffer account as an insurance against any non-permanence risks.

In PCC-Mongolia, a 10-20% discount was applied based on the identification and assessment of the risks of non-realization of the climate benefits and non-permanence. For carbon sequestration offset projects in Australia, a risk of reversal buffer and permanence period discount is applied, usually 0-20%, depending on the type of project.

Alberta used a unique approach to satisfy the criterion of additionality. Since reduced and no-tillage practices were already being adopted in the province Alberta used an 'adjusted baseline' to meet additionality requirements. In this case, the quantification discounted currently eligible practices, crediting only the additional SOC sequestration. The discount rate was adjusted with the increased adoption of eligible practices against the national agriculture census conducted every five years. The discount rates can reach 40% in some cases. Regarding permanence, Alberta adopted an "Assurance Factor," developed using a risk-based assessment of the probability of reversal, in which a 10% discount was applied on every verified ton created under the protocol. The risk assessments were conducted by polling agricultural extension specialists and examining industry practice surveys from the last couple of decades, deriving a reversal risk percentage projected into the future.

2.3.6 Supporting actions for SOC MRV implementation

Simply laying out an approach for SOC accounting has not been enough to implement a SOC MRV. Supporting actions should be considered in setting up and running an MRV system; a few are discussed below.

2.3.6.1 Benefit-sharing

Benefits generated from climate outputs are usually shared among the beneficiaries based on performance, and payments are only triggered after the emission reduction (or SOC sequestration) is verified. The design and implementation of the benefit-sharing mechanism should ensure a robust degree of efficiency and transparency to incentivize stakeholders' participation. In this context, local communities are expected to benefit the most. However, benefit-sharing arrangements at the project level are usually designed for the unique conditions of that project.

Overall, the ways payment for results is distributed includes an agreement with farmers or other beneficiaries, usually decided after meetings and public consultations. We found that benefit-sharing mechanisms have allocated 60 -70% of income from the sale of certificates or other sources to participating communities, whereas 30-40% is retained to cover organizational, coordination, monitoring, and administration costs and as a risk buffer.

The benefit-sharing scheme agreement also includes payment conditions to ensure implementation and permanence of eligible practices during the project's life cycle or beyond and lays out requirements applicable in the event of farmers' non-compliance. For example, in the HVTCFP-Timor Leste project, farmers must re-plant any damaged or harvested tree during or beyond the 30-year project period upon penalty of repayment of the carbon payments received. In PCC-Mongolia, the payments are based on the level of project implementation using three performance monitoring levels as follows:

1. **Green** – indicates that the project is likely to achieve the expected benefits and that performance-related payments or in-kind support should be made in full.
2. **Orange** – indicates that the project's activities are insufficient to achieve the expected benefits and that corrective actions may be required. Performance-related payment should be withheld until a green performance level is reached.
3. **Red** – indicates that the project's activities are insufficient to achieve the expected benefits and that corrective actions may be required. No performance-related payment should be made until a green performance level is reached.

2.3.6.2 Co-benefits of SOC sequestration

If well designed, SOC projects can safeguard and generate further social and environmental outcomes. Furthermore, assessing co-benefits is considered an asset of carbon projects and helps to engage stakeholders in project uptake and scale (Costa Jr. et al. 2020).

PCC-Mongolia, for example, assessed biodiversity conservation (i.e., protection of key wildlife species and habitats through herders' participation in management and governance of biodiversity) and improvements in livelihoods and well-being (i.e., collaborative processing and marketing of livestock products, livelihood diversification, and protection of locally important cultural landscapes and resources). Through an independent environmental and social assessment, KACP evaluated other beneficial impacts beyond emission reduction (and carbon sequestration), such as improved water conservation and rural economy, increased institutional development and gender balance, and reduced poverty.

However, indicators for evaluating SOC co-benefits will vary from project to project depending on which particular social and environmental domains the project seeks to develop. Example indicators are found in Table 7. Furthermore, several dedicated guidelines and protocols can help assess SOC co-benefits, which are interestingly summarized by Mirova-Ecosphere's ESG principles (Figure 4).

Table 7. Examples of indicators for monitoring SOC sequestration co-benefits.

Indicators of SOC sequestration co-benefits

Production	Environmental	Socioeconomic
▪ % of agricultural land under improved practice ▪ % of livestock herd that consists of improved breeds ▪ Annual livestock losses ▪ Yield per livestock unit, crop and ha ▪ Hectares under agroforestry ▪ Yield variability per ha and crop	▪ Water use efficiency ▪ Biodiversity conservation ▪ Forest area as a proportion of total land area ▪ Recovery of degraded land	▪ % of food nutritionally improved ▪ Prevalence of undernourishment ▪ Target population with land-use or ownership rights ▪ Number of jobs created ▪ Income increase ▪ Gender balance ▪ Land tenure ▪ Capacity building ▪ Institutional development

Figure 4. Mirova-Ecosphere's ESG principles (Source: Mirova/Ecosphere+)

2.3.6.3 Stakeholder engagement

The basic stakeholder engagement structure encompasses government, research organizations, and non-state actors. In national and sub-national programs (e.g., Alberta and Australia), the government usually regulates and manages the offset program and provides broader infrastructure (e.g., laboratory equipment and meteorological stations). Research institutions develop protocols and tools for SOC MRV. Furthermore, non-state actors (e.g., NGOs and consulting companies) support farmers, develop projects and provide feedback and inputs on SOC MRV tools and protocols. This structure is similar in local- and regional-scaled projects, except that local governments act as supporters rather than regulators.

Stakeholder engagement is part of the rules and requirements of VCM. For example, the Safeguards of the VCS Standard include a local stakeholder consultation prior to verification and maintaining ongoing communication to allow stakeholders to raise concerns about potential negative impacts during project implementation (see VCS Standard Section 3.16 Safeguards).

From the farmer's perspective, SOC sequestration is a co-benefit and an entry point for participating in SOC projects. Ecosystem services (e.g., soil conservation), higher productivity and food security are considered the biggest incentives and core values for farmers and as the things that might arguably "secure" permanence.

In this context, non-government (NGOs) and private-sector organizations (i.e., aggregators and consulting companies) play a crucial role. These entities usually provide strategic planning, training, and advisory services for farmers and engage and stimulate them to join projects and generate substantial outcomes that would otherwise be prohibitive.

In addition, these entities have also provided scrutiny to the system, especially by reviewing eligible practices and the accounting systems and working with research institutions to develop processes and data systems that lower transaction costs.

Finally, local projects may serve as a model for local government and development partners to improve national inventories and reporting communications to the UNFCC and exploring carbon market possibilities with several private-sector emission reduction commitments and potential modalities under Article 6 of the Paris Agreement.

2.4 Emerging innovations for SOC accounting and monitoring

As stated above, determining and monitoring SOC requires a number of activities directed towards direct soil measurements, farming data acquisition and the use of models, which may represent significant barriers for project development and scaling-up actions.

To make SOC accounting and monitoring more fit for purpose, affordable and accurate in comparison with conventional methods (e.g., field surveys and laboratory measurements), various techniques have been developed (Angelopoulou et al. 2019, 2020; England & Rossel, 2018). The most promising emerging innovation relies on the use of remote sensing techniques. Other promising initiatives have addressed cost-effective methods of directly measuring SOC stocks.

Remote sensing: The use of remote sensing can reduce monitoring and verification costs and make carbon credit trading more accessible (Angelopoulou et al. 2019; Smith et al. 2019; Szakács et al. 2011). The application of remote sensing for SOC MRV can be summarized as:

- Track management that impacts soil carbon (e.g., tillage and cover cropping);
- Tracking vegetation productivity to estimate potential changes in soil carbon (i.e., developing proxies for the amount of organic matter inputs);
- Developing a soil carbon sampling strategy by stratifying the landscape more efficiently and optimizing the number of soil samples to assess SOC changes.

Soil measurements: Determining SOC stocks and calibrating models requires SOC and soil bulk density measurements, which are rather costly. To make more affordable and accurate measurements than conventional laboratory measurements (e.g., dry and wet combustion), various laboratory and proximal sensor techniques for SOC content have been developed (Table 8). Promising results have come from laboratory and proximal sensing spectroscopy in the visible and near-infrared (VNIR)–short wave infrared (SWIR) wavelength region (Angelopoulou et al. 2020; England & Rossel 2018).

- A recent study reported that the most rapid and cost-effective method for measuring soil organic carbon concentration appears to be visible–near-infrared (vis–NIR) spectroscopy and, for bulk density, active gamma-ray attenuation (England & Rossel 2018) (Table 9).
- By combining mid-infrared (MIR) spectroscopy and X-ray fluorescence (XRF) spectral methods with machine learning techniques, ICRAF has recently developed a rapid, portable, and non-destructive measurement approach for a range of nutrients in organic amendments, such as carbon, nitrogen, and other micronutrients – with great potential for SOC analysis. This approach is also scalable, as the calibration process for XRF can be at least partially automated, provided each new instrument is calibrated against common standards. Moreover, in conjunction with machine learning, this is an attractive solution to support nutrient management with minimal cost for analysis per sample (Towett et al. 2020).

- Indigo Ag. has recently launched a challenge focusing on innovations to develop agriculture solutions to speed, reward and quantify SOC sequestration. The challenge has received 265 applications from 44 countries, of which 15 have been shortlisted, on innovative methods to quantify SOC. The winner developed a laser-induced spectroscopy technique, determining 15 soil properties in less than a minute.

Table 8. Assessment of proximal sensing technologies in terms of their readiness to underpin carbon accounting methodologies (England & Rossel 2018)

Method	Features					
	Rapid	Accurate*	Cost	Developed	In use	Radioactive source of energy
Soil organic carbon						
Color	Yes	No	$	Yes	Yes	No
Visible–near-infrared (vis-NIR)	Yes	Yes	$-$$	Yes	Yes	No
Mid-infrared (mid-IR)	Yes	Yes	$$	Yes	-	No
Laser-induced breakdown spectroscopy	Yes	Yes	$$-$$$	Yes	-	No
Inelastic neutron scattering	Yes	Yes	$$$	No	Yes	Yes
Soil bulk density						
vis-NIR, mid-IR	Yes	No	$-$$	Yes	Yes	No
Active gamma-ray attenuation - transmission	Yes	Yes	$	Yes	Yes	Yes
Active gamma-ray attenuation - backscatter	Yes	No	$	Yes	Yes	Yes
Gamma- and X-ray computed tomography	No	-	$$$	No	No	Yes

*relative to the conventional dry-combustion method for SOC concentration and volumetric ring method for bulk density

2.5 Emerging initiatives on SOC

Several recent initiatives aim to improve the capacity to account for and monitor SOC changes in agricultural systems globally. Although some initiatives are at the planning stage, they offer insights into the frontiers of SOC accounting and monitoring in agricultural systems.

ICRAF's Land Degradation Surveillance Framework (LDSF). This is a systematic monitoring framework for assessing soil and land health. This methodology has been implemented in over 40 countries in collaboration with multiple partners, including national governments and international organizations, and is currently used to track changes over time and monitor restoration efforts across sub-Saharan Africa (SSA). All data are subjected to advanced data analytics and robust statistical analysis. Soil samples are analyzed using MIR spectroscopy to predict fundamental soil properties such as soil organic carbon, total nitrogen, pH, base cations, and texture. All georeferenced LDSF data are stored in the ICRAF LDSF Database for efficient, safe storage and fast retrieval and to facilitate analysis.

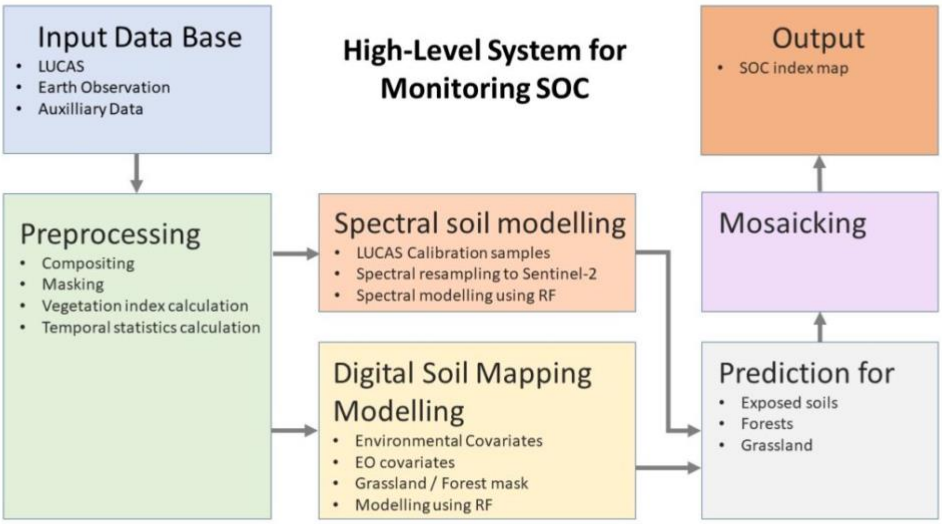
FONTAGRO and Global Research Alliance (GRA)'s Carbon sequestration opportunities in soils in Latin America and the Caribbean (LAC): The objective of this project is to contribute to the design of land use and management with high potential for SOC sequestration in agricultural production systems of LAC. To achieve this, the project will (1) provide LAC countries with tools for reporting their SOC stocks inventories in Tier 2; (2) based on these tools, it will identify at least one opportunity for carbon sequestration in SOC in five countries in LAC (Argentina, Colombia, Costa Rica, Chile, and Uruguay) and quantify its impact in both net total GHG emissions (using Life Cycle Assessment) and farm profitability (economic analysis); and (3) build local capacities for quantifying and monitoring SOC stocks in classical experiments and at regional scales. This project will design strategies for climate change mitigation and adaptation potential in LAC agricultural systems by accomplishing these three main points.

IICA (Latin America) - Living Soils of America: Led by IICA and the Carbon Management and Sequestration Center (CMASC) at Ohio State University, this international initiative will serve as a bridge between science, the public policy sphere, and development work in the field to restore soil health in the Americas. To this end, and using the most advanced management strategies, technical cooperation will work with governments, international organizations, universities, the private sector, and civil society organizations to assist in slowing land degradation and depletion of soil organic matter by agricultural processes.

The Ecosystem Services Market Consortium (ESMC): The ESMC is a collaboration of members from across the US agricultural supply chain aimed at launching a national-scale ecosystem services market designed to sell carbon and water quality and quantity credits for the agriculture sector by 2022. The ESMC MRV component will rely on remote sensing tools, utilizing satellite technology to track conservation tillage and coverage crops and technologies. ESMC is focused on simplifying the quantification and verification processes both on the farm and as part of efficient, cost-effective asset generation. Currently, ESMC and the Ecosystem Services Market Research Consortium (ESMRC) is focused on the research, development, demonstration, and deployment of cost-effective, scalable technologies and approaches to launch a market for ecosystem services.

Indigo Carbon: Program to enable farmers to be paid for improving their soil health. Farmers enrolled in the program are equipped by Indigo Ag. with digital agronomy tools to help with the collection of activity data and verify SOC sequestration and GHG emissions. Indigo Ag. has developed a methodology under VERRA - VCS and Climate Action Reserve to facilitate the MRV process of generating carbon credits. Indigo has also recently launched a challenge focusing on innovations designed to develop agriculture solutions to speed, reward and quantify SOC sequestration. The challenge has received 265 applications from 44 countries, of which 15 have been shortlisted, as innovative methods of quantifying SOC.

WORLDSOILS: This project aims to develop a Soil Monitoring System to provide global-scale SOC estimates on an annual basis. This project will rely on earth observation spectroscopy-based methods, together with in-situ measurements and modeling techniques, to improve spatial resolution (Figure 5). SOC maps will be generated as one of the final products. The initiative will also convene stakeholders for SOC-related index development.



(Source: WORLDSOILS)

Figure 5. Proposed architecture of the WORLDSOILS project for generating SOC maps

Soils Revealed: An interactive platform for visualizing soil carbon losses and sequestration potential under different land and agriculture management. This platform, launched in 2020, currently houses a 250m resolution implementation of IPCC scenarios for soil carbon baselines and futures based on management alternatives and will produce global maps of soil carbon change based on machine learning calibrated on four decades of ground samples.

iSDAsoil: This platform provides soil maps at 30-meter resolution for African countries. The platform was developed using machine learning techniques with more than 130,000 soil samples. It offers data on soil organic carbon and density (among other soil properties) for over 20 billion locations across Africa.

Verra Early Finance Carbon Units (EFCU): One of the main issues of carbon projects in the land-use sector is to attract up-front investment for the implementation of practices. Since substantial and detectable SOC sequestration may occur only after a few years, trading carbon credits at early stages, to support project implementation, is challenging. Verra has recently developed the EFCU to overcome this barrier. EFCUs are "future" carbon credits issued based on the project development design (PDD), which are replaced by carbon credits once the project is verified. Although not specifically designed for SOC/Land-use projects, this mechanism may help to enhance confidence in project outputs and attract investment at the early stages of the project.

2.6 Conclusions and key messages

Several protocols, tools, and standards exist for accounting and monitoring of SOC changes in agricultural systems. These existing SOC MRV systems rely on similar indicators but vary in input data details, together with providing a rational structure that can be implemented in diverse contexts and improve the accuracy of estimates over time. Table 9 shows major features of implemented MRV of SOC.

Practice-based (or activity-based) accounting and monitoring have been key to the implementation of existing SOC MRV in local and regional projects and programs. By using tracking practices (less expensive) rather than direct soil measurements (more expensive), practice-based approaches are a cost-effective way of estimating SOC changes. They are more robust when accompanied by process-based models for deriving rates of SOC sequestration, which, along with field measurements for model validation and periodic verification of actual SOC sequestration, is the approach most commonly recommended and applied in VCM methodologies.

In this context, developing look-up tables for different countries and regions with model-informed SOC variation factors may further reduce project costs and verification complexity by permitting practice-based accounting and monitoring with known uncertainties and providing a rational structure capable of being implemented in various contexts and improved as better data become available over time.

When using models, it is recommended that their calibration be validated and improved against field measurements to reduce uncertainties, which impose limitations for specific countries and contexts in the short run. In such cases, basic accounting approaches (e.g., IPCC-Tier 1) are a good starting point.

Furthermore, recent innovations and applicability of remote and proximal sensing techniques and soil databases will, in the near future, play a key role in improving data availability, reducing costs, and improving accuracy in estimating SOC changes.

In addition, this report identifies major measures to support SOC MRV implementation that can be broadly categorized as (1) decision-making bodies composed of policy makers, academia, project implementers, and farmers; (2) measures in the early stages of involvement of farmers, practitioners, and non-state actors (e.g., consulting companies and NGOs); and (3) capacity-building activities to support the implementation of meaningful eligible practices by farmers.

Table 9. Major features of implemented MRV of SOC

Principles	Features of successful implementation of soil carbon MRV
SOC accounting and monitoring	▪ Use of practice-based accounting and monitoring for cost-effective SOC MRV. ▪ Adoption of model-informed look-up tables for reducing cost and complexity of SOC accounting and monitoring. ▪ Process-based models continuously improved and calibrated against field measurements for accuracy. ▪ Building datasets for filling data gaps (e.g., field surveys and climate stations). ▪ Discounts applied for conservativeness, based on SOC accounting uncertainties and permanence, as well as project leakage and implementation.
Emerging innovations	▪ Major innovations are remote-sensing-related, especially for gathering activity data and estimating SOC changes when coupled with models. ▪ Soil probes, portable analyzers and artificial intelligence are promising innovations for lowering costs and increasing the speed of direct SOC measurements.
Supporting actions for SOC MRV implementation (Institutional arrangement and stakeholder engagement)	▪ Decision-making body composed of policy-makers, academia, project implementers and farmers. ▪ Participatory planning, monitoring and evaluation of a farmer-led implementation system. ▪ Community-based stakeholders on board to ensure the permanence of the project after an intensive development phase. ▪ Provision of substantial technical assistance and meaningful eligible practices to farmers, enhancing productivity, generating extra revenue, and improving resilience. ▪ Researchers to develop robust scientific methodologies and rigorous peer review procedures. Practitioners to review protocols and ensure practicality. Value-chain actors to understand potential and evaluate investments. ▪ Inter-ministerial coordination, including between central and local government, building linkages with complementary land-planning and environmental programs. ▪ Alignment with the country's GHG inventory and national communications with the UNFCCC.

3 Proposed SOC MRV system categories

The required level of certainty and accuracy in a SOC MRV system depends on its purpose. In the voluntary carbon market, a high level of certainty is required to issue carbon credits; in other circumstances, a rough estimate of SOC change is sufficient for reporting. Generally, the higher the targeted certainty and accuracy, the more sophisticated and resource-intensive the MRV system (Figure 6; Table 10).

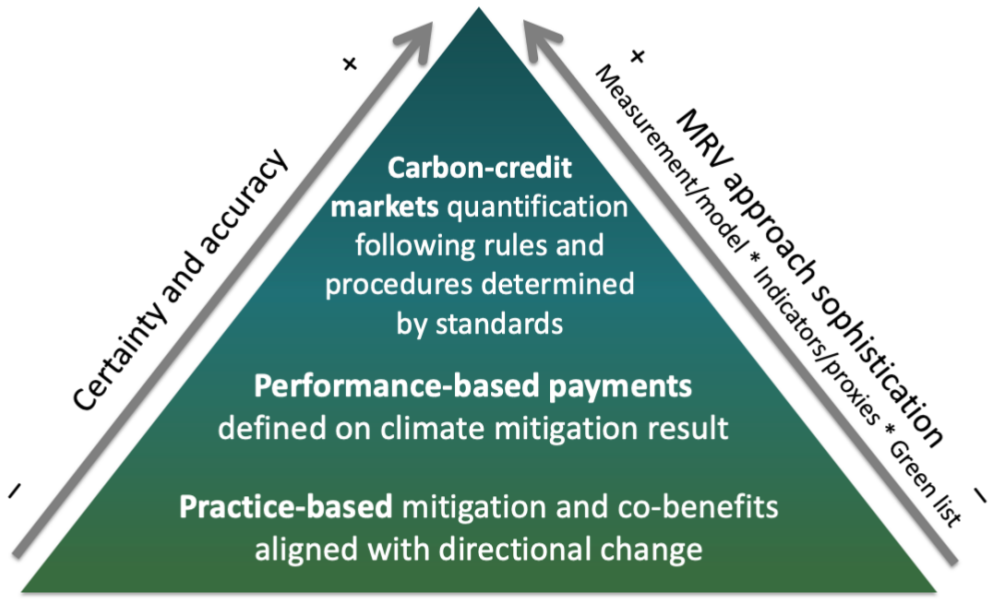


Figure 6. Fit-for-purpose MRV of soil carbon.

For WBG projects intended for monitoring SOC, it is important to have clarity on the following questions in order to choose an adequate SOC MRV system: (1) What is the purpose of the SOC MRV system, and why does SOC need to be monitored in the project? (2) What resources are available for SOC MRV?

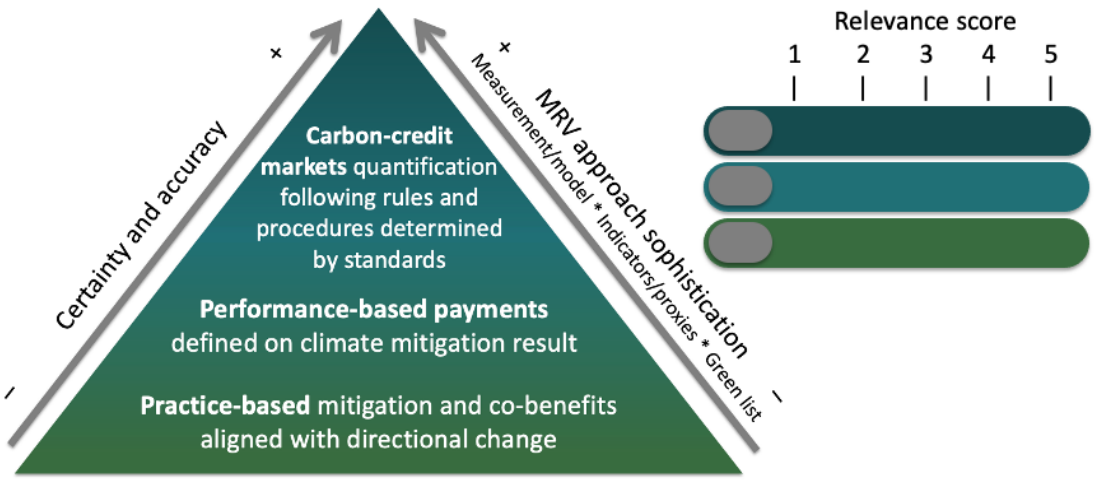
It is important to notice that all MRV systems take an activity-based monitoring approach with various degrees of granularity.

Table 10. Proposed MRV systems with Conditions for WBG projects to meet applicability of MRV protocols.

Category of soil carbon MRV	Purpose	Parameters	Data sources and MRV Methods	Technical requirements	Personnel requirements	Quick options for improvement
"Basic" Practice-based	Basic SOC MRV for public communication and inter-bank reporting	Activity data: Tier 2 SOC EF: Tier 1	National statistics, published default values	Typical M&E systems, mostly based on period field reporting (non-statistical)	Closely linked to the existing advisory and extension system	GIS based activity data using global available land-use datasets
"Intermediate" Performance-based	Results-based payments and NDC reporting	Activity data: Tier 3 SOC EF: Tier 2	GIS based activity data assessments, control farmer surveys, published local/regional research data	Structured (numerical)Field surveys ideally using digital data collection and central databases	Surveys done by enumerators, verified by field extension staff	Use of data collection toolkits, development of standard operating procedures for field data collection including development of sampling and monitoring plan
"High-end" carbon certification	Carbon credit production	Activity data: Tier 3 SOC EF: Tier 2/3	Field GPS tracking of areas combined with GIS; statistical farm-based surveys with uncertainty requirements	Combination of digital field data collection and central Management Information Systems to automatize analyses and reporting	MRV staff with clear roles and responsibilities for each level; central MRV unit. Involvement of beneficiaries in monitoring	Standard Operating Procedure for all activities related to MRV incl. quality control; provision of continuous training and maintenance

4 Incentive and design structures for adoption of MRV systems

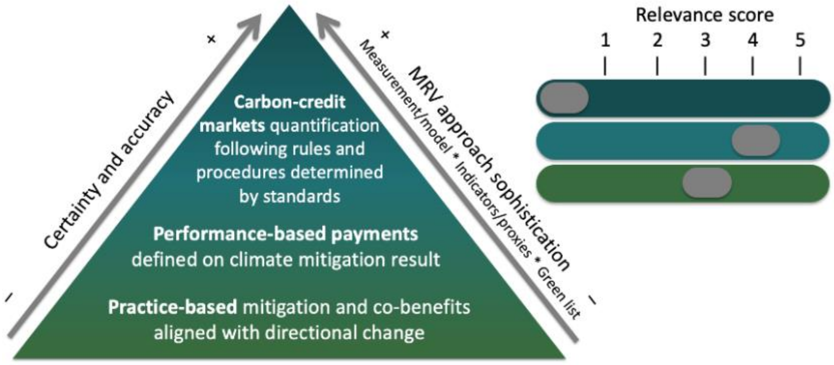
To ensure the implementation of efficient and fit-for-purpose MRV systems, it is important to have incentive structures in place that encourage the fulfillment of the necessary tasks by the stakeholders involved. Based on the outputs from the previous sections and inputs from the technical and project working group, certain principles encourage the successful uptake of SOC MRV systems. This report presents these principles in relation to the MRV system categories identified above, with a relevance rating from 1 (low relevance) to 5 (high relevance) using the following chart:



The scoring is based on experience from replicating and adapting the Kenya Agriculture Carbon Project's (KACP) monitoring system for other projects (e.g., the COMACO Landscape Project in Zambia and the Burkina Faso SALM Project), and even integrating such systems into national agriculture MRV systems (e.g., in Kenya). Furthermore, it is based on interviews with a number of project developers who are currently involved in an MRV system of this kind for various purposes.

4.1 Design Principles for successful uptake of SOC MRV systems

4.1.1 The MRV system is based on existing institutional structures that provide accountability in ways appropriate to the project/ national context

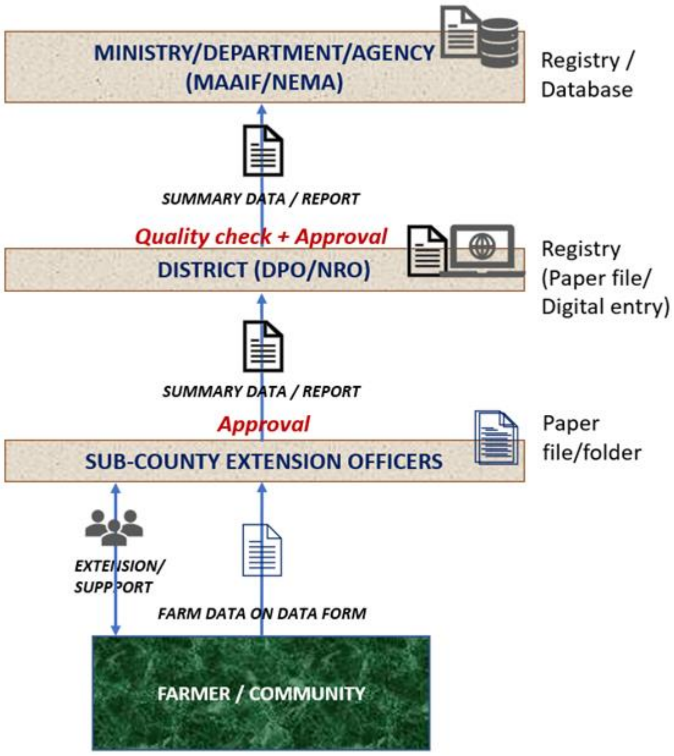


Project MRV systems seeking certification to issue carbon credits from SOC and other carbon pools are usually primarily driven by the methodological requirements under the specific carbon standard. However, where mitigation targets have to be met (e.g., NDCs), assessment and alignment with existing structures is of highly relevant.

This principle requires a thorough assessment of existing MRV structures, especially in the agriculture sector, to identify ways of integrating SOC monitoring. This includes an understanding of the institutional and regulatory environment, as well as the available structures and arrangements for the collection of farm-based data. Table 11 depicts an example of the existing agriculture monitoring and evaluation (M&E) system in Uganda, to integrate a SOC MRV system.

Table 11. Sectors and focal points for data and information in local district governments in Uganda and current data flows taking place from the farmer/community level to the Ministry/Department/Agency level via the established government structure.

Sector/data scope	District focal point	Reporting status	Ministry/Department/ Agency to report to
Agricultural data: statistics on crops, livestock, entomology, fisheries, and related matters	District Department of Production Office (DPO)	Regular reporting using specified templates	Ministry of Agriculture Animal Industry and Fisheries (MAAIF)
Natural resources & environmental data: land-uses, land degradation, forest resources, wetland resources, water resources, etc.	District Department of Natural Resources Office (DNRO)	Irregular reporting. Done in the form of occasional reports, e.g., "District State of Environment Report"	Ministry of Water and Environment (MoWE)/National Environment Management Authority (NEMA)
Climate change information/matters	District Department of Natural Resources Office (DNRO)	Irregular reporting. No defined format	Ministry of Water and Environment (MoWE)/Climate Change Department (CCD)

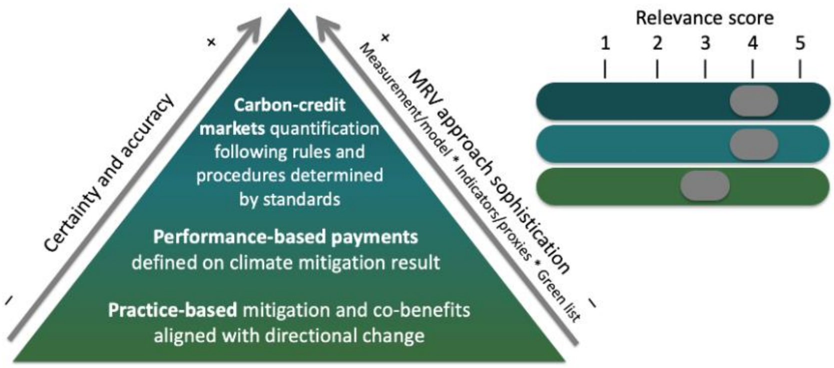


Source: UNIQUE, 2020

Important points for consideration during the assessment include:

- Current process of data collection alongside the routine agricultural extension work and involvement of the different levels of the existing institutional structure.
- The specific extension approach and data collection at the farm level: Which farmers are receiving training (farmers' groups, lead farmers, etc.), and how? Who trains and interviews farmers and reports to higher levels? Who is responsible for oversight and quality control?
- Assessment of reporting forms or templates currently used for routine collection or compiling of specific agricultural subsector statistics, namely: crops, livestock, practices, etc.
- Understanding of the routine cycles of data collection, frequency, processing, and reporting and archiving of the data and information.
- Understanding the challenges and capacity needs and gaps within the existing systems in place as well as with a view to any new MRV system to be developed/adopted.

4.1.2 Aligning the system with farmers' interests through a bottom-up activity-based approach



The relevance of this approach is considered high in particular for projects where farmers are, ideally, directly involved in the MRV system and have the ambition of establishing a long-term system. Such long-term systems are especially relevant for carbon certification. For instance, the minimum crediting period for a carbon project involving SOC under the VCS is 20 years.

Most of the farm activity data and proxy indicators used in many SOC process-based modeling approaches will come from and be collected with the help of smallholder farmers. However, SOC data per se have no obvious value to farmers. In order to be relevant to farmers, emphasis will be placed on collecting farm-level data that they would find useful, but which at the same time are used for soil carbon and GHG emission calculation. Such data relate primarily to monitoring the productivity of the farming system.

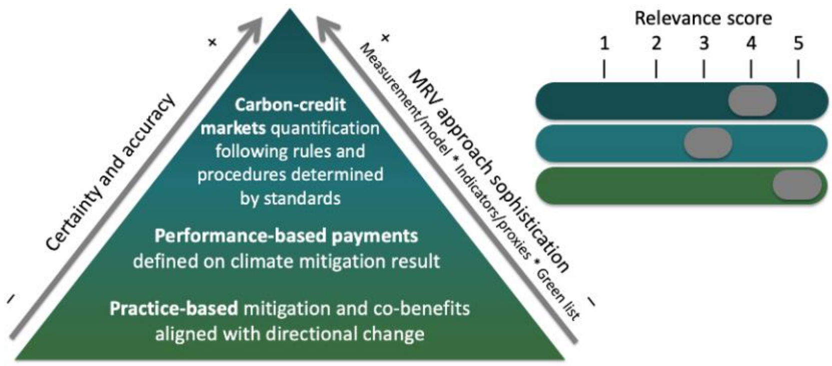
Therefore, when engaging farmers in the design and implementation of the proposed data system, emphasis will be placed on using the data collection system to monitor farm productivity and its relation to farm practices and long-term impacts on productivity. This is meant to align data collection closely with farmers' data interests and engage them in farm-level data collection in a way they can relate to their farm management.

Other advantages of a bottom-up approach, particularly in cases involving smallholders in diverse conditions, are:

1. Splitting up into smaller landscape units, which facilitates linking this system to specific adaptation and/or mitigation projects and initiatives, and programs with the focus on SOC and climate-smart land-use that provide local data for a specific region.

2. Source of data on the primary producers of agricultural commodities. This is of particular importance for maximizing the efficiency and adaptive capacity of agricultural production along entire value chains.

4.1.3 Activity-based MRV approach is designed to achieve multiple benefits



Particularly in programs where SOC represents one indicator among many for assessing the performance of transformational or directional change (e.g., World Bank investments, GCF programs, and FLR initiatives), collecting a farm's activity data should ideally serve the assessment of multiple indicators. On the other hand, a program with a specific mitigation target and performance-based payments might focus on optimizing data collection for the specific assessment, such as the modeling or measurement of SOC.

However, MRV systems for all categories should ideally focus on multiple benefits, and particularly on providing incentives for maintaining the system over time. Above all, the system should be transparent for farmers who are actively involved in the implementation of practices related to SOC sequestration. Furthermore, it should provide mutual benefits for any ongoing or future program/project implementation, extension, and impact monitoring.

This includes identifying specific training needs and priority interventions for extension services. Activity monitoring engages the farmer, provides information crucial to improving extension and self-learning structures, and creates an environment conducive to committing the farmers to the relevant adaptation or mitigation activities.

4.1.4 Activity data typically monitored to achieve multiple benefits

Monitoring should be focused on collecting information that is essential for assessing multiple project impacts and for decision-making regarding project implementation (e.g., determining farmer training needs). In order to measure the impacts, essential data must be collected to track changes in farming practices and their impacts in terms of yield changes and resulting carbon stored. Thus, monitoring starts with baseline data collection and continues throughout the project at frequent intervals. In general, the following aspects will be monitored:

1. Data for the SOC modeling[1],
    - Crop yields and yield increase over time (per crop season): only the most dominant crops are monitored and used for the modeling in order to reduce its uncertainty.
2. Adoption of SALM practice such as residue management, composting and agroforestry.
3. Trees planted in the project: trees will be monitored at every verification event or at least every five years.
4. Livestock numbers and feeding regimes, e.g., open grazing or improved management such as zero-grazing.
5. Practices used by the farmer that generate project GHG emissions, e.g.:
    - use of inorganic fertilizers
    - burning of crop residues
    - use of diesel- or petrol-powered machinery in agricultural management
    - increased use of fossil fuels for cooking and heating attributable to the project
6. Farmer training needs, for both individual farmers and farmer groups
7. Overall farm development, e.g., performance of farm enterprise
8. Extension performance at different project sites
9. Project livelihood impacts, e.g., changes in income and health (nutrition) status

The data monitored from 1-5 are used for estimating project carbon changes. Those from 6-9 can be monitored for assessing overall project impact and for improving project implementation.

In addition to assessing project impacts, another important function of monitoring is to establish the carbon revenue distribution system when such revenues are generated by the project. The revenue distribution system has to be simple, transparent, and robust. The following are options for distributing the carbon revenue:

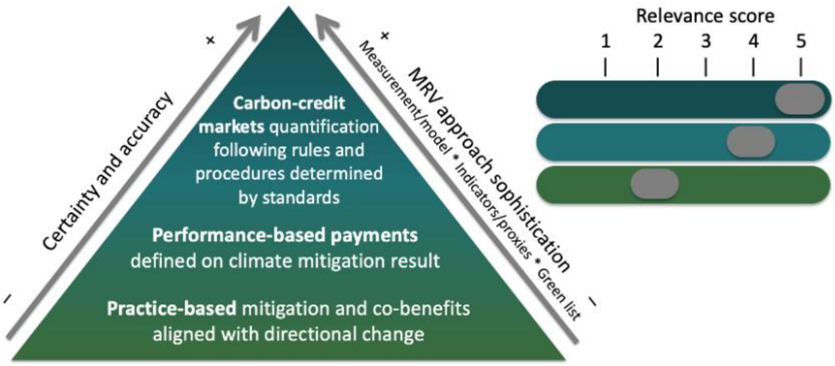
- Full distribution among farmer groups to reward them for the climate mitigation (carbon sequestration) that they have achieved through SALM implementation, or

[1] Additional data for SOC modeling are climate data (rainfall and temperature); soil texture (% clay); crop calendar (start and end of crop season). These data are available from local institutions and/or collected from other sources, so do not need to be included in regular monitoring.

- A share of the revenue can be kept to cover project costs and the rest distributed to the farmer groups, or
- The full carbon revenue can be used to refinance the project and additional project activities such as value chain development, investment, or marketing support for farmers.

The decision about carbon revenue distribution must be transparent, and participating farmers must be made fully aware of, and be involved in, the decision-making.

4.1.5 The quantified climate benefits are real and accurately quantified with known uncertainties



For all categories of SOC MRV systems, it is important for estimated, measured, or modelled benefits to represent the actual situation on the ground (e.g., actual SOC removals) and not simply to be artifacts of incomplete or inaccurate monitoring. In addition, it is important to apply the logical theory of change for performance-based and carbon crediting schemes where changes and benefits of SOC can be attributed to the impacts of the particular project activities being promoted and are not a result of other factors, including climate change.

For carbon crediting schemes, MRV systems must accurately quantify the uncertainties involved. Therefore, these projects usually require a statistical sampling approach for their activity-based MRV system in order to collect relevant parameters at the farm or household level. For each parameter, the precision and accuracy2 must be defined; therefore, the uncertainty of a mitigation activity (e.g., SOC sequestration as a result of composting or residue retention) is quantified. Most crediting schemes require a precision level of 10% to 15% error margin (at 90% to 95% confidence intervals); however, most carbon methodologies and standards also allow deduction

[2] Accuracy is the degree of closeness of estimates to the true value; accurate measurements lack bias and systematic error. Precision is the level of agreement between repeated measurements; precise measurements have a lower random error.

mechanisms if these uncertainty levels cannot be reached. In the info box below, a sampling design of the Kenyan Agri MRV+ system is presented, which sets out to collect activity data from farms in order to measure mitigation and adaptation performance, including SOC.

For projects where SOC represents an indicator for the assessment of transformational or directional change, the uncertainties of the applied MRV system should be assessed in a more descriptive way by acknowledging the gaps and potential sources of uncertainties without quantification. Nevertheless, the principle of conservativeness should be adhered to in such systems.

Box 2. Sampling design of the Agri MRV+ system in Kenya

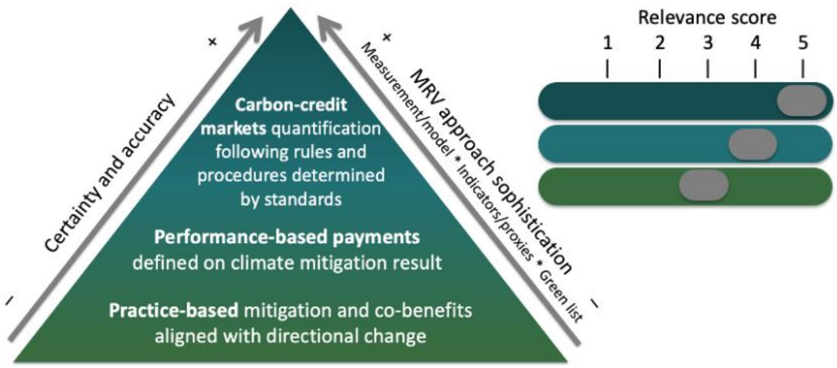
The sampling design (sampling method, number of households to be sampled within a county in Kenya) is driven by the principle of monitoring climate benefit performance with known uncertainties. Therefore, the sampling requirements need to be designed in such a way that the data collected during the activity baseline and monitoring survey (ABMS) meet minimum confidence/precision criteria. This system follows the IPCC Good Practice Guidance for determining mean parameters from a county meeting the 10% precision level at the 90% confidence interval. However, given the vast differences between agricultural systems in Kenya, this overall uncertainty requirement is supplemented by a set of flexible precision criteria that need to be adapted to the county level.

Following the IPCC concept of core categories, the 90/10 precision level only needs to be met by the parameters reflecting the dominant agricultural systems in a particular county. In other words, in a county with subsistence maize and bean farming that has no significant livestock production (dairy or meat production), the only parameters that need to meet the uncertainty requirements are those that concern the dominant farming systems. The sampling plan for each county should document and rank the core categories based on existing data.

The trade-off between sample size and cost always needs to be considered. If the sampling in a county requires a large sampling size at a high cost to achieve the desired precision level, it is more important to reduce costs and discount the estimated climate benefit by a factor reflecting the higher uncertainties in that county.

Climate adaptation performance is more strongly weighted than mitigation performance. This means that parameters needed to analyze of adaptation performance need to be more heavily weighted to meet the uncertainty requirements, especially in counties highly exposed to climate change and extreme events. However, this MRV+ design, with its activity-based monitoring, collects data with mutual use for both adaptation and mitigation.

4.1.6 The system includes provision for quality control and quality assurance



One of the key gaps in many existing data collection systems is inadequate (if any) quality control and assurance (QC/QA) procedures. Setting clear standards is essential for ensuring integrity across all MRV categories, with carbon crediting schemes and other performance-based programs as higher priorities. This means that all procedures required by an MRV system (data recording, survey activities, data processing, analysis, and data archiving and reporting) are encoded in explicit rules that are transparently communicated, taught, and verified. The following procedures should be considered necessary for a SOC MRV system to be implemented to ensure reliable data is collected (irrespective of the number and complexity of parameters collected).

4.1.6.1 Procedures for reliable data collection

- Protocols or standard operating procedures (SOPs) for the data collection process
- Pre-testing and continuous testing of the data collection tools during and after the design and pilot phases of the new MRV system.
- Training of all actors involved in the data collection and transmission phases in the use of SOPs and detection and management of errors.
- If digital data collection tools are applied (e.g., smartphones, tablets, etc.), several in-built data quality checks to automatically detect erroneous entries, e.g., limiting the fields of entry to figures, texts, etc. as appropriate; setting expected min-max values for certain parameters; drop-down lists, etc.

4.1.6.2 Procedures for verification of data entry and analysis

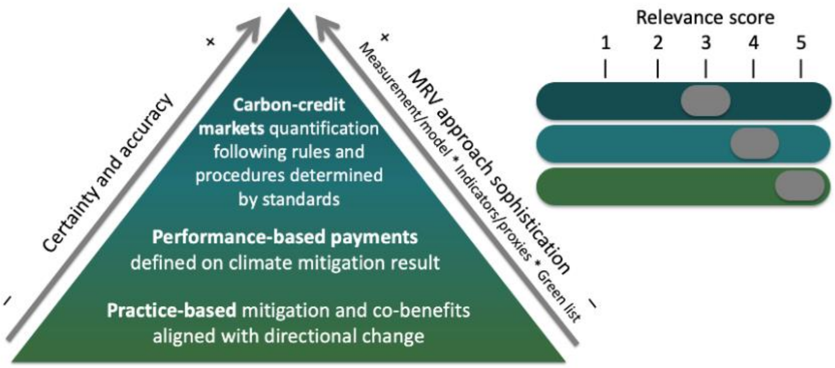
- SOPs for data verification, detection, and management of errors.
- Training all those involved in the data transmission, storage, and analysis phases of data on the established protocols and SOPs.

- Implementation of a data verification scheme to check the data quality at both farmer and project level. These checks identify errors such as omissions (missing data), wrong/implausible values, units, etc. Any error found is then relayed to the data collector/sender to correct.
- If a centralized database is applied, in-built data quality checks to detect, flag and relay and communicate possible errors to responsible persons so that remedial actions are taken.
- Occasional review of all data, including their analysis, can be undertaken by a third party to verify data quality.

4.1.6.3 Dealing with outdated and missing data

- Any new MRV system should have the ambition to collect data regularly, e.g., seasonally/annually. This will ensure the availability of up-to-date activity data from the farms – within the scopes of data collection templates.
- Missing data can arise from: (1) omissions when filling in data templates, (2) lack of clarity or comprehension by stakeholders in the system, e.g., due to requesting information in units or at a level of detail that farmers are not familiar with, (3) requesting data over a long recall period, (4) respondent failure to respond due to fatigue or other reasons. Measures to be implemented to deal with the issue of missing data include:
    - Collecting data seasonally/annually to shorten recall periods.
    - Pre-test and testing of the data tool (templates/App) in the piloting phase and occasionally during the implementation of the system.
    - Thorough training of data collectors and QC/QA personnel.
    - Implementing checks for completeness of data entries before any data submissions to the system.
    - Implementing data verification procedures by GBTs, CBTs, and DLG experts as described in the section above – so that missing values are detected and follow-ups made to correct them.

4.1.7 Cost-effective MRV design



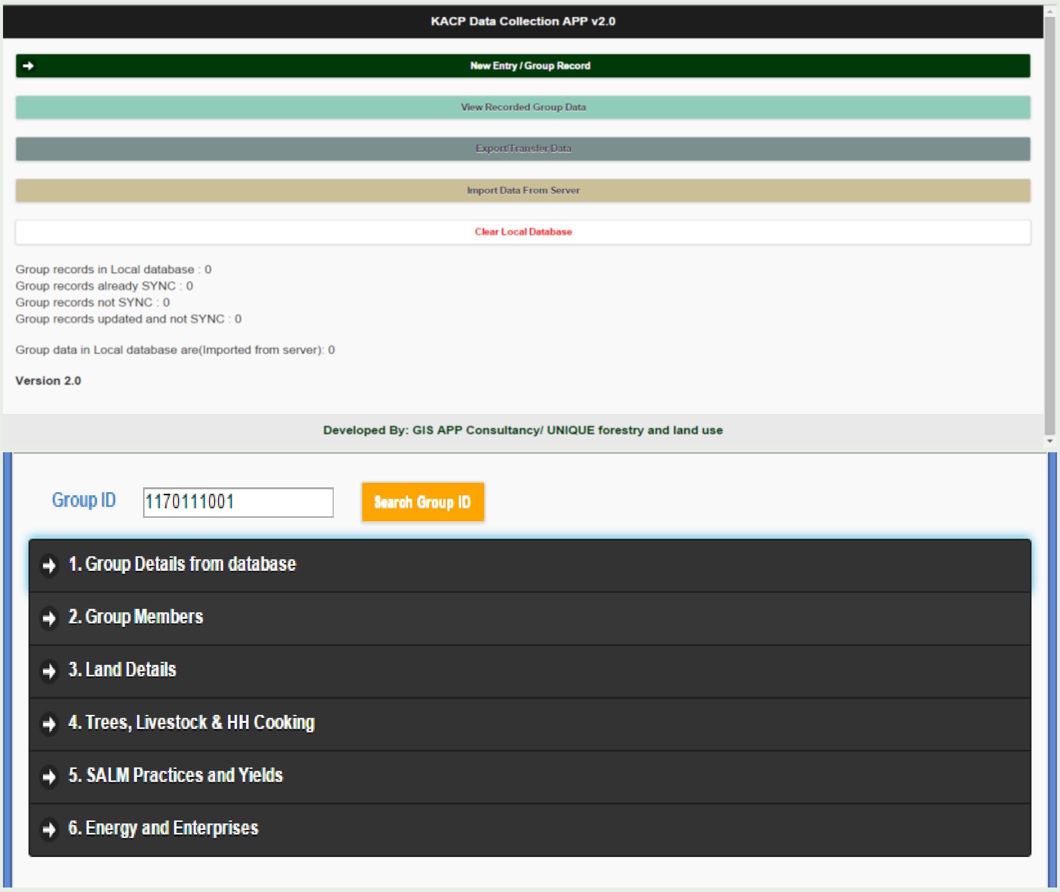
Above all, any MRV system monitoring the performance of SOC mitigation activities needs to be cost-efficient. However, for MRV categories with set rules and requirements in terms of uncertainty and verifiable results, there is a trade-off between certainty and cost, which often leads to demanding MRV systems, including in terms of costs. Nevertheless, there are important points to consider to reduce costs:

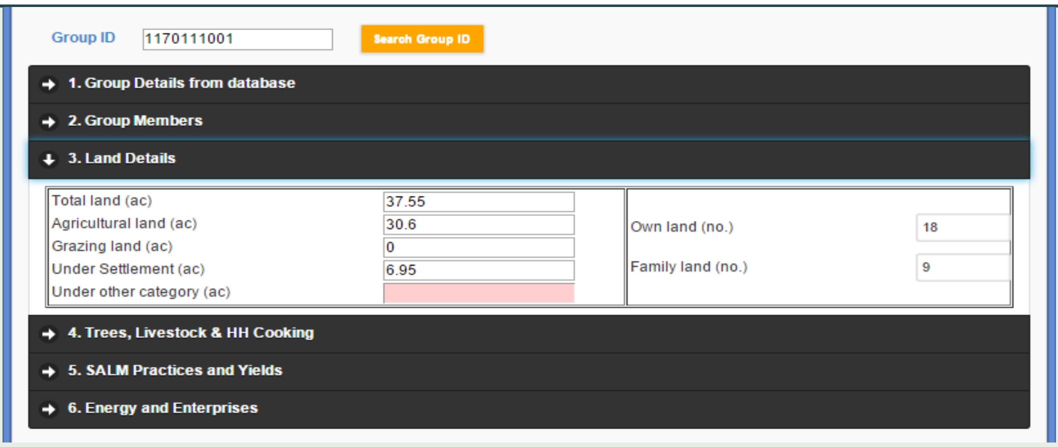
- Linking the system to existing national M&E institutional structures and using many parameters which are already monitored regularly as part of any existing system (see above). For instance, the proposed WBG Burkina Faso agricultural carbon project would build on the existing governmental extension services while partnering with strong non-governmental actors (civil society organizations) that are actively operating in the project areas to provide agricultural extension and training on SALM. The particular entities, personnel, and responsibilities for SALM training and baseline and project data collection and management must be defined through a thorough and wider process of stakeholder consultation in particular project sites.
- Using existing available datasets from global, regional, or national sources. These data are needed to establish a relationship between the activity-based farm data and other important conditions (e.g., climate, soil conditions, available GIS data and databases, etc.).
- Developing easy-to-use digital data collection solutions and web-based analysis tools for data collection, automatic processing, and reporting. The following Info Box describes the fully functioning digital SOC MRV system for the KACP project in place since 2014, now being verified for the 4th time under VCS.

Box 3. Smallholder Activity-Based Project Monitoring and Information System in Kenya

A web-based data entry system (the Project MIS system) was adopted to accelerate data entry on a more standardized basis. The web-based system includes a data entry module, which can work offline, and data can be synced to the project server whenever the internet is available. The module has several mathematical and logical validations to avoid data entry mistakes and control mechanisms to ensure data quality. The data sent to the server is immediately available for further processing using different web-based interfaces. All the calculations to monitor project performance and provide the parameters needed for the RothC soil modeling and other calculations related to the SALM methodology, previously done in Excel, are now integrated into the MIS system.

The following screenshots show the interface of the web-based data entry system:





Since 2014, all farm-based data are collected by an SMS phone-based system at the farmer group level. Kenya, with its M-PESA system of money transfer, can be considered the world's leading country in terms of mobile money transfer. Over 17 million Kenyans, equivalent to more than two-thirds of the adult population, use this system on a regular basis. This means that most farmers in the project region are equipped with a simple mobile phone and are well acquainted with its use and handling of SMS messages. Against this backdrop, the annual farm group summary record sheet containing all relevant summary data of a particular farmer group is sent by SMS using a standard protocol.

With this system, the project has flexible options for collecting and entering data into the web-based MIS, either through the data entry interface or directly through the SMS-based system. In summary, some of the key features of the system are listed below:

- Centralized online database
- Dashboard to monitor progress
- Login options for specific usage rights for data viewing and editing
- Edited records log – old value, new value, edited by, time and reason
- Restriction on data editing by setting deadlines
- Summary analysis of data through a single click (no need for Excel-based tools)
- Random selection of a farmer group sample for QA/QC performed by the system
- Provision for sending comments to lower admin unit
- Data export to Excel
- Login management for changing passwords and setting deadlines for editing
- Creation of new farmer groups in which MIS system creates ID (eliminating scope for duplicate ID)
- Data validation (mathematical and logical)

The following screenshots show the interfaces of project MIS, with an automatic calculation of the organic C inputs to the soil and the adoption of SOC-relevant practices:

View/Update Data | View Farmer's DB | Data Changes Log | QA/QC (RS) | Manage Logins | Results | Summary | SMS Data

2017 | Kisumu | Refresh

Data updated last on : (UTC+03:00)

General information (Kisumu - 2017)

Total number of groups	Total number of farms
620	8960

Land	Average ha / farm	Total ha	% of total land
Total Land	0.91	8168.19	
Agricultural land	0.65	5837.07	71.46
Grazing ground	0.08	741.38	9.08
Settlement	0.12	1114.36	13.64
Others	0.06	515.58	6.31

Ownership		
Ownership	Number of farms	% of total farms
Family	6569	73.31
Own	4300	47.99

HH cooking and heating		
Material	Number of groups	% of total groups
Firewood	526	84.84
Charcoal	105	16.94
Manure	6	0.97
Grasses	3	0.48
Kerosene	76	12.26

Crops yields & residues (Kisumu - 2017)

Composting & livestock (Kisumu - 2017)

Tree biomass & soil input (Kisumu - 2017)

Implementation of SALM practices (Kisumu - 2017)

View/Update Data | View Farmer's DB | Data Changes Log | QA/QC (RS) | Manage Logins | Results | Summary | SMS Data

2017 | Kisumu | Refresh

Data updated last on : (UTC+03:00)

General information (Kisumu - 2017)

Crops yields & residues (Kisumu - 2017)

Yields per crop in kg/ha

crop	Season	Total area ha	Total production kg	Area weighted mean kg/ha	Mean kg/ha	SD kg/ha	No groups
maize	Season 1	3609.55	12478871.70	3457.18	3844.98	4333.18	514.00
maize	Season 2	3249.04	10869421.50	3345.43	3504.07	4306.15	494.00
beans	Season 1	2321.62	1175603.75	18229.38	834.74	650.49	490.00
beans	Season 2	2212.83	1029402.50	16747.12	708.95	621.45	443.00
sorghum	Season 1	1017.38	730627.60	32316.56	1202.25	1616.15	372.00
sorghum	Season 2	279.50	160127.40	25781.13	821.30	637.12	145.00
sw_potato	Season 1	329.63	3804620.80	13668.32	19064.74	23712.88	248.00
sw_potato	Season 2	327.57	2986167.68	10795.30	15532.94	18466.93	205.00
gnut	Season 1	60.08	53915.00	32306.10	905.77	1442.28	78.00
gnut	Season 2	67.08	30978.75	16625.26	628.76	630.37	74.00

Residues per crop in tC/ha

crop	Season	Total area ha	Total residues tC	Area weighted mean tC/ha	Mean tC/ha	SD tC/ha	No groups	SE %	Pmin tC/ha	Pmax tC/ha	% area
maize	Season 1	3609.55	6058.46	1.68	1.83	1.66	514	4.00	1.53	1.82	49.00
maize	Season 2	3249.04	5314.04	1.64	1.70	1.65	494	4.00	1.49	1.78	53.00
beans	Season 1	2321.62	1272.90	0.55	0.68	0.27	490	2.00	0.52	0.57	32.00
beans	Season 2	2212.83	1175.78	0.53	0.63	0.26	443	2.00	0.51	0.56	36.00
sorghum	Season 1	1017.38	638.45	0.63	0.81	0.62	372	4.00	0.56	0.69	14.00
sorghum	Season 2	279.50	159.82	0.57	0.67	0.24	145	3.00	0.53	0.61	5.00
sw_potato	Season 1	329.63	173.24	0.53	0.59	0.21	248	2.00	0.50	0.55	4.00
sw_potato	Season 2	327.57	165.17	0.50	0.56	0.16	205	2.00	0.48	0.53	5.00
gnut	Season 1	60.08	42.60	0.71	0.71	0.59	78	9.00	0.58	0.84	1.00
gnut	Season 2	67.08	35.55	0.53	0.60	0.26	74	5.00	0.47	0.59	1.00

Composting & livestock (Kisumu - 2017)

Tree biomass & soil input (Kisumu - 2017)

View/Update Data | View Farmer's DB | Data Changes Log | QA/QC (RS) | Manage Logins | Results | Summary | SMS Data

2017 | Kisumu | Refresh

Data updated last on : (UTC+03:00)

General information (Kisumu - 2017)

Crops yields & residues (Kisumu - 2017)

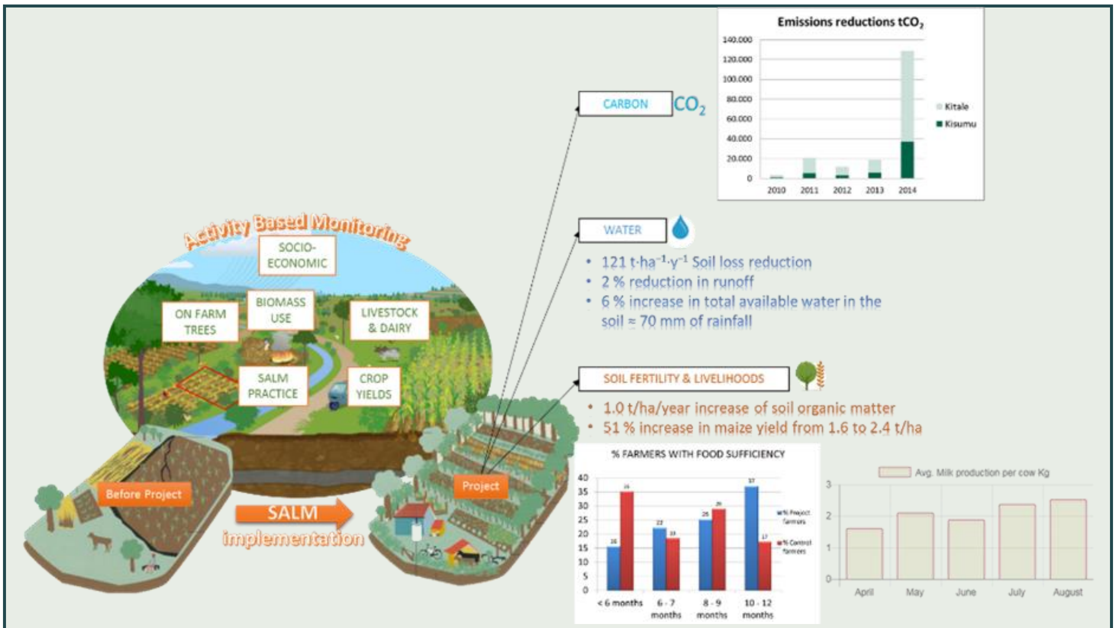
Composting & livestock (Kisumu - 2017)

Tree biomass & soil input (Kisumu - 2017)

Implementation of SALM practices (Kisumu - 2017)

SALM practices	1st season area ha	2nd season area ha	1st season % of total agricultural land	2nd season % of total agricultural land
Burning of residue	14.9	10.3	0.3	0.2
Compost raw manure and residue	4733.9	4907.5	81.1	84.1
Mulching + cover crops	3875.5	3682.1	66.4	63.1
No Till	42.3	54.0	0.7	0.9
Reduced tillage	3640.9	3771.6	62.4	64.6
Removing residue	1564.0	1515.9	26.8	26.0
Residue for mulching	3673.0	3509.0	62.9	60.1
Terraced fields	2932.2	2841.8	50.2	48.7
Use of improved varieties	4384.7	3489.3	75.1	59.8
Use of inorganic fertilizers	844.9	1048.2	14.5	18.0
Use of machinery	0.0	0.0	0.0	0.0
Use of raw manure	0.0	0.0	0.0	0.0
Water harvesting	2368.7	2362.8	40.6	40.5

The proxy indicators collected and self-monitored by the farmers are used to monitor measurable impacts of multiple project benefits, as illustrated in the chart below:



Multiple impact monitoring from the MIS system

Source: UNIQUE, farm sketches adapted from Vi Agroforestry

5 Putting principles into practice: Recommendations for design features of selected WBG projects regarding SOC MRV

5.1 Niger Community Action Project for Climate Resilience (Niger CAPCR)

5.1.1 Project Brief (based on project documentation)

This program is in its final stages of implementation and started in 2012. Its overall objective is to improve the resilience of the population and production systems to climate change and variability, targeting 38 communes in all eight regions of Niger. It is structured into two main components: Component 1 aims at mainstreaming climate resilience into national- and local-level development strategies; Component 2 focuses on the integration and implementation of climate resilience practices into integrated crop-livestock-forest systems.

The Sustainable Land and Water Management (SLWM) practices cover a wide spectrum of field practices of which many are relevant to soil carbon sequestration. in particular: cropland management (mulching, reduced tillage, crop rotation, agroforestry); soil and water conservation measures (small water retention/water run-off infrastructure); vegetative measures (vegetated strips, windbreaks, assisted natural regeneration, dune fixation, bushfire management); and developing grazing areas (fodder).

To date, the project has implemented SLWM on around 4,800 ha of cropland and 38,900 ha of silvopastoral areas. The project monitoring further reports an average crop yield increase of about 50% while forage yield increased by 15%.

5.1.2 Existing MRV Design

This national program has established a basic MRV system to report on the main indicators on a national scale. As an overview the following indicators are collected and reported:

- Information on financing provided for different SLWM practices is annually collected at the commune level;
- There is no monitoring of practices and practice changes at farmer field level;

- The agricultural productivity of the main crops is evaluated annually, relative to control sites, including the evaluation of biomass in general (herbaceous, wet/dry biomass);
- Geo-referencing information on all implementation sites.

Overall, this current MRV design does not represent a project or activity-based approach rather than a wholesale approach for reporting SLWM financing on a national scale. Since other SLWM projects are being implemented in Niger, the question remains of how an adequate MRV system should look like where SOC is used as an indicator (among others) for SLWM performance in order to reward the national efforts, for which minimum information is available.

5.1.3 Potential ambition of a SOC MRV system

To establish a low-cost, low transaction but robust results based SLWM financing approach (ex. cooperative/bilateral approach under Paris Agreement Article 6 for NDC implementation that can be accepted by a donor) where SOC serves as proxy indicator for performance of SLWM in different projects

5.1.4 SOC MRV design recommendations

Using SOC as a proxy indicator for the implementation of NDC-targeted activities, such as SLWM in Niger, with multiple programs and projects all contributing to the performance on a national level, a Benchmarking SOC Monitoring System could be established.

This means that on a national level, the performance efforts of various projects and programs all targeting the implementation of different SLWM practices within cropland and pastoral land is measured over time by introducing a SOC mitigation score, for instance from 1 (=low performance) to 5 (=maximum, optimal performance). This permits the following :

- Comparison of different projects and programs implemented under different conditions in the country, e.g., targeting different levels of implementation and monitoring (communes, farms, watersheds)
- Comparison of programs implemented within different agro-ecological conditions and land-uses (cropland, pastureland, etc.)
- Aggregate project/program level performance to a national SOC mitigation score and comparing it to the national benchmark set, e.g., in the NDC

The benchmarking must minimally be done on a national level, and ideally on the project/program level, to represent the maximum mitigation potential. This reflects an optimal ex-ante estimation of

tCO_2 sequestered per year within the soil, which also requires the definition of a baseline scenario. Typical assumptions for reaching this maximum mitigation score typically should include the following indicators, which could be based on the NDC targets or other agricultural sector development plans:

- Yield target of the main crops including forages and fodder 100% met;
- Area targeted for implementation 100% met;
- Adoption of all SOC-relevant SLWM practices on 100% of the target area.

The ex-ante estimate shall assess the maximum CO_2 benefits assumed to be reached if all goals on the project, program, and national levels are met.

Since MRV focuses only on SOC, not all the potential SLWM practices have a quantifiable SOC benefit. However, the scope of the MRV could easily be increased to include, for instance, mitigation benefits from biomass (trees and shrubs) or other relevant performance indicators such as reduced topsoil erosion, water benefits, etc.

To date, the most relevant SOC SLWM practices are all related to the increase and retention of biomass left to decompose on soils, including practices such as mulching, composting, cover crops, reduced tillage, planting of soil fertility trees, forages, etc.

To derive an ex-ante benchmark estimate, an existing GHG accounting tool can be used, such as the FAO Ex-Ante Carbon-balance Tool (EX-ACT, see other tools presented in this report). Even the IPCC SOC practice-based estimation approach applies to this exercise, provided that the results represent optimal performance levels in terms of SOC benefits.

Below, an example is given of the RothC soil model to derive an ex-ante estimate. This soil model has been successfully applied even in voluntary carbon projects to monitor verified SOC benefits (see the Burkina Faso case study below). It can also be very useful to model ex-ante SOC benefits with a minimum of data and information. The original RothC model is available from the Rothamsted Research Centre[3], while several service providers have very user-friendly RothC model applications available[4].

[3] https://www.rothamsted.ac.uk/rothamsted-carbon-model-rothc

[4] Please contact Unique forestry and land-use

5.1.5 RothC soil model parametrization

The following information is necessary to parametrize soil models for different agro-ecological regions in the country.

1. Choice of the precise latitude representative for a specific project, program or specific agro-ecological zones. For instance, Google Earth can be used.
2. Mean, minimum, and maximum monthly temperatures and monthly precipitation are required for each RothC model, ideally aiming for 5-year average values, aiming at more robust data. Such climate data can be obtained from local weather stations or online resources such as WorldClim. For such ex-ante modeling, the same data can be used for the baseline and benchmark scenario. However, it might be beneficial to include aspects of climate change impacts into this modeling exercise by reflecting future changes in temperatures and precipitation (if available).
3. For each RothC model to be configured, the soil clay content is required in %. If no national or local soil data is available, the Harmonized World Soil Database (HWSD) can be used[5], for instance. Normally, clay contents are the same for the baseline and the benchmark scenario
4. Since RothC modeling is done on a monthly basis, a cropping calendar for each model has to be defined in terms of when the planting and harvesting occurs. Later in the process, the intervals at which organic matter inputs from biomass (e.g., through mulching) are applied on the field can be defined.

5.1.6 Running RothC soil models

To run the model to derive the SOC benefits, two kinds of data and information are required, representing first the baseline scenario and then the benchmark scenario:

1. The carbon input values in tC/ ha from practices, such as mulching composting, manure application, etc.
    - The total areas on which these input values are applied representing the adoption rate. For instance, if a RothC model is configured for 5,000 ha of cropland in a certain project or agro-ecological region, on what % of this area are certain practices and their soil input values already implemented in the baseline scenario, and on how much of this land is the same practice implemented under optimal benchmarking conditions (ideally 100%)?

[5] http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en/

2. The soil input values in tC/ha can be derived from published literature or indirectly from crop yields (if the main practice is mulching or composting) and livestock (if manure is applied to the soil) using IPCC conversion pathways. Using crop yields also allows the factoring in of optimal yield increases targeted by a program or nation, compared to the baseline:
   - For crop yields, use conversion equations reported in Table 11.2 in Volume 4 of the 2006 IPCC GPG.
   - To calculate manure inputs, use Tables 10.4 and 10.9 in Volume 4 to estimate manure produced per livestock type based on regional livestock statistics. Use a conversion of 0.4 to convert volatile solids (kg dry organic matter per animal) to carbon.

5.1.7 Monitoring requirements

Ideally, monitoring a project or program should take place annually and capture the following minimum data to derive the SOC mitigation score for a particular year compared to the benchmark:

- Georeferenced areas of implementation. The level at which this is reported can vary between projects or programs. In this example, it is assessed at the commune level but could be at the farm or higher levels, such as watersheds. The important thing is to maintain a defined level for each project or program and assign unique IDs to each (e.g., IDs for each commune, farm, etc.).
- For each identified level of implementation and assigned IDs, an assessment of adoption areas (ha or % of total) for each relevant and implemented SLWM practice.
- Yield data for target crops (kg/ha), ideally applying to each assigned level of implementation and assigned IDs.
- Livestock types and numbers, ideally for each assigned level of implementation and assigned IDs.

On the higher levels of implementation (communes, watersheds, etc.), these data should represent weighted average values and, ideally, establish a quality control system to verify the data efficiently (for instance, through a few control farmers). If data are collected at the field or farm level, then a statistical survey design (simple random or stratified random sampling) should be implemented.

5.2 Kazakhstan Sustainable Livestock Development Program

5.2.1 Project Brief (based on project documentation)

The Sustainable Livestock Development Program will be implemented from 2021 to 2025 and has the objective of supporting the development of environmentally sustainable, inclusive, and competitive beef production in Kazakhstan. The program will support the integration of the livestock sector with national climate adaptation and mitigation policies. In terms of climate change mitigation in beef production, it will address issues on sustainable grassland management (land degradation, biodiversity conservation), pollution control (manure management on feedlots and slaughterhouse waste management), and mitigation of net GHG emissions along the value chain – from feed production to slaughterhouses. Kazakhstan's NDC sets an economy-wide unconditional target of 15% reduction in GHG emissions by 2030, compared to the base year of 1990. Although, the 17.53 million metric tons of CO_2eq of direct emissions from livestock account for only about 8% of the total national GHG emissions (but 80% of national agriculture emissions), an increase in emissions from the sector would further jeopardize Kazakhstan's capacity to achieve its target. The Program will thus support a roadmap for including livestock sector mitigation targets in the NDCs.

The Program is estimated to contribute to the net mitigation of GHG emissions from the livestock sector in Kazakhstan by 5.6 million tons CO_2eq over the five years. This is achieved through three main fields of intervention, of which one focuses on SOC sequestration. This will be achieved through the adoption of improved grazing management practices, which allow more reactive management of grazing pressure (in time and space), contributing to improved grass growth (Lal 2009). Increasing SOC stocks under perennial grasses depends mainly on enhancing carbon inputs from plant roots and residues. Ranchers can achieve this by managing plant biomass removal from grazing or increasing forage production. To improve productivity and soil conditions on grazing lands, the Program will promote the adoption of intensive grazing practices by employing high animal stocking rates for short durations, from a few hours to a few days, on pasture with frequent movement of animals and relatively long "rest periods" for the vegetation between grazing events. The improved grazing management practices promoted under the Program generate productivity gains and greater financial returns for farmers, so it is assumed that these practices will continue.

5.2.2 Potential ambition of a SOC MRV system

Project documentation mentions that, to date, no specific system is in place to report emissions from the livestock sector on a periodic basis, with a level of granularity that allows improvement in management practices (i.e., IPCC Tier 2; see IPCC 2019). The Program will support the development of a specific MRV system for the livestock sector. This activity is ongoing and should be completed during the first year of Program implementation. Using the new system, the Program will monitor emissions and sequestration throughout implementation as part of the M&E plan. The data and monitoring system used to demonstrate net mitigation of the Program will form the basis on which to update the NDC and develop the related road map.

5.2.3 SOC MRV design recommendations

A SOC MRV system should be developed as an integral part of a wider national livestock MRV system with at least an IPCC Tier 2 approach. Given the need for establishing this system, especially within the context of the emerging national carbon market, to provide financial incentives for farmers to continue the improved grassland management practices beyond the Program's lifetime, the MRV system should be developed as a transitional results-based payment and NDC reporting to carbon credit production system moving over time from Tier 1 to at least a combined Tier 2/3 system.

Moving forward, the establishment of such a system requires a thorough assessment of the incentive and design structures for the adoption of MRV systems, as outlined in Section 4 above:

1. Assessment of existing institutional structures that provide accountability in ways appropriate to the Program and national context;
2. Alignment of the MRV system with ranchers' interests, ideally through a bottom-up activity-based monitoring approach where proxy indicators are monitored and used for SOC modeling;
3. Assessment and design of the activity-based SOC MRV approach to achieve multiple benefits both for the farmers, as well as Program and national (NDC) reporting;
4. MRV design roadmap to move from lower to higher IPCC Tiers, which guarantees that climate benefits are real, accurately quantified, and have known uncertainties;
5. Assessment and establishment of a system that includes provision for quality control and quality assurance;
6. Assessment and establishment of a cost-effective MRV design.

Figure 6 summarizes the general sequence of steps for MRV design and implementation (from top to bottom) while ideally moving over time from Tier 1 to Tier 3.

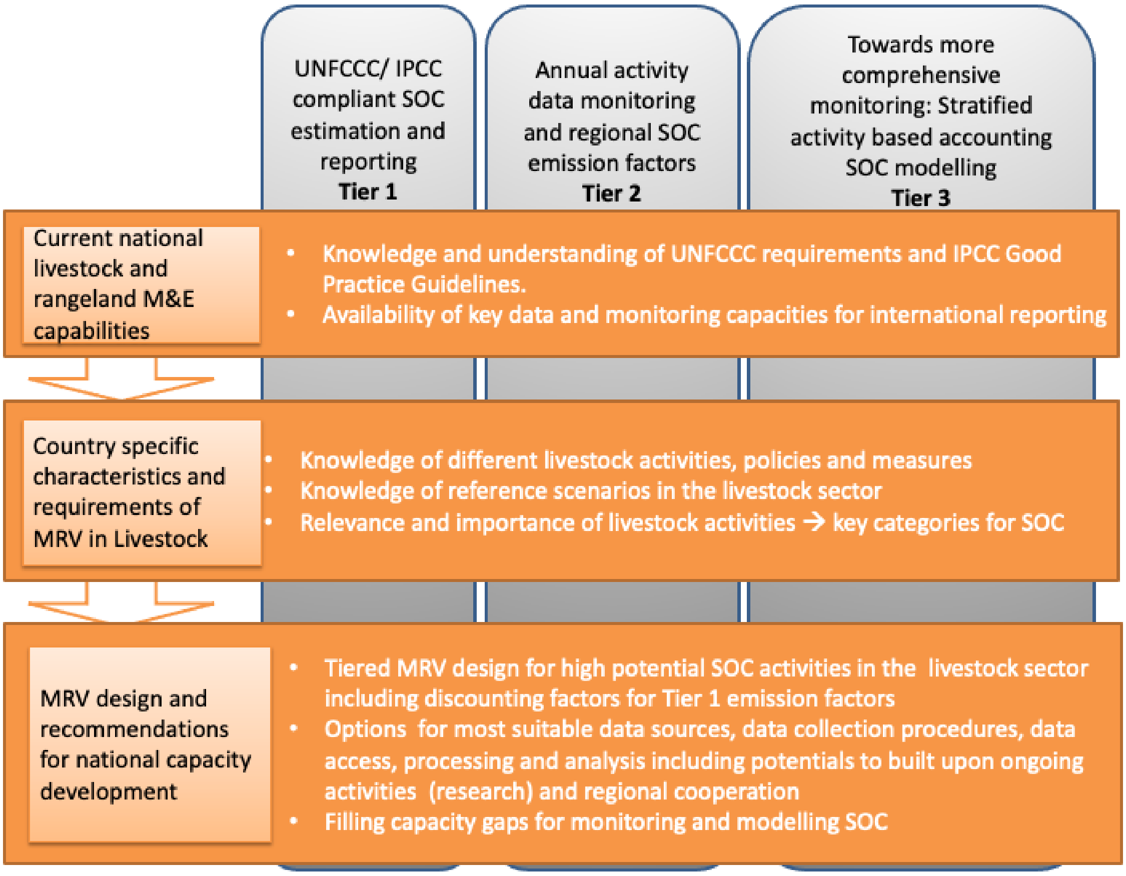


Figure 6. The general sequence of steps towards the MRV design and implementation (from top to bottom) while ideally moving over time from Tier 1 to Tier 3.

Conceptually, a SOC MRV system could initially be established using the ex-ante benchmarking approach outlined under the Niger Case Study (page 46).

When moving towards a higher level of IPCC Tier requirements, with the potential to certify SOC carbon credits and other emission reductions under the national carbon market or any international voluntary market, the MRV system should be designed in line with accepted (verified) carbon market standards and methodologies. Therefore, a quick review of approved and pending methodologies under the VCS and other approved GHG programs, which fall under the activity category of grassland management and livestock production, is presented below to determine whether an existing methodology could be used as standard guidance. Seven methodologies were identified in Table 12.

Five of the seven methodologies account for emission reductions in terms of absolute GHG emissions within the project boundary (i.e., an area-based accounting approach). These five accounting approaches do not consider the land-sparing effects of more efficient land use or the GHG effects of productivity improvements in livestock commodity production. Therefore, these methodologies do not incentivize sustainable intensification of grassland or livestock production, in which more intensive production increases output at a greater rate than the increases in GHG emissions.

Table 12. Review of potential Methodologies to be used to set up SOC MRV System

Methodology	Title	GHG Program	Comments
VM0026	Sustainable Grassland Management	VCS	VM0026 does not include emissions from off-farm production of fodder and feeds either as an emissions source within the project boundary or as a source of leakage, and it does not include emissions from lime; an applicability condition is that at least 95% of manure is deposited on pasture, which may not be the case if sustainable intensification of grassland involves confinement of animals in the fattening phase; land-use change (including afforestation/reforestation of grasslands) is not permitted.
VM0032	Methodology for the Adoption of Sustainable Grasslands through Adjustment of Fire and Grazing	VCS	VM0032 restricts applicability to projects where there is no change in the density or time spent by animals in confinement, and projects that do not involve soil tillage. Lime is also not included, and off-farm production of fodder and feeds, either as an emissions source within the project boundary or as a source of leakage, is not included. Land-use change affecting grasslands (including afforestation/reforestation) is not permitted.
VM0017	Adoption of Sustainable Agricultural Land Management	VCS	VM0017 restricts applicability to regions where land under cultivation in the region is constant or increasing in the absence of the project and forest land is constant or decreasing over time. Livestock emissions sources and emissions from lime are not included in the scope of the methodology. Emissions from off-farm production of fodder and feed are not included either as an emissions source within the project boundary or as a source of leakage.
VM0041	Reduction of enteric methane using feed supplement	VCS	VM0041 only includes enteric fermentation and project emissions from supplement production, but not from production of basal forage or other feeds. No other emissions sources likely to be affected by grassland intensification are included.
VM0042	Methodology for improved agricultural management	VCS	VM0042 includes most relevant sinks and sources (but not lime). But it penalizes activities to restore grassland and increase livestock productivity that increase absolute GHG emissions within the project boundary.
Grazing Land and Livestock Management (GLLM)	Methodology for Grazing Land and Livestock Management	American Carbon Registry (ACR)	GLLM includes most relevant sinks and sources (but not lime). However, it applies discounts to activities aiming to restore grassland and increase livestock productivity that increase absolute GHG emissions within the project boundary.
GS dairy methodology	Methodology for Quantification of GHG Emission Reductions	Gold Standard	This GS methodology incentivizes reductions in GHG intensity of dairy production but it is only

	from Improved Management in Smallholder Dairy Production Systems using a Standardized Baseline		applicable to dairy production by smallholder farms. It does not account for beef production and is not applicable to farms that employ staff or by farms run by companies. Soil and biomass carbon pools are not included.
Quantification protocol for reducing GHG emissions from fed cattle	Quantification protocol for reducing GHG emissions from fed cattle	Alberta Carbon Offset Program	This methodology incentivizes reductions in GHG intensity of beef production. It is applicable only to the finishing stages of beef cattle production in feedlots in Alberta, Canada. Soil and biomass carbon pools are not included.

Overall, there is a gap in available methodologies to incentivize land-sparing and productivity improvements in grassland-based livestock production, which includes accounting for SOC. Nevertheless, in terms of specifically SOC monitoring, the VCS Methodologies VM0026, VM0017, VM0042, and ACR Grazing Land and Livestock Management (GLLM) provide monitoring guidance for SOC.

When reviewing these methodological approaches, it is important to decide on three main options relating to setting up the baseline, demonstrating additionality, and monitoring against the baseline to certify potential SOC benefits. In general, there are three options:

1. A project-based methodology
2. A performance benchmark for additionality with either a performance benchmark or a project method for the crediting baseline.
3. An activity-based positive list for additionality with either a project method or a performance benchmark for the crediting baseline.

Each approach has its advantages and disadvantages. For all approaches, the livestock program can use a program-level approach to roll out new implementation areas over time (Table 13).

Table 13. Advantages and disadvantages of methodological approaches for SOC accounting and monitoring

	Advantages	**Disadvantages**
Project-based methodology	Tailored to a specific project design logic	Challenges in scaling up to include similar projects with different conditions.
Performance benchmark	Simplifies additionality	High data requirements to analyze the distribution of performance and trends over time.
Activity-based positive list	Simplifies additionality	The project activity needs to be precisely specified, which may limit flexibility in use. Notwithstanding, either project- or performance methods are necessary for baseline.

Given the nature of this livestock program's national scale, a performance benchmark or a project-based approach is recommended. This performance benchmark could then transition over time from the simple approach described above to a benchmark, following carbon standard requirements.

The VCS Methodology Requirements specify the data and data quality required to set a performance benchmark (VCS MR Section 3.4.6). Briefly outlined, the data can be:

1. Primary survey data: if used, they must be representative sample survey data from an applicable region in Kazakhstan (e.g., region with similar climate and soil conditions), as well as recent and publicly available;
2. Secondary data: if data from publications are used, it must be demonstrated that they are based on representative sample surveys, are recent and, ideally, peer-reviewed.

The data should be analyzed to show the distribution of performance in the region, and to select a performance benchmark that is conservative in terms of limiting the potential for approval of non-additional projects.

The performance benchmark can be characterized by any unit relevant to describe activities related to SOC changes. It must be possible to convert the chosen unit into a reliable estimate of SOC changes.

In the Kazakhstani farming/ ranch systems described, one of the following two methods is applied: either a random sample of ranches throughout the whole region; or analysis comparing production practices between different farm types, each of which has been randomly sampled. If the latter is the case, then the analysis may be similar to defining the program's improved livestock production strategy, as one farm type is compared with another.

If the performance and activity-based approaches are difficult to implement, then a project-based methodology can be adopted; in which case, additionality must be justified following the standard methodology requirements, either with reference to an existing tool[6] or by writing specific additionality requirements that reflect the common additionality approaches.

[6] https://verra.org/wp-content/uploads/2017/11/VT0001v3.0.pdf

5.3 Burkina Faso Agricultural Carbon Project (BUFACAP)

5.3.1 Project Brief (based on project documentation)

The Burkina Faso Agricultural Carbon Project (BUFACAP) is a national program that contributes to climate mitigation and adaptation efforts set out in the country's NDC in the Agriculture, Forestry and Other Land-use (AFOLU) sector. It promotes sustainable agricultural land management on smallholder landholdings and is implemented across all administrative regions in the country, which falls within the Sudanian and Sudano-Sahelian Agro-Ecological Zones (AEZs).

The main objectives are to sustainably increase smallholders' agricultural productivity, income, and welfare; promote adaptation to climate change and build resilience in agrarian landscapes; reduce land degradation; and enhance tree and forest cover in line with the National REDD+ agenda. The sustainable land management (SALM) practices promoted include compost or manure application; residue management (mulching); a range of agroforestry practices; natural regeneration of trees; a range of soil and water conservation practices (e.g., erosion control structures, etc.); a range of integrated livestock management practices (e.g., forage crops, livestock housing, biogas digesters, etc.); and a range of agronomy practices (e.g., mixed cropping, intercropping, nutrient management, crop rotation, etc.).

The project involves a consortium of institutions coordinated by the Forest Investment Program (FIP) of Burkina Faso to promote the adoption of sustainable land management practices across the project regions. The activities are expected to result in increased and sustainable agricultural production, tree and forest conservation, and land restoration. GHG emission reductions will be generated through increased carbon storage in tree biomass and soils within the agricultural landscapes.

5.3.2 Potential ambition of a SOC MRV system

The program is currently being developed under the VERRA - VCS Carbon Standard using a specific soil carbon accounting methodology (VM0017) for subsequent certification and production of carbon credits. Therefore, the SOC accounting and monitoring system is developed in line with the specific methodological requirements (Box 4).

Box 4. Agricultural soil carbon monitoring & the Verra VCS SALM methodology

Project developers of soil carbon projects must be able to document and accurately quantify SOC stock changes to meet the accuracy (uncertainty) requirements of the SALM methodology.

The World Bank developed the SALM methodology within the framework of the Kenya Agricultural Carbon Project (KACP). This methodology offers the means to estimate and monitor GHG emissions from project activities that reduce emissions from agriculture through the adoption of SALM practices in the agricultural landscape by applying the activity-based modeling approach. Coupled with published research on management impacts of SOC (to verify model results), this approach is able to estimate the uncertainty associated with SOC sequestration rates. The main features of the methodology are presented below:

Key features of the VCS approved SALM methodology

Key Highlights

- Significant innovation for the agriculture sector;
- Primary carbon pools: living biomass (trees) and soil organic carbon (SOC);
- Agricultural activities in the baseline will be assessed and adoption of sustainable agriculture practices will be monitored as a proxy of the carbon stock changes, using activity-based model estimates;
- First of its kind: Uses Roth-C Model to quantify changes in soil C;
- Use of other models is possible;
- Direct measurements of soil C pool are not required: activity-based monitoring is used to obtain the model inputs.

Applicability conditions

- Land is either cropland or grassland at the start of the project;
- The project does not occur on wetlands;
- The land is degraded and will continue to be degraded or degrade naturally;
- The area of land under cultivation in the region is constant or increasing in absence of the project;
- Forest land in the region, as specified by the national CDM forest definition, is constant or decreasing over time;
- Demonstration that the use of the Roth-C model is appropriate to the projects' climatic region or the agro-ecological zone.

The methodology offers an ABMS approach to estimate soil carbon stock changes combined with CDM-approved methodological tools to monitor tree carbon sequestration.

Soil carbon models

Selecting suitable SOC model

- To use the SALM methodology, the selected model must have been validated in the same agro-ecological zone or IPCC climate zone as the project.
- In Africa, the Rothamsted C soil decomposition model (RothC) and the CENTURY ecosystem models are the most widely used to predict soil carbon stock changes. They have been tested in some, but not all, agro-ecological zones. The assessment revealed that Century is more suitable for rangelands and regions with homogenous land cover. However, in Sub-Saharan Africa, land-use is very scattered and the RothC proved to be more suitable for smallholder agricultural carbon projects with limited data availability.

RothC model

- Suggested for use (but not obligatory) in the SALM Methodology.
- Calculates the SOC changes due to changes in soil inputs e.g., crop residues and manure. The increase or decrease of SOM in the soil is the result of the decomposition of the added organic materials.
- The inputs required by the model are:
  - Soil clay content (%)
  - Climate parameters: monthly mean, minimum, and maximum temperatures (°C), monthly precipitation (mm), monthly pan evaporation (mm)
  - Additional residue inputs, due to crop management changes (tC ha-1)
  - Additional manure inputs, due to manure management changes (tC ha-1)
  - Soil cover in each month (bare or covered)
  - Decomposability of the incoming plant material (ratio between decomposable plant material (DPM) and resistant plant material (RPM)
  - Model equilibrium SOC density values and SOC changes due to activity and related input changes. The increase or decrease in SOC is the result of the decomposition of the added organic materials.

The basic idea is that agricultural activities in the baseline will be assessed, and adoption of SALM practices will be monitored as a proxy for the carbon stock changes, using activity-based model estimates.

A digital platform is conceptualized within the framework of this carbon project, allowing different project implementers in the country to register under the VCS BUFACP Project. The platform permits the registration and management of different SALM projects under one carbon project, leading to various advantages, including lower transactions costs; transparent and standardized use of operating procedures to register farmers and monitor emission reductions and removals (from soil organic carbon in particular); and transparent reporting capability for any issued carbon credits within a national accounting system.

The SALM platform will provide the basis for the development of a wider concept for a digital platform to include further emission reduction activities in the AFOLU sector, in particular, livestock, forest conservation, afforestation and tree restoration activities monitored at the project level and, ideally, integrated into the national AFOLU MRV system.

5.3.3 MRV Design

The project uses a participatory group approach to register participating community members, provide training and other support, and undertake monitoring. Participating farmers are organized into groups (or are members of already established groups), and the members receive training and capacity-building regarding the implementation of project activities on their lands. Registering participants, training and capacity-building are undertaken by the extension structure set up by the project, which includes the staff of respective implementing partners, as well as lead (exemplary) farmers from within the farmer groups. Additional training is provided by government extension staff and Non-Governmental Organization (NGO) development projects. **The adoption of practices is monitored by annual surveys (Figure 7).**

The proposed institutional structure of the SALM monitoring system in Burkina Faso is presented in the figure below. The monitoring system includes two types of monitoring: permanent farm monitoring (PFM); and Farmer Group Monitoring (FGM). The main distinction between the two is that PFM is implemented entirely by the project staff (field extension and M&E unit) on a selected representative sample of farms, hence, representing the entire project area.

Meanwhile, the FGM is a farmer-self assessment where each contracted farmer group self-collect annual records of all data needed to monitor the project and report to the field extension staff. The PFM is used to establish the project baseline and compare it with the FGM data as a quality control measure. The FGM provides the data used to quantify the project's climate mitigation outcomes (tCO_2e).

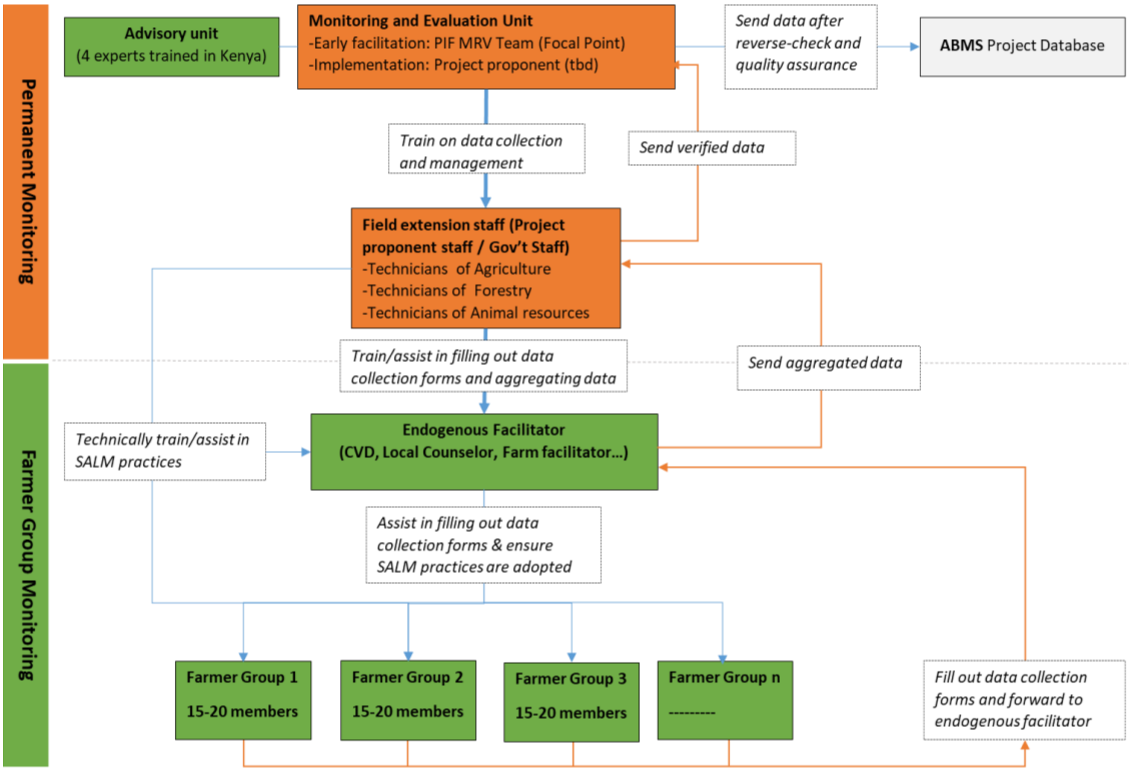


Figure 7. Proposed monitoring system for Burkina Faso

For Burkina Faso, the roles and responsibilities of different institutions for SALM monitoring have been elaborated separately according to the type of monitoring – permanent farm monitoring or farmer group monitoring.

5.3.3.1 Permanent Farm Monitoring

Permanent farm monitoring will be undertaken by the M&E Unit and the field extension staff. The M&E Unit leads the activity-based monitoring system and is responsible for coordinating the training of field extension staff on SALM practices, data collection, and data management techniques. The Unit is further responsible for checking the quality of the data before transmitting it to the database.

The field extension staff include governmental technicians from agriculture, forestry, and animal resource departments in the locality concerned coordinated by the M&E unit. The field extension staff are responsible for training and assisting the Endogenous Facilitator in filling out data collection forms and collecting data. They further provide training to producers in adopting SALM practices and collecting and verifying the data collected by the Local Facilitator (Table 14).

Table 14. Roles in permanent farm monitoring

Institution	Roles	Responsibilities
Monitoring and Evaluation Unit	▪ Overall coordination of monitoring system ▪ Training technicians in data collection techniques and use of data collection forms ▪ Supporting technician training (training of trainers' approach) on SALM practices to be introduced by the project (e.g., in cooperation with Vi Agroforestry) ▪ Verify data quality at the producer level (sample of producers)	Transmit the refined information to the database
Advisory Unit	▪ Provide lessons learnt from Kenya field visit on a demand driven basis	Resource persons
Field extension staff	▪ Train producers in techniques and practices related to agricultural resources ▪ Technically assist the implementation of best practices ▪ Check the quality of the data collected	Ensure the application of the best practices adopted

5.3.3.2 Farmer group monitoring

Two entities are engaged in monitoring of farmer groups. The first are the Local Facilitators, who are selected from among the farmer groups. Their task is to train farmer groups to fill out data collection forms and to collect the completed forms at the group level. The Facilitator conducts an initial quality check of the data provided and follows up with the farmer groups to correct any erroneous, unclear or missing data. The data collected at the farmer group level is then passed on to the field extension staff.

The second entity of the farmer group monitoring is the farmer groups themselves. These should comprise 15-20 farmers who have voluntarily and individually agreed to engage in the activity-based monitoring system. Their engagement is based on a signed farmer commitment form that clarifies the responsibilities of each farmer to provide respective data. The groups are responsible for providing the relevant information requested in the data collection form and are assisted by the Local Facilitators, who then receive the completed forms. The farmer groups are trained in SALM practices by the field extension staff. Since farmer groups are already widespread throughout the country, existing groups may well serve as the larger pool from which farmer groups for a pilot project are formed (Table 15).

Table 15. Roles in farmer group monitoring

Institution	Roles & Responsibilities
Local Facilitator	▪ Assist the producers in filling out data collection forms ▪ Collect information from farmer groups ▪ Verify and collect the data ▪ Pass on collected information to project field extension staff ▪ Ensure the practical implementation of the SALM practices adopted
Farmer group	▪ Collect farm-based activity data on the following, via data collection forms: ▪ Crop yields ▪ Animal numbers

- Field areas
- Numbers of trees in the fields
- Needs in terms of capacity-building
- Respect of commitments to the project
- Application of the applicable SALM practices
- And finally, the groups pass on information on agricultural yields, livestock, trees etc. to the Local Facilitator

Monitoring should focus exclusively on collecting essential information for assessing project impacts and inform decision-making regarding project implementation (e.g., determining farmer training needs). In order to measure the carbon impacts, essential data must be collected to track changes in farming practices and their impacts in terms of yield changes and resulting carbon storage. Thus, monitoring starts with baseline data collection and continues throughout the project at frequent intervals. In general, the following aspects are monitored:

1. Data for SOC modeling[7], i.e.,
   - **Crop yields and yield increases over time (per crop season):** Only the main crops are monitored and used in modeling to reduce uncertainty.
2. Adoption of **SALM practices** such as residue management, composting, and agroforestry.
3. **Trees planted by the project:** Trees will be monitored at every verification event or at least every five years.
4. **Livestock numbers and feeding regimes,** e.g., open grazing or improved management such as zero grazing.
5. **Farmer practices that generate project emissions,** e.g.:
   - use of inorganic fertilizers;
   - burning of crop residues;
   - use of diesel or petrol-powered machinery in agricultural management;
   - increased use of fossil fuels for cooking and heating, attributable to the project.
6. **Farmer training needs,** both for individual farmers and farmer groups.
7. **Overall farm development,** e.g., performance of farm enterprise.
8. **Extension performance** at different project sites.
9. **Project livelihood impacts,** e.g., changes in income and health (nutrition) statuses.

[7] Additional data for SOC modeling include climate data (rainfall and temperature); soil texture (% clay); crop calendar (start and end of crop season). These data are available from local institutions and/or collected from other sources and do not need to be included in regular monitoring.

The data monitored as displayed above in points 1 to 5 are used for estimating project carbon changes. Those in points 6 to 9 can be monitored for assessing overall project impacts and improving project implementation.

In addition to assessing project impacts, another important task of monitoring is to establish the carbon revenue distribution system. The revenue distribution system must be simple, transparent, and robust. The following are a few options for carbon revenue management:

- They can be fully distributed within the farmer groups to reward them for the climate mitigation (carbon sequestration) which they have achieved through SALM implementation; or
- A share of the revenue may be kept to cover project costs and the rest distributed to the farmer groups; or
- The full carbon revenue may be used to refinance the project or additional project activities such as value chain development, investment or marketing support for farmers.

For the present proposed project, it remains to be decided what exactly the carbon revenue distribution and uses will entail. The decision regarding carbon revenue distribution must be transparent, and participating farmers must be made fully aware and be involved in the decision-making process.

Annex 1. Primary methods of SOC accounting and monitoring of carbon projects in the compliance and voluntary market

Standard	Project name	Focus area	Status	Country	SOC accounting and monitoring
SOC enhancement - Compliance					
Canada Government	Alberta Emission Offset System	Crop management	Active	Canada	Modeling (CENTURY)
Australia Government	Australian Carbon Farming Initiative / Emissions Reduction Fund	Crop and grassland management	Active	Australia	Direct soil measurements and modelling (FullCam)
SOC enhancement - Voluntary					
Verra - VCS	Agricultural Land Management Project in Hujgal & Kalari Cluster watershed	Crop, grassland, and agroforestry management	Under development	India	RothC model validated for similar AEZs/ climate regions.
Verra - VCS	Northern Great Plains Regenerative Grazing	Grazing management	Under development	USA	Soil measurements (baseline) and SNAPNA model (developed from the grasslands of Montana).
Verra - VCS	Livelihoods Mount Elgon Project	Agroforestry and livestock management	Under validation	Kenya	RothC model validated for similar AEZs/ climate regions.
Verra - VCS	Agricultural Soil Carbon Through Improved Grassland Management	Grassland management	Under validation	New Zealand	Soil measurements (methodology confidential due to commercially sensitive information)
Verra - VCS	Agricultural Land Management project in Beed District	Soil, crop and forestry management	Registered	India	RothC model validated for similar AEZs/ climate regions.
Verra - VCS	Kenya Agricultural Carbon Project	Crop, grassland and agroforestry management	Registered	Kenya	RothC model validated for similar AEZs/ climate regions.
Verra - VCS	Northern Kenya Grasslands Project	Grassland management	Registered	Kenya	SNAP model. Measurements will be taken for model estimates validation.
Nori	Harborview Farm Purchases	Soil and crop management	Registered	USA	COMET model validated for similar AEZs/ climate regions.

Nori	Garrett Land & Cattle	Soil, crop and livestock management	Registered	USA	COMET model validated for similar AEZs/ climate regions.
Plan Vivo	Pastures, Conservation, Climate Action – Mongolia	Assisted natural regeneration and grassland management.	Registered	Mongolia	CENTURY model validated for one project area and replicated in other similar areas within the same project. Soil measurements may apply.
Plan Vivo	Halo Verde Timor Community Forest Carbon	Affor/Reforestation, assisted nat. regener., agrofor., crop manag.	Registered	Timor Leste	SHAMBA (RothC) model validated for similar AEZs/ climate regions.
Plan Vivo	Ecosystem restoration and valorisation by associations of landless farmers in the Tembien Highlands (North Ethiopia)	Assisted natural regeneration	Registered	Ethiopia	Use of an empirical model developed in scientific literature. Soil samples will be taken every five years for validation of model estimates.
Climate Action Reserve	Indigo U.S. Project No.1	Soil enrichment	Listed	USA	Direct soil measurements and modeling.
California's Healthy Soils Program	California's Healthy Soils Program	Whole orchard recycling (WOR)	Registered	USA	DNDC model look-up tables standardized for USA conditions.
Avoided SOC loss					
Climate Action Reserve	Veseth and Veseth Ranch	Avoided grassland conversion	Listed	USA	DAYCENT model standardized for USA conditions.
Climate Action Reserve	Raven's Nest Nature Preserve	Avoided grassland conversion	Registered	USA	DAYCENT model standardized for USA conditions.
Climate Action Reserve	Medford Spring Grassland Conservation	Avoided grassland conversion	Registered	USA	DAYCENT model standardized for USA conditions.
Climate Action Reserve	May Ranch Avoided Grassland Conversion	Avoided grassland conversion	Registered	USA	DAYCENT model standardized for USA conditions.
Climate Action Reserve	Lightning Creek Ranch	Avoided grassland conversion	Registered	USA	DAYCENT model standardized for USA conditions.
Climate Action Reserve	Heartland Ranch Phase 3	Avoided grassland conversion	Registered	USA	DAYCENT model standardized for USA conditions.
Climate Action Reserve	Heartland Ranch Phase 2	Avoided grassland conversion	Registered	USA	DAYCENT model standardized for USA conditions.
Climate Action Reserve	Heartland Ranch Phase 1	Avoided grassland conversion	Registered	USA	DAYCENT model standardized for USA conditions.
Climate Action Reserve	BNW West	Avoided grassland conversion	Registered	USA	DAYCENT model standardized for USA conditions.
Climate Action Reserve	BNW Ranch	Avoided grassland conversion	Registered	USA	DAYCENT model standardized for USA conditions.
Climate Action Reserve	Bluesource - Weaver Avoided Grassland Conversion Project	Avoided grassland conversion	Listed	USA	DAYCENT model standardized for USA conditions.

Annex 2. People interviewed

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References

Angelopoulou T, Tziolas N, Balafoutis A, Zalidis G, Bochtis D. 2019. Remote sensing techniques for soil organic carbon estimation: A Review. *Remote Sensing* 11:676. Available at: https://doi.org/10.3390/rs11060676

Angelopoulou T, Balafoutis A, Zalidis G, Bochtis D. 2020. From laboratory to proximal sensing spectroscopy for soil organic carbon estimation – A Review. *Sustainability* 12:443. Available at: https://doi.org/10.3390/su12020443

Assefa D, Rewald B, Sandén H, Rosinger C, Abiyu A, Yitaferu B, Godbold DL. 2017. Deforestation and land-use strongly effect soil organic carbon and nitrogen stock in Northwest Ethiopia. *Catena* 153:89–99.

England J, Rossel RA. 2018. Proximal sensing for soil carbon accounting. *Soil Discussion.* Available at: https://doi.org/10.5194/soil-2017-36 https://soil.copernicus.org/articles/4/101/2018/soil-4-101-2018.pdf

Bossio, D A, Cook-Patton, S C, Ellis P W, Fargione J, Sanderman J, Smith P, Wood S, Zomer RJ, von Unger M, Emmer I M, Griscom B W. 2020. The Role of Soil Carbon in Natural Climate Solutions. *Nature Sustainability*. Available at: https://doi.org/10.1038/s41893-020-0491-z

Colomb, V, Touchemoulin, O, Bockel, L, Chotte, J L, Martin, S, Tinlot, M, Bernoux, M. 2013. Selection of appropriate calculators for landscape-scale greenhouse gas assessment for agriculture and forestry. *Environmental Research Letters* 8(1). Available at: https://doi.org/10.1088/1748-9326/8/1/015029

Costa Jr C, Dittmer K, Shelton S, Bossio D, Zinyengere N, Luu P, Heinz S, Egenolf K, Rowland B, Zuluaga A, Klemme J, Mealey T, Smith M, Wollenberg E. 2020. How soil carbon accounting can improve to support investment- oriented actions promoting soil carbon storage. CCAFS Info Note. Wageningen, The Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available at: https://hdl.handle.net/10568/110284

Denef K, Paustian K, Archibeque S, Biggar S, Pape D. 2012. Report of Greenhouse Gas Accounting Tools for Agriculture and Forestry Sectors. Interim report to USDA under Contract No. GS23F8182H. Available at: https://www.virtualfarm.psu.edu/assets/uploads/content/Denef_et_al_2012_GHG_Accounting_Tools_v1.pdf

DuBuisson M, Zavariz B. 2020. Grassland Project Protocol. Climate Action Reserve (CAR). Available at: https://www.climateactionreserve.org/wp-content/uploads/2020/02/Grassland_Protocol_V2.1.pdf

Ellert BH, Bettany JR. 1995. Calculation of organic matter and nutrients stored in soils under contrasting management regimes. *Canadian Journal of Soil Science* 75:529–538.

Gao B, Huang T, Ju X, Gu B, Huang W, Xu L, Rees RM, Powlson DS, Smith P, Cui S. 2018. Chinese cropping systems are a net source of greenhouse gases despite soil carbon sequestration. *Global Change Biology* 24: 5590-5606.

Hijbeek R, van Loon M P, van Ittersum M K. 2019. Fertiliser use and soil carbon sequestration: opportunities and trade-offs. CCAFS Working Paper No. 264. Wageningen, the Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available at: https://hdl.handle.net/10568/101190

IPCC. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Program. (Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K, Eds.). Japan: Intergovernmental Panel on Climate Change (IPCC). Available at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/

IPCC. 2019. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Program. (Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K, Eds.). Japan: Intergovernmental Panel on Climate Change (IPCC). Available at: https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html

Lal R. 2004. Soil carbon sequestration impacts on global climate change and food security. *Science* 304:1623-1626.

Lugato E, Leip A, Jones A. 2018. Mitigation potential of soil carbon management overestimated by neglecting N_2O emissions. *Nature Climate Change* 8: 219.

Mekuria W, Veldkamp E, Corre MD, Mitiku H. 2011. Restoration of ecosystem carbon stocks following exclosure establishment in communal grazing lands in Tigray, Ethiopia. *Soil Science Society of America Journal* 75:246–256. Available at: https://doi.org/10.2136/sssaj2010.0176

Minasny B, Malone BP, McBratney AB, Angers DA, Arrouays D, et al. 2017. Soil carbon 4 per mille. *Geoderma* 292:59–86.

Olander L, Haugen-Kozyra K. 2011. Using Biogeochemical Process Models to Quantify Greenhouse Gas Mitigation from Agricultural Management Projects. Technical Working Group on Agricultural Greenhouse Gases (T–AGG) Supplemental Report. Available at: https://nicholasinstitute.duke.edu/sites/default/files/publications/using-biogeochemical-process-paper.pdf

Paustian K, Collier S, Baldock J, Burgess R, Creque J, DeLonge M, et al. 2019. Quantifying carbon for agricultural soil management: from the current status toward a global soil information system. *Carbon Management*. Available at: https://doi.org/10.1080/17583004.2019.1633231

Pries CEH, Castanha C, Porras RC, Torn MS. 2017. The whole-soil carbon flux in response to warming. *Science* 355:1420–1423.

Sanderman J, Hengl T, Fiske GJ. 2017. Soil carbon debt of 12,000 years of human land use. *PNAS* 114:9575–9580.

Szakács GGJ, Cerri CC, Herpin U, Bernoux M. 2011. Assessing soil carbon stocks under pastures through orbital remote sensing. *Scientia Agricola* 68:574-581. Available at: https://doi.org/10.1590/S0103-90162011000500010

Smith P, Martino D, Cai Z, Gwary D, Janzen HH, Kumar P, McCarl B, et al. 2007. Greenhouse gas mitigation in agriculture. *Philosophical Transactions of the Royal Society B* 363:789-813. Available at: https://dx.doi.org/10.1098/rstb.2007.2184

Smith P, Soussana J, Angers D, Schipper L, Chenu C, Rasse DP, et al. 2019. How to measure, report and verify soil carbon change to realise the potential of soil carbon sequestration for atmospheric greenhouse gas removal. *Global Change Biology*. Available at: https://doi.org/10.1111/gcb.14815

Tennigkeit T, Solymosi K, Seebauer M, Lager B. 2012. Carbon intensification and poverty reduction in Kenya: Lessons from the Kenya Agricultural Carbon Project. *Field Actions Science Reports, Special Issue 7*. Available at: http://factsreports.revues.org/2600

Towett E K, Drake L B, Acquah G E, Haefele S M, McGrath S P, Shepherd K D. 2020. Comprehensive nutrient analysis in agricultural organic amendments through non-destructive assays using machine learning. *PLoS ONE* 15(12). Available at: https://doi.org/10.1371/journal.pone.0242821

Vermeulen S, Bossio D, Lehmann J, Luu P, Paustian K, Webb C, Augé F, Bacudo I, Baedeker T, Havemann T, Jones C, King R, Reddy M, Sunga I, von Unger M, Warnken M. 2019. A global agenda for collective action on soil carbon. *Nature Sustainability* 2-4 2019. Available at: https://doi.org/10.1038/s41893-018-0212-z

Wolff M, Guo L, Gunasekara A. 2020. Whole orchard recycling: Inclusion in the CDFA healthy soils initiative program. California Department of Food and Agriculture (CDFA). Available at: https://www.cdfa.ca.gov/oefi/healthysoils/docs/CDFA_WOR_Report.pdf

Wollenberg E, Richards M, Smith P, Havlík P, Obersteiner M, et al. 2016. Reducing emissions from agriculture to meet the 2°C target. *Global Change Biology* 22:3859–64. Available at: https://doi.org/10.1111/gcb.13340

Glossary

Activity data	Data on the magnitude of a human activity resulting in emissions or removals taking place during a given period of time. Data on energy use, land areas, management systems, lime and fertilizer uses are examples of activity data.
Baseline emissions	A baseline is a measurement, calculation, or time used as a basis for comparison. Baseline emissions are the level of emissions that would occur without policy interventions or without the implementation of a project. Baseline estimates are needed to determine the effectiveness of emission reduction programs (also called mitigation strategies). Also known as business-as-usual emissions.
Carbon dioxide (CO_2)	A naturally occurring gas that is also a by-product of burning fossil fuels and biomass and from land-use changes and other industrial processes. It is the principal anthropogenic greenhouse gas that affects the Earth's radiative balance. It is the reference gas against which other greenhouse gases are measured and therefore has a Global Warming Potential of 1.
Carbon dioxide equivalent (CO_2e)	A metric used to compare emissions of various greenhouse gases. It is the mass of carbon dioxide that would produce the same estimated radiative forcing as a given mass of another greenhouse gas. Carbon dioxide equivalents are computed by multiplying the mass of the gas emitted by its global warming potential.
Carbon intensity	The amount of carbon by weight emitted per unit of activity data.
Carbon sequestration	In the land-use sector, the removal of carbon dioxide from the atmosphere in biomass or the soil.
Climate smart agriculture (CSA)	Agriculture that sustainably increases productivity, enhances adaptive capacity, and reduces or removes greenhouse gas emissions where possible.
Emissions	The release of a substance (usually a gas when referring to the subject of climate change) into the atmosphere.
Greenhouse gas	Any gas that absorbs infrared radiation in the atmosphere. Greenhouse gases include, but are not limited to, water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrochlorofluorocarbons (HCFCs), ozone (O_3), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

Hectare (ha)	A metric unit of square measure, equal to 10,000 square meters.
Intergovernmental Panel on Climate Change (IPCC)	Established jointly by the United Nations Environment Program and the World Meteorological Organization in 1988, the purpose of the IPCC is to assess information in the scientific and technical literature related to the issue of climate change. With its capacity for reporting on climate change, its consequences, and the viability of adaptation and mitigation measures, the IPCC is also looked to as the official advisory body to the world's governments on the state of the science of the climate change issue. For example, the IPCC organized the development of internationally accepted methods for conducting national greenhouse gas emission inventories.
Land-use and Land-use Change (LULUC)	Land-use refers to the totality of arrangements, activities and inputs undertaken in a certain land cover type (a set of human actions). The term land-use is also used in the sense of the social and economic purposes for which land is managed (e.g., grazing, timber extraction and conservation). Land-use change refers to a change in the use or management of land by humans, which may lead to a change in land cover. Land cover and land-use change may have an impact on sources and sinks of greenhouse gases or other properties of the climate system, and may thus have a radiative forcing and/or other impacts on climate, locally or globally.
Low-emission agriculture	Agriculture that reduces emissions relative to a future baseline projection rather than a past base year.
Low-emission development (LED)	Development that reduces emissions relative to a future baseline projection rather than a past base year.
Net GHG emissions	The sum of GHG emissions less the amount of carbon sequestration, usually expressed in tCO_2e.