

IN-DEPTH GUIDE

GHG protocol Land Sector and Removals Standard

Understanding uncertainty in soil organic carbon measurement



BUILDING TRUST IN NATURE BASED SOLUTIONS

Over the past 40 years, I have worked at the intersection of science and policy, covering the development of international frameworks, including the UN Sustainable Development Goals, European environmental policy, earth observation and data systems and been directly involved in their implementation on the ground. And I can honestly say that never has it been more critical that we put forward the best available scientific data to address the social and economic impacts of climate change and ecosystem degradation.



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Global climate policy is anchored in the UN Framework Convention on Climate Change (UNFCCC), alongside national and voluntary frameworks that guide implementation. Throughout my career, I have been an institutionalist and internationalist, convinced that climate data and methodologies must be internationally applicable, scientifically robust, and aligned with the global governance structures that draw on the deepest and broadest research base. Climate change is global, and the standards used to measure progress must be global too.

This belief underpins Downforce's approach. From the outset, our methodology has been built around internationally agreed standards. ISO provides a unified framework for reporting and verification, developed through national standards bodies, and is complemented by the Greenhouse Gas Protocol's guidance for accounting emissions and removals. While additional national and voluntary initiatives will continue to emerge, companies operating across international supply chains need methodologies that work consistently across jurisdictions and standards that provide a common, trusted foundation.

Trust is the central objective of these frameworks. In the context of soil carbon removals, trust begins with

recognising the natural variability of soils and the complexity of their response to management and climate. Credible reporting depends on ongoing monitoring, conservative verification approaches, and sufficient time-series data to distinguish real change from natural variability. When this is done well, farmers, companies, financial institutions and investors can have confidence in the sustainability outcomes they report.

Agricultural supply chains represent one of the most significant opportunities for corporate climate action, yet accurately measuring and reporting carbon removals at scale has remained a fundamental challenge. Downforce was founded to address the challenge of uncertainty in soil carbon removals. Our approach is designed to capture true spatial and temporal variability, systematically assess uncertainty, and communicate it transparently. This briefing accompanies our full methodology documents and aims to support those working in the land sector in better understanding uncertainty in soil carbon measurement – an essential step in building credible, trusted climate action.



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Introduction to Downforce Technologies



DOWNFORCE TECHNOLOGIES

Downforce Technologies is a leader in delivering actionable soil health data that is locally relevant and globally scalable, with historical perspective. Our platform combines ground-based data including historic soil samples with satellite observations using a combination of machine-learning and statistical analysis to measure Soil Organic Carbon (SOC) levels from 2017 onwards.

Soil is the largest land-based store of carbon and has the capacity to remove significant carbon from the atmosphere if managed well. Our methodology for measuring and reporting on carbon removals aligns with the global standards including the GHG protocol, SBTi FLAG and the ISO 14064 standard, and has been applied across more than 2.5 million hectares in 22 countries.

We empower farmers, landowners and supply chain companies to implement more sustainable agricultural solutions by combining our scientifically validated soil data with their land management practices to deliver contextual understanding and actionable insights.

By advancing measurement approaches that scale, we are accelerating the global transition towards sustainable agriculture which in turn will drive greater farm profitability, productivity and long-term climate resilience.

Downforce is a founding member of the [International Soil Carbon Industry Alliance \(ISCIA\)](#) which seeks to inform policy processes with scientific and professional experience.

Downforce is also an active contributor on many soil carbon standards and directives, including the WRAP/Mondra Carbon Removals Taskforce and the Carbon Removals Taskforce Expert Working Group for permanent biogenic removals under the [European Union Carbon Removals Certification Framework](#).



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The importance of soil



WHAT IS SOIL ORGANIC CARBON AND WHY IT MATTERS

Soil organic carbon (SOC) refers to the carbon component of organic compounds present in soils, originating primarily from plant residues, root exudates, animal inputs and microbial biomass. Through photosynthesis, plants draw carbon dioxide from the atmosphere and transfer carbon below ground via roots and decaying biomass. Soil microorganisms subsequently decompose this material, transforming and stabilising carbon within the soil matrix through complex biological, chemical and physical processes.

SOC underpins many of the fundamental functions of healthy soils. It contributes to soil structure and aggregation, enhances water retention and infiltration, supports nutrient cycling, and sustains diverse and resilient microbial communities. At the global scale, soils store more carbon than the atmosphere and terrestrial vegetation combined. As a result, SOC stocks – the total quantity of carbon stored within a given depth and area of soil – are a critical indicator not only of soil health and productivity, but also of the capacity of land systems to contribute to climate change mitigation through carbon sequestration (McGlade and Morris 2024).

Soil organic carbon (SOC) is a foundational component of both productive agricultural systems and credible land-based climate action. SOC represents the carbon stored in soils as a result of plant productivity, biological activity and land management, linking on-farm practices directly to climate, resilience and long-term soil function. Globally, soils contain more carbon than the atmosphere and terrestrial vegetation combined, making SOC stocks a material factor in the climate performance of agricultural supply chains.

SOIL ORGANIC CARBON FLOWS

SOC stocks are not static. They reflect the balance of continuous carbon flows into, within and out of the soil system. These flows include inputs from plant residues and root exudates; transformations through microbial processing and stabilisation; and losses through respiration, leaching, decomposition, erosion and disturbance. When SOC is compared between years, observed changes represent the net outcome of these competing processes over time.

SOC flows are highly sensitive to land management, vegetation dynamics and climatic conditions. Changes in cropping systems, grazing pressure, residue management or tillage can alter both the magnitude and timing of carbon inputs and losses. Likewise, interannual climate variability and extreme events can temporarily or permanently shift soil carbon dynamics. Whether a soil functions as a net carbon sink or source over time therefore depends on how these interacting drivers evolve.



CHALLENGES IN CAPTURING SOIL ORGANIC CARBON VARIABILITY

Assessing soil health and carbon sequestration potential requires an accurate representation of how SOC varies across space and through time. This is far from straightforward. SOC exhibits pronounced spatial heterogeneity, varying with depth and across scales from metres to kilometres, reflecting underlying geology, topography, soil type and the legacy of past land management. Superimposed on this spatial complexity is strong temporal variability: SOC can fluctuate over weeks or months between seasons, responding to crop growth, residue inputs, tillage, mulching and moisture dynamics. Longer-term trends may only emerge over multiple years, shaped by climate patterns, extreme weather events and sustained changes in land management and biodiversity (Wuest & Durfee 2024).

As a result, a soil sample taken at a single location and point in time is unlikely to represent SOC conditions even a short distance away or a few weeks later, let alone across an entire field or farm over a year (Knox et al. 2023). Conventional soil sampling protocols, if applied frequently and at sufficient density to capture this variability, can be costly, logistically challenging and still yield estimates with substantial uncertainty. As a result, SOC measurement approaches that rely solely on sampling tend to generate high uncertainty when scaled across agricultural supply chains.

TOWARDS AN IMPROVED APPROACH

Addressing this complexity requires MRV approaches that are designed for complexity and scale. Advances in digital twin technologies and data fusion now make it possible to combine field observations with spatially explicit environmental data and remote sensing, generating high-resolution, temporally consistent representations of SOC dynamics.

At Downforce, we use the latest scientific evidence to deliver a multi-disciplinary approach that brings together three complementary elements: landscape-scale analysis, targeted physical soil sampling, and advanced remote sensing.



Landscape-scale classification and analysis

Robust land classification is fundamental to SOC mapping and monitoring as SOC follows broadly predictable patterns linked to land use, crop type and environmental context. Mapping land cover, management zones and within-field variability allows conclusions to be drawn from fewer samples with greater confidence.

Environmental data layers – such as soil maps, geology, topography, land cover, climate and weather – provide essential context for spatial interpolation and for understanding how SOC patterns observed at sampled locations extend across a farm or landscape (Knox et al. 2023; Morone et al. 2023; Lakey 2025; Lakey and Morris 2024; Lakey et al. 2026).

Strategic physical soil sampling

Physical soil sampling remains an essential part of embedding SOC estimates into empirical data layers. However, to avoid misrepresentation of an area or farm, sampling must be carefully designed to reflect landscape heterogeneity and farming systems and combined with appropriate laboratory methods. Consistency in sampling depth, timing and analytical techniques is critical to ensuring that comparisons across space and time are both robust and meaningful. Significant care is also needed in the application of advanced statistical methods to translate point measurements into robust estimates of SOC stocks and their uncertainty (Lakey et al. 2023, 2024). Sampling protocols thus need to balance gains in robustness and confidence against the practical and financial costs to land managers (see Section on Uncertainty).

Advanced remote sensing

Remote sensing can further enhance the accuracy and efficiency of SOC estimation across agricultural landscapes (Abdulraheem et al. 2023). Observations of vegetation dynamics, soil moisture and surface conditions from satellites or drones provide frequent, spatially continuous data that help interpret SOC changes over time. Correcting for atmospheric effects such as cloud and haze (Cresson et al. 2022) ensures consistency and reliability, allowing remote sensing to complement both landscape analysis and physical sampling.

Together, these elements provide a more realistic and scalable approach to understanding SOC dynamics – one that acknowledges natural variability, reduces uncertainty where possible, and supports credible monitoring and reporting of soil carbon outcomes over time.



THE DOWNFORCE SOIL ORGANIC CARBON METHODOLOGY

The Downforce SOC Methodology aligns with ISO 14064-1 (for quantifying organisations' net GHG inventories) and ISO 14064-2 (for quantifying net GHG for carbon projects). The Downforce SOC Methodology was validated by DNV on 29/09/2023. The methodology was then expanded to align with ISO 14064-1, which SGS Global audited and confirmed as also in alignment with the Oxford Offsetting Principles and ICVCM Core Carbon Principles (CCPs) on 16/12/2024. The SOC Methodology is used to deliver quantitative assessment of soil carbon stocks, removals and emissions for over 100 customers, covering over 2.5 million hectares. Several clients have also used our methodology to have their net carbon position statements, such as Net Zero, independently verified by SGS with "reasonable assurance".

The Downforce SOC Methodology applies the six principles of relevance, completeness, consistency, accuracy, transparency and conservativeness, as set out in ISO 14064-1:2019/ISO 14064-2:2019 and the additional two principles of permanence and comparability as set out in the GHG Protocol Land Sector and Removals Standard (Part 1:3.2).

The Downforce SOC Methodology supports both GHG inventory accounting for removals associated with company operations and their value chains, and intervention/project carbon accounting for removals which can be credited for GHG claims within the value chain or for transfer between entities. The method adheres to IPCC national inventory guidelines for Tier 3, GHG Protocol Agricultural Guidance and LULUCF Guidance for Project Accounting, GHG Land Sector and removals Guidance (LSRS), ISO 14064-2:2019, Clean Development Mechanism (CDM) and various jurisdictional land sector approaches including voluntary and AFOLU sector project methodologies.

The Downforce Technologies methodology meets the quantitative uncertainty assessment requirements of the GHG Protocol Land Sector and Removals Standard (LSRS), including estimation of uncertainty magnitude and conservative interpretation of reported removals.

Further details on the Downforce SOC Methodology are available on request from info@downforce.tech.



LSRS REPORTING REQUIREMENTS

- Assess the **magnitude of uncertainty**.
- Demonstrate that reported removals are **conservative relative to uncertainty**, i.e. show that removals are not overstated relative to uncertainty bounds. This **requires numerical uncertainty estimates** (e.g. Standard Deviation, confidence intervals).
- **Apply Tier 3 methods**, to provide quantitative uncertainty analysis linked to spatial variability, temporal variability, model and attribution, and scaling and aggregation uncertainty as qualitative assessment is insufficient.
- Put in place ongoing monitoring and resampling, to detect sustained change over time requires numerical variability estimates.
- Ensure verification and assurance readiness – LSRS is designed for auditability and assurance bodies requiring quantitative uncertainty.

DTL METHODOLOGY

- **Meets** the assessment of the **magnitude of uncertainty**.
- **Meets/Exceeds** the requirement to demonstrate that reported removals are conservative relative to uncertainty bounds using **numerical uncertainty estimates** (Standard Deviation, confidence intervals and a 3-year CMA).
- **Meets** the requirements for Tier 3 methods by providing measurements linked to spatiotemporal variability, model and attribution uncertainty, scaling and aggregation uncertainty.
- **Exceeds** monitoring and resampling requirement to detect sustained change over time using numerical variability estimates.
- **Meets** the need to ensure verification and assurance readiness for auditability and assurance bodies requiring quantitative uncertainty.



International Frameworks for Carbon Removal Measurement



1. GHG PROTOCOL AND THE LAND SECTOR AND REMOVALS GUIDANCE (LSRS)

The Greenhouse Gas (GHG) Protocol is the world's most widely used framework for greenhouse gas accounting and reporting. It provides globally consistent standards that underpin corporate, project and value-chain emissions reporting, and is jointly developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD).

The Land Sector and Removals Standard (LSRS) extends the GHG Protocol to cover land-based emissions and removals, including land use change, land management emissions, and carbon removals in soils & biomass. The LSRS provides guidance on data selection, quantification methods, uncertainty management, traceability and reporting, with a focus on ensuring credibility and consistency in removals accounting.

1.1 Requirements for GHG Removals Reporting

Under the LSRS, reporting greenhouse gas removals is optional, but where removals are reported, stricter requirements apply than for emissions. These requirements reflect the higher risk of overestimation and the need for conservativeness and transparency.

This rigorous, international framework for land-based GHG accounting ensures that reported removals are credible, comparable and decision-useful, providing the foundation for trustworthy corporate climate reporting and target-setting.

REQUIREMENTS FOR COMPANIES AND PROJECTS REPORTING REMOVALS

Use of higher-tier methods

Removals must be quantified using Tier 2 or Tier 3 approaches; Tier 1 methods are not permitted. For soil and land-based removals, Tier 3 methods are effectively required.

Clear separation of emissions and removals

Gross emissions and gross removals must be reported separately, with no inappropriate netting.

Calibration, validation and monitoring

Models and remote sensing approaches must be calibrated and validated using independent data, with ongoing monitoring over time.

Primary and traceable data

Removals accounting requires empirical, spatially explicit data with physical traceability to the relevant land units and carbon pools. This includes physical soil samples, spectroscopic measurements, earth observation datasets, local weather data, topography, land use, land cover, geology and soil property databases.

Quantitative uncertainty assessment

Companies must assess and report uncertainty and demonstrate that reported removals are conservative relative to the uncertainty range.

Transparency and documentation

Methods, assumptions, data sources, and quality controls must be fully documented to enable review, verification and assurance.



1.2 Data requirements

The Land Sector and Removals Standard (LSRS) sets clear expectations for the **quality, specificity and transparency of data** used to quantify and report land-based greenhouse gas emissions and removals. These requirements are designed to ensure that reported results are credible, conservative and decision-useful, particularly where removals are included.

DATA REQUIREMENTS

Appropriate data quality and tier selection

Companies must use the most accurate and representative data available, prioritising higher-tier methods for significant sources and sinks. For removals, the use of Tier 2 or Tier 3 data and methods is mandatory, with Tier 3 effectively required for land-based carbon removals.

Spatial and temporal representativeness

Data must reflect the geographic location, land use, management practices and timeframe of the reported activities. Spatial resolution and traceability should be consistent with the reporting boundary and intended use of the data.

Quantitative uncertainty information

Companies must assess and document uncertainty associated with input data and results. For removals, data must support statistically robust uncertainty estimates and conservative reporting assumptions.

Primary and traceable data for removals

Removals reporting requires empirical, spatially explicit data with physical traceability to the relevant land management units, carbon pools and time periods. Proxy or generic secondary data are not sufficient for removals.

Clear separation of data categories

Data must enable the disaggregation of:

- land use change emissions,
- land management emissions, and
- carbon removals (gross emissions and gross removals must be reported separately).

Documentation and transparency

All data sources, assumptions, data gaps, quality indicators and validation procedures must be documented to support review, assurance and comparability over time.

Together, these data requirements ensure that land-sector emissions and removals reported under the LSRS are grounded in high-quality, traceable evidence and can withstand scrutiny from regulators, assurance providers and other stakeholders.

Downforce Technologies provides a soil organic carbon (SOC) monitoring, reporting and verification (MRV) methodology that combines environmental data

from surveys and remote sensing with empirically grounded modelling to deliver primary data under the Greenhouse Gas Protocol Land Sector and Removals Standard (LSRS). This enables companies with agricultural supply chains to quantify and report Scope 3 land management removals in a way that is scalable, conservative and consistent with emerging international standards and regulatory expectations.



IN BRIEF

Downforce provides primary data

In line with the GHG Protocol Land Sector and Removals Standard, Downforce Technologies generates primary data outputs for soil carbon removals through spatially explicit, empirically grounded modelling and monitoring. The methodology uses primary and high-quality secondary input datasets, and the resulting SOC estimates are site-specific, traceable, calibrated, validated and conservatively reported. These outputs therefore qualify as primary data under the LSRS for the purposes of removals accounting.

1.3 Tiered approach (as described in the LSRS and Part 2 of the draft LSRG)

The IPCC Guidelines specify the use of a tiered approach for the GHG Protocol, to quantify land-based emissions and removals. The tier system reflects increasing levels of data specificity, methodological sophistication, and accuracy, and is directly linked to expectations around uncertainty management and confidence in reported results (LSRS,

section 6). Under the LSRS, soil carbon removals may only be reported where methods demonstrate empirical grounding, traceability, conservative assumptions and statistically meaningful uncertainty estimates. Tier 3 approaches are therefore not simply preferable, but essential for credible removals accounting at scale (LSRS, section 6.3).

IPCC TIER DEFINITIONS

Tier 1 methods

Represent the lowest level of complexity. They rely on global default emission factors or carbon stock-change factors, combined with broadly aggregated activity data. As described in Chapter 16, Tier 1 approaches carry large uncertainty ranges and are insufficiently sensitive to local soils, climate conditions, or land management practices (LSRG, Table 16.1 and discussion, pp. 6–7). Under the LSRS, Tier 1 methods are not acceptable for reporting removals, as they cannot demonstrate the accuracy, traceability or conservativeness required.

Tier 2 methods

Use country- or region-specific data, parameters or emission factors that better reflect prevailing environmental conditions. These approaches reduce uncertainty relative to Tier 1 and may be appropriate for emissions accounting where higher-resolution data are unavailable. However, Tier 2 methods remain limited in their ability to represent spatial heterogeneity and farm-level management change, particularly for soil organic carbon (SOC) dynamics (LSRG, Chapter 16.1.1 and Table 16.6, pp. 6–13).

Tier 1 methods, based on global default factors, and **Tier 2** methods, based on regional or national averages, are **not sufficient for removals accounting under the LSRS** due to their inability to capture site-specific management effects, spatial heterogeneity and temporal dynamics, or to demonstrate conservative estimates in the presence of uncertainty (LSRG, Chapter 16.1.1; Tables 16.1 and 16.6, pp. 6–13).



IPCC TIER DEFINITIONS

Tier 3 methods

Represent the highest level of methodological rigor and are explicitly required for the reporting of removals under the LSRS. Tier 3 approaches are based on spatially explicit, model-based or measurement-based quantification that is calibrated and validated using primary data, and that includes quantitative treatment of uncertainty. They are capable of representing land management impacts over time. The LSRS specifies that removals accounting must use empirical data, Tier 2 or Tier 3 methods (but not Tier 1), and must demonstrate that reported values are conservative relative to the uncertainty range and statistically robust (LSRG, Table 16.7, p. 14).

GHG PROTOCOL TIERS

Aspects	Tier 1	Tier 2	Tier 3
Data basis	Global default factors	National / regional averages	Primary data + calibrated models
Spatial resolution	Coarse	Moderate	High-resolution, spatially explicit
Sensitivity to management	None	Limited	Explicitly represents management change
Temporal dynamics	Static	Simplified	Captures interannual variability
Uncertainty treatment	Broad, implicit	Reduced, often qualitative	Quantitative, propagated and conservative
Eligibility for removals under LSRS	Not allowed	Not sufficient	Required and compliant

The Downforce Technologies Soil Organic Carbon Methodology, as set out in TECH001: DNC001 Project SOC Methodology and TECH005: DNC001 Organisation GHG Inventory Methodology is explicitly designed to meet Tier 3 requirements as defined by the IPCC Guidelines and operationalised in the GHG Protocol LSRS. Specifically:



HOW DOWNFORCE MEETS LSRS UNCERTAINTY REQUIREMENTS

Spatially explicit modelling

Implemented through pixel-level analysis (10 m × 10 m resolution) across defined Carbon Estimation Areas, as described in TECH001 Sections 2.3.3–2.3.6.

Calibration and validation

Procedures are embedded within the methodology, including periodic re-analysis and sensitivity testing of Functional Classes (TECH001 Section 2.3.7); aligning with LSRG guidance on model validation (Chapter 16.3.6, pp. 24–25).

Conservativeness and permanence safeguards

Applied through the use of resilience baselines, moving averages and buffer/reserve mechanisms (TECH001 Sections 1.4.6 and 2.3.4), ensuring that removals are not overstated in the presence of uncertainty.

Primary and empirical data

Incorporated through validated earth observation datasets, soil property databases and, where applicable, physical soil sampling, consistent with LSRS requirements for primary data use in removals accounting (LSRG, Table 16.7, p. 14).

Quantitative uncertainty assessment

Formally addressed through statistical analysis, error propagation and conservative treatment of results, as documented in TECH001 Table G.1 (Uncertainty Assessment and Analysis), consistent with LSRG Section 16.6 and Table 16.7.

The methodology integrates spatially explicit modelling, high-resolution remote sensing, and empirical data inputs, supported by systematic calibration and validation against independent observations and data sources. Uncertainty is explicitly quantified and propagated through the analysis, with conservative assumptions applied where data limitations exist. This ensures that reported soil carbon removals meet the methodological, statistical and transparency requirements of the LSRS for Scope 3 land management removals reporting (LSRG, Section 16.6 and Table 16.7, pp. 14–15).

IN BRIEF

Downforce provides Tier 3 data

The Downforce Technologies Soil Organic Carbon MRV Methodology meets the requirements of a Tier 3 approach as defined under the IPCC Guidelines and the GHG Protocol Land Sector and Removals Standard (LSRS). The methodology applies spatially explicit, empirically grounded quantification methods, incorporates calibration and validation procedures, and includes quantitative uncertainty assessment and conservative treatment of results, consistent with Tier 3 requirements



1.4 Resampling requirements

Under LSRS section 13.2, the requirements are that model-based approaches must report uncertainty ranges and regularly recalibrate models with regional samples, at minimum every 5 years. This requirement ensures models remain calibrated and accurate over time.

DOWNFORCE MEETS AND EXCEEDS THESE RESAMPLING REQUIREMENTS THROUGH

Public dataset integration

Ingests soil sample data from environmentally similar soils via public datasets (USDA, ISRIC, LUCAS, ICRAF, national soil surveys), reducing the need for client-specific resampling

Continuous model updates

Remote sensing data updates models every 10 days, maintaining calibration accuracy

IN BRIEF

Downforce meets resampling requirements

The Downforce Technologies Soil Organic Carbon MRV Methodology meets the resampling and monitoring requirements of the GHG Protocol Land Sector and Removals Standard (LSRS). The methodology applies consistent, repeated observation of soil carbon stocks over time through annual monitoring, spatially explicit modelling, and periodic calibration and validation using empirical data. This approach enables the detection of observed change, supports quantitative uncertainty assessment, and is consistent with LSRS requirements for removals reporting.



2. SBTI FOREST, LAND AND AGRICULTURE (FLAG)

The Science Based Targets initiative (SBTi) is a global body enabling businesses to set ambitious emissions reductions targets in line with the latest climate science. It is focused on accelerating the progress of companies across the world to halve emissions before 2030 and achieve net-zero emissions before 2050. The initiative is a collaboration between CDP, the United Nations Global Compact, World Resources Institute (WRI) and World Wildlife Fund for Nature (WWF), and is one of the We Mean Business Coalition commitments. The SBTi defines and promotes best practice in science-based target setting, offers resources and guidance to reduce barriers to adoption, and independently assesses and approves companies' targets.

2.1 FLAG Target Requirements

The Science Based Targets initiative (SBTi) Forest, Land and Agriculture (FLAG) framework establishes specific requirements for companies with material land-based emissions. Companies for which FLAG emissions exceed 20% of total Scope 1, 2 and 3 emissions are required to set a separate FLAG target, covering at least 67% of relevant Scope 3 FLAG emissions. FLAG targets must be supported by granular, disaggregated data, including emissions and removals by commodity and region, with clear separation between land use change emissions, land management emissions and removals.

2.2 Removals in FLAG Targets

Carbon removals represent a significant component of FLAG-aligned mitigation pathways, accounting for approximately 30% of potential mitigation. While the inclusion of removals in FLAG targets is optional, any removals reported must be calculated using methodologies aligned with the GHG Protocol Land Sector and Removals Standard (LSRS). FLAG does not introduce separate removals accounting rules; instead, it requires that removals data meet LSRS standards

while also providing commodity-specific, regionally disaggregated and practice-attributed reporting.

SBTi FLAG does not create separate removals methodological requirements – it mandates GHG Protocol LSRS standards for all removals calculations, with additional requirements for commodity-specific and regionally disaggregated reporting.

SBTi FLAG DATA GRANULARITY REQUIRED FOR REMOVALS REPORTING

Emissions and removals per commodity and region	Clear distinction between emissions and removals
Disaggregated data separating land use change from land management emissions	Practice-level attribution linking interventions to outcomes



2.3 Downforce's SBTi FLAG Alignment

The Downforce Technologies Soil Organic Carbon MRV Methodology is inherently aligned with SBTi FLAG requirements because it meets the GHG Protocol LSRS criteria for Tier 3, primary data removals reporting. Downforce enables FLAG-compliant reporting through spatially explicit, commodity-level monitoring, regional coverage across major agricultural geographies, clear separation of emissions and removals, and direct linkage between land management practices and measured outcomes. The provision of annual, observation-based monitoring data supports tracking of realised progress against FLAG targets rather than projections, offering the opportunity for readjustment of interventions if positive change is not being detected.

DOWNFORCE DELIVERS FLAG-REQUIRED DATA GRANULARITY THROUGH

Commodity-specific monitoring

Farm-level tracking disaggregated by crop type

Regional coverage

Active monitoring across UK/EU, USA, Canada, Australia, and Africa

Clear emissions/removals separation

Distinct reporting of land use change, land management emissions, and carbon removals

Practice-level attribution

Direct linkage between interventions and measured outcomes

IN BRIEF

Downforce can be used for SBTi

Downforce Technology Methodology meets the requirements of the Science Based Targets initiative (SBTi) Forest, Land and Agriculture (FLAG) framework. The methodology is aligned with the GHG Protocol Land Sector and Removals Standard (LSRS), applies Tier 3 quantification methods, produces primary data outputs, and provides the commodity-level, regionally disaggregated and practice-attributed information required for FLAG reporting. On this basis, the Downforce methodology is suitable for supporting SBTi FLAG-compliant accounting and tracking of land management emissions and removals, including Scope 3 reporting.



3. ISO 14064 ALIGNMENT AND THIRD-PARTY VALIDATION

ISO 14064 is an international standard that provides principles and requirements for quantifying, monitoring, reporting, and verifying GHG emissions and removals. It forms part of the broader ISO 14000 family of environmental management standards – notably sitting alongside ISO 14067, which focuses on measuring the carbon footprint of products. Developed in response to the Kyoto Protocol and international climate commitments under the UNFCCC, ISO 14064 emerged from collaborative work between ISO, the World Resources Institute (WRI), and the World Business Council for Sustainable Development (WBCSD) to create standardized, internationally recognized GHG accounting frameworks.

3.1 The Role of ISO 14064 in GHG Accounting

The standard is compatible and complementary with the GHG Protocol – organizations typically use the GHG Protocol to identify and calculate emissions and removals and subsequently use ISO 14064 for reporting and third-party verification. In 2007, ISO, WRI, and WBCSD formalized their collaboration through a Memorandum of Understanding, jointly promoting both standards and showing their alignment.

In September 2025, this collaboration reached a new milestone when ISO and GHG Protocol announced a landmark partnership to harmonize their existing portfolios of GHG standards and co-develop new

standards. This partnership will combine the ISO 1406X family of standards with the GHG Protocol Corporate, Scope 2, and Scope 3 Standards into harmonized co-branded international standards, creating a common global language for emissions accounting.

While the GHG Protocol is widely recognized by voluntary reporting programs like CDP and SBTi, ISO 14064 is more commonly required by regulatory and accreditation bodies and emphasizes third-party verification by approved auditors to ensure data credibility.

THE ISO 14064 SERIES CONSISTS OF THREE PARTS

ISO 14064-1:2018

specifies principles and requirements at the organization level for quantification and reporting of GHG emissions and removals. It includes requirements for the design, development, management, reporting and verification of an organization's GHG inventory.

ISO 14064-2:2019

specifies principles, requirements and guidance for quantification, monitoring and reporting of GHG emissions and removal at the project level.

ISO 14064-3:2019

specifies principles and requirements and provides guidance for those conducting or managing the validation and/or verification of GHG assertions. It can be applied to organizational or GHG project quantification, including GHG quantification, monitoring and reporting carried out in accordance with ISO 14064-1 or ISO 14064-2.



ISO 14064 provides the verification framework for GHG Protocol-compliant inventories, offering independent assurance that emission and removal claims are accurate and credible. With the 2025 harmonization partnership, these complementary standards are now converging into a unified global framework that simplifies carbon accounting for companies, investors, and policymakers worldwide.

3.2 Third Party Verification of ISO 14064

ISO standards are jointly designed by global experts from national standards bodies to be verified by any organisation that acts as an authorised ISO verifier. This enables broad adoption, verification and certification by organisations around the world and removes the need for a single central verifier.

Third-party verification under ISO 14064 provides credibility to GHG reporting and net zero claims whilst enhancing market reputation for environmental responsibility and transparency. The verification process involves independent assessment of GHG statements against ISO 14064 requirements, ensuring data is credible, consistent, and transparent.

ISO 14064 VERIFICATION DELIVERS CRITICAL BENEFITS

Regulatory compliance

Meets current and future emissions reporting requirements.

Market access

Verified net emission reductions can be eligible for conversion into carbon credits for voluntary or compliance markets.

Stakeholder confidence

Provides investors, customers, and partners with independently verified net GHG emissions data.

Global recognition

Verification conducted under ISO is recognized globally, providing assurance across international markets and regulatory frameworks.



3.3 Downforce Soil Organic Carbon Methodology ISO 14064 Validation

Downforce has a scalable MRV solution with a 3rd party validated SOC methodology, supporting both project-level intervention and organisation-level inventory accounting, providing food and agriculture companies with pre-validated, audit-ready carbon accounting that satisfies LSRS, SBTi FLAG, and ISO 14064 requirements simultaneously.

DOWNFORCE PROVIDES ISO 14064 VALIDATED DATA

Methodology validation

Downforce's proprietary remote sensing and empirical modeling methodology has been validated against the ISO14064 standard by DNV, a leading verification body.

Third-party verification

SGS Global have completed third-party verifications, with reasonable assurance, of Downforce Technologies' GHG reporting under ISO 14064 standards on behalf of supply chain clients.



Measuring uncertainty



1. QUALITATIVE AND QUANTITATIVE UNCERTAINTY

Scientific uncertainty is especially relevant in biogenic carbon removals quantification where complex, variable, and long-term processes are at play and inherent randomness, or variability, cannot be reduced. Showing this variability is critical in any assessment of SOC. Factors influencing carbon sequestration, such as changes in rainfall, soil moisture, atmospheric conditions, biodiversity, flooding, fires, land management and climate change, are not fully predictable and can change over multiple scales.

DEFINING UNCERTAINTY

Qualitative uncertainty

Describes uncertainty in descriptive terms, identifying the main sources of potential error or variability without assigning numerical values. In practice, this involves explaining where uncertainty arises – such as data gaps, assumptions, model limitations, natural variability or measurement constraints – and indicating whether these factors are likely to have a low, moderate or high influence on reported results. Qualitative uncertainty helps users understand the nature of uncertainty but does not allow its magnitude to be tested or applied in decision-making.

Quantitative uncertainty

Assigns numerical values to uncertainty, enabling its magnitude to be measured, compared and incorporated into reporting and assurance. In practice, this involves calculating metrics such as standard deviation, confidence intervals, probability distributions or uncertainty ranges, often based on repeated observations, statistical analysis or model diagnostics. Quantitative uncertainty allows companies to demonstrate conservativeness, assess confidence in reported results, track change over time and support verification.

Together, qualitative and quantitative uncertainty provide complementary insights. Qualitative assessment explains *why* uncertainty exists, while quantitative assessment shows *how much* uncertainty matters. For land-based and biogenic systems – particularly when reporting removals – quantitative uncertainty is essential to ensure credible, conservative, and decision-useful reporting.



2. UNCERTAINTY IN THE CONTEXT OF THE GHG PROTOCOL LAND SECTOR AND REMOVALS STANDARD

The earlier GHG Protocol Product Standard *requires* that companies assess and report **qualitative uncertainty** in their inventories and allows quantitative uncertainty. The Value Chain (Scope 3) Standard recommends qualitative uncertainty and encourages quantitative treatment. Under these standards quantitative uncertainty is optional.

The Land Sector and Removals Standard (LSRS) goes beyond this. It raises the bar for land-based removals, because of the higher risk of over-estimation and permanence concerns. The key LSRS position is that for emissions, qualitative uncertainty may be sufficient. For removals, especially soil and biogenic removals, **quantitative uncertainty assessment is *required* in practice**. Companies cannot demonstrate conservativeness without quantifying uncertainty.

THE LSRS STATES THAT COMPANIES MUST

Assess the **magnitude of uncertainty**

Demonstrate that reported removals are **conservative relative to uncertainty**, i.e., show that removals are not overstated relative to uncertainty bounds. This requires numerical uncertainty estimates (e.g. Standard Deviation, confidence intervals)

Apply higher-tier (Tier 2 or Tier 3) methods, as these include quantitative uncertainty analysis. Qualitative discussion alone is insufficient at Tier 3

Put in place ongoing monitoring and resampling to detect sustained change over time, this requires numerical variability estimates.

Ensure verification and assurance readiness - LSRS is designed for auditability and assurance bodies requiring quantitative uncertainty.

Thus, under the GHG Protocol Land Sector and Removals Standard, companies reporting land-based removals are required to quantitatively assess uncertainty to demonstrate conservative, statistically robust reporting.



3. ASSESSING UNCERTAINTY

The following section addresses how Uncertainty is characterised in the GHG Protocol LSRS and previously published guidance under Part 2. A description of Quantitative Uncertainty Guidance can be found at:

<https://ghgprotocol.org/sites/default/files/Quantitative%20Uncertainty%20Guidance.pdf>

Model uncertainty which arises from simplifying assumptions embedded in models, is described in the GHG Protocol Quantitative Uncertainty Guidance. The LSRS addresses this form of uncertainty by requiring Tier 3 methods to be calibrated, validated, and conservatively interpreted for land-based removals (LSRS section 6; LSRG Chapter 16, where there is a discussion of model selection, calibration and

validation and requirements to assess model limitations and assumptions). The LSRS deliberately **does not repeat the theoretical uncertainty taxonomy** from the Quantitative Uncertainty Guidance. Instead, it **operationalises** it through requirements for calibration and validation, empirical testing, sensitivity analysis, and conservative interpretation of results.

3.1 Uncertainty Assessments of GHG Emissions and Removals

Uncertainty for single parameters arises in the key inputs used to calculate inventories for direct emissions, removals, activity data, emission factors and global warming potential (GWP) values. Where emissions are directly measured, uncertainty in the measurement replaces the need to assess uncertainty in activity data and emission factors. This logic underpins continuous emissions monitoring systems (CEMS) and is well established in ISO, IPCC and GHG Protocol guidance. However, for removals, especially land-based and biogenic removals (e.g. SOC), the situation is fundamentally different. Even when removals are “directly measured” (e.g. soil sampling, biomass measurements).

THIS IS BECAUSE

- the removal is inferred from change over time, not observed instantaneously;
- measurements are sparse in space and time relative to whole system variability;
- results must be scaled and interpreted across areas, depths and years.



MODELS ARE THUS REQUIRED TO

- interpolate between measurements,
- separate signal from natural variability,
- attribute change to management rather than climate or background trends.



AS A RESULT

Measurement uncertainty alone is never sufficient for removals. Under the GHG Protocol Land Sector and Removals Standard (LSRS), companies must also assess:

- spatial variability uncertainty,
- temporal variability uncertainty,
- model and attribution uncertainty, and
- scaling and aggregation uncertainty.

This is why LSRS requires **Tier 3 methods** for removals, to deliver **quantitative uncertainty assessment**, and requires **conservative interpretation** of observed change. The table below shows the difference between direct measurement of emissions and land-based removals assessments.

LSRS UNCERTAINTY REQUIREMENT FOR EMISSIONS VS REMOVALS

Aspect	Direct emissions	Land-based removals
Observation	Instantaneous	Change over time
Role of activity data	Replaced by measurement	Still required
Role of emission factors	Replaced by measurement	Not applicable
Measurement uncertainty	Often	No
Need for modelling	Limited	Essential
Need to assess variability	Limited	Critical

3.2 Parameter Uncertainty

A parameter is a quantity that defines or constrains how a system behaves within a model or calculation. It is usually assumed as fixed within a given model run, is often derived from empirical studies, averages, or calibration and used to relate variables to one another. Examples include Emission Factors (e.g. kg CO₂ per unit of activity), decomposition rate constant in a soil carbon model, conversion factor from SOC to CO₂e, model coefficients linking vegetation cover to SOC change.

Parameter uncertainty can be expressed as a range or probability distribution. Methods for estimating single parameter uncertainty include measured uncertainty (e.g. standard deviation), literature-based default uncertainties, probability distributions, uncertainty factors, and expert judgement approaches such as the pedigree matrix.



3.2.1 Measured Uncertainty

For directly measured emissions (e.g. stack monitoring) measured uncertainty replaces uncertainty in activity data and emission factors. This logic underpins continuous emissions monitoring systems (CEMS) and is well established in ISO, IPCC and GHG Protocol guidance.

For land-based removals, including soil organic carbon, changes are not directly observed as instantaneous flows but are inferred from measured changes in carbon stocks over time. As a result, direct in-situ soil sampling does not eliminate the need for modelling, scaling and attribution. Measurement uncertainty therefore represents only one component of total uncertainty, which must also include uncertainty arising from spatial and temporal variability, model structure, parameterisation and aggregation. This integrated uncertainty treatment is required under the GHG Protocol Land Sector and Removals Standard and underpins Tier 3 approaches to removals accounting.

Measured uncertainty comes directly from the data itself. When soil carbon is measured repeatedly over time or across a field, the results are never the same. Some variation is caused by real differences in soil, weather, and management; some comes from measurement noise. Standard deviation is a simple way of describing how much the results typically vary around an average value.

In soil carbon removals, measured uncertainty is essential because soils are naturally variable. Even with good management, SOC can rise in some places and fall in others or fluctuate between years. By calculating standard deviation from repeated observations, Downforce can distinguish between short-term noise and sustained change.

KEY TAKEAWAY

Measured uncertainty shows how much soil carbon naturally varies. Downforce Technologies uses this to make sure reported removals reflect real, sustained gains rather than short-term fluctuations.



3.2.2 Literature-based default uncertainties

Sometimes it is not possible to directly measure uncertainty for every input, especially when using widely accepted datasets or parameters (such as soil properties or climate factors). In these cases, published scientific studies and international guidance provide typical uncertainty ranges based on past research.

These default uncertainties act as a conservative fallback. They ensure uncertainty is not ignored simply because direct measurements are unavailable.

KEY TAKEAWAY

Where direct uncertainty data are missing, Downforce Technologies uses conservative, science-based defaults so uncertainty is not underestimated.

3.2.3 Probability Distributions

The GHG Protocol Land Sector and Removals Standard (LSRS) does not prescribe a single probability distribution for all land-sector variables. Instead, it requires that uncertainty representations be appropriate to the variable being modelled, assumptions be scientifically justified, and results be conservative and transparent. This applies equally to emissions, activity data, SOC stocks, SOC change, and negative removals (i.e. net SOC losses).

LOGNORMAL DISTRIBUTIONS

Lognormal distributions are used in assessing uncertainty in activity data (e.g. fuel use, fertiliser application rates, livestock numbers) and emission factors, as they better reflect the orders of magnitude that occur in the physical, statistical and practical realities of how these variables behave across regions and management systems. Relative uncertainty (e.g. $\pm 10\%$) remains consistent across scales, which aligns with how uncertainty is typically understood and reported in emissions accounting. Values tend to be skewed with most values clustering near a central tendency reflecting the uncertainty arising from multiple interacting factors (measurement error, temporal variation, spatial heterogeneity). Lognormal distributions integrate well with common uncertainty propagation techniques such as Taylor series expansion and Monte Carlo simulation, which allow uncertainty to be expressed using geometric means and geometric standard deviations, which are standard in life cycle assessment and GHG accounting.



When uncertainties are propagated, lognormal distributions tend to produce wide upper tails; this reduces the risk of underestimating emissions or over-stating removals and supports conservative reporting – an explicit requirement under the GHG Protocol and especially under the Land Sector and Removals Standard (LSRS). The GHG Protocol, IPCC Guidelines, ISO guidance, and life cycle assessment literature all recognise lognormal distributions as a reasonable and often preferred representation of uncertainty for activity data and emission factors. Their use enhances methodological consistency, transparency and acceptance by auditors and regulators.

NORMAL DISTRIBUTIONS

Normal distributions are used in assessing uncertainty for soil organic carbon (SOC) change and removals, where the variable of interest represents a change through space and time rather than an absolute quantity. SOC change may take positive or negative values, reflecting gains or losses in soil carbon, and short- to medium-term variability around a mean often approximates symmetric behaviour. In these cases, normal distributions provide a realistic representation of observed variability without imposing artificial constraints on the sign of change.

Normal distributions are particularly suitable for representing residual variability around fitted SOC trends, interannual fluctuations, and the aggregation of multiple independent influences such as climate variability, management practices and measurement noise. Unlike lognormal distributions, which restrict values to be positive, normal distributions allow negative outcomes to be fully represented, ensuring that potential SOC losses are not structurally excluded. This supports conservative reporting by avoiding systematic bias toward positive removals.

Normal distributions integrate well with standard statistical diagnostics and uncertainty estimation approaches, including the use of arithmetic means, standard deviations and confidence intervals, which are widely understood and readily interpretable by users of the data. When applied to SOC change, they facilitate transparent communication of both the magnitude and direction of uncertainty, consistent with Tier 3 modelling practices.



The use of normal distributions for SOC change and removals is recognised in IPCC land-sector methodologies and broader environmental statistics literature as appropriate where empirical evidence supports approximate symmetry. When clearly documented and empirically justified, their application under the LSRS enhances realism, transparency and auditability, while ensuring that reported removals remain conservative and scientifically defensible.

KEY TAKEAWAY

For SOC change over time and space (Δ SOC), which may be positive or negative and reflects net gains or losses in soil carbon between reporting periods, Downforce Technologies represents uncertainty using normal distributions where empirically justified. Normal distributions are applied to annual and multi-year SOC change estimates and to residual variability around fitted SOC trends, as these variables typically exhibit approximately symmetric behaviour around a mean when aggregated across space and time.

This ensures that uncertainty treatment is physically realistic, statistically appropriate, and conservative. In particular, the use of normal distributions for SOC change allows potential negative removals (net SOC losses) to be fully represented, avoiding structural bias toward positive outcomes and supporting conservative interpretation of results. All distribution choices are documented, empirically supported through diagnostics and validation, and applied consistently over time in line with Tier 3 requirements under the LSRS.

3.2.4 Uncertainty factors

Uncertainty factors are simple multipliers that describe how reliable the data are. High-quality, recent, site-specific data have low uncertainty factors. Older, less relevant, or less precise data have higher ones. These factors are used to scale uncertainty consistently when combining different data sources, ensuring that weaker data do not appear more precise than they really are.

KEY TAKEAWAY

Uncertainty factors help ensure that better data carry more weight, and weaker data are treated cautiously.



3.2.5 Expert Judgement and the Pedigree Matrix

When direct measured uncertainties are unavailable, expert judgement is used in a structured and transparent way through a pedigree matrix, as described in the GHG Protocol Quantitative Uncertainty Guidance. The pedigree matrix scores data against criteria such as precision, completeness, how up to date it is, how representative it is of the location and practice. Each score translates into an uncertainty range. If information is limited, conservative scores are applied. Once the single parameter uncertainty values have been determined using this approach, the values can be propagated in a similar fashion as probability distributions using techniques such as Monte Carlo simulation or Taylor Series expansion. In the pedigree matrix an uncertainty factor is assigned to each of the five data quality indicators and four data quality criteria (very good, good, fair, and poor). The uncertainty factors can then be used to compute the square of the geometric standard deviation. Uncertainty factors are ultimately based on expert judgment.

KEY TAKEAWAY FOR USERS

Expert judgement is not guesswork. Downforce uses a recognised, transparent system to turn data quality into conservative uncertainty estimates to make expert judgement explicit, repeatable, and auditable rather than subjective.



4. MODEL UNCERTAINTY

“Lastly, model uncertainty stems from the use of models with built-in assumptions that are not widely relevant. Models are simplified representations of physical processes and may leave out certain components to focus on one specific process. While this may be useful to learn about the process in question, including the foregone components may lead to different results, and thus introduces modelling error. For example, a forest management company might model forest growth using a constant growth rate as an approximation for carbon stocks, when forest growth is really an S-curve. While the linear growth rate is probably a good approximation for the accumulation of carbon in the forest, it introduces some measurable error. This type of error can be addressed by improving the extent to which a model reflects the processes in question.”

GHG Protocol – Quantitative Uncertainty Guidance

<https://ghgprotocol.org/sites/default/files/Quantitative%20Uncertainty%20Guidance.pdf>

Model uncertainty stems from built-in assumptions that may not always be relevant. For example, soils respond differently to the specifics of individual land management practices; however, in combination they may introduce some measurable errors.

Downforce Technologies methodology addresses this type of error by improving the initial identification of land management practices using an empirical model which relates a set of remotely measurable variables

to the variables of interest e.g., soil organic carbon.

The model assumptions have been designed to introduce fewer errors than assuming a set of complex dynamical relationships, especially as often the specific relationship may not be well understood. The Downforce Technologies empirical model produces statistics that characterise the model uncertainty through fit of the model, R² and model error.



5. COMBINING DIFFERENT SOURCES OF UNCERTAINTY IN SOIL CARBON REMOVALS

When estimating soil carbon removals, uncertainty comes from many sources at the same time: natural soil variability, weather and climate effects, measurement limitations, data gaps, and the assumptions built into models. Each source on its own may seem small, but together they can influence how confident users are in the overall result.

Simply adding these uncertainties together would give misleading results. Instead, they must be **combined in a structured and statistically sound way**, so that the overall uncertainty reflects how all the contributing factors interact. This approach is recommended in the GHG Protocol Quantitative Uncertainty Guidance and is especially important for soil carbon, where variability across space and time is high.

IN PRACTICE, COMBINING UNCERTAINTY MEANS

Accounting for **measured variability** in soil carbon over time and across fields

Including **parameter uncertainty** from inputs such as soil properties and climate data

Reflecting **model uncertainty**, where models simplify complex biological processes

Recognising **scenario uncertainty**, where different assumptions or management choices lead to different outcomes

The Downforce Technologies methodology addresses this by combining multiple uncertainty sources using probability-based methods rather than relying on single-point estimates. Uncertainty is calculated at fine spatial and temporal scales and then propagated through the analysis, so that the final reported uncertainty reflects the full system rather than any one data input. Where uncertainty is higher, results are interpreted conservatively to avoid overstating removals. Scenario modelling is routinely undertaken to test the effects on uncertainty arising from inclusion of different data layers and statistical treatments. The outcomes are evaluated in a Quality Assurance protocol using a range of criteria including proximity to organic soils, and statistical threshold tests (RMSE (magnitude of average error) and R2 (% of variance explained)). This combined approach ensures that soil carbon gains are only recognised when they are large enough to stand out from background variability and measurement noise.



Overall quantitative uncertainty can be reported in many ways, including qualitative descriptions of uncertainty source as well as quantitative depictions, such as error bars, histograms, etc. However, it is impossible to represent a true measure of total combined uncertainty in a single, consistent way. For this reason, it is important to provide as complete a disclosure of uncertainty information as possible so that users of the information may then weigh the total set of information provided in judging their confidence in the information.

KEY TAKEAWAY

Soil carbon uncertainty comes from many sources at once. Downforce combines these sources in a structured, conservative way so reported removals reflect real, sustained change – not optimistic assumptions or isolated measurements.



6. UNCERTAINTY IN EXISTING FRAMEWORKS

Several international standards, methodologies, and frameworks set guidance or recommended limits on acceptable uncertainty levels, expressed as $\pm\%$ confidence intervals or standard deviations around estimated soil organic carbon (SOC) stock changes. There are no globally fixed or legally binding uncertainty thresholds for soil carbon removals. This section references both LSRS and the previously issued LSRG.

The IPCC Guidelines for National Greenhouse Gas Inventories (2006, 2019 Refinement) recommend quantifying and reporting uncertainties for soil carbon stock changes in each land-use category, combining uncertainties from sampling, analytical and model errors and reporting at a 95% confidence levels, i.e. mean \pm uncertainty (standard error). Typical expectations are that Tier 1 (default factors) have $\pm 50\text{--}100\%$ uncertainty and Tier 2 and 3 (country-specific or model-based data) have $\pm 10\text{--}30\%$ uncertainty.

Carbon standards often set practical uncertainty limits for crediting and there is growing convergence towards requiring uncertainty $< \pm 20\%$ (95% confidence) for verified removals or high-integrity carbon credits and encouraging MRV systems (Monitoring, Reporting, Verification) that integrate remote sensing, modelling, and stratified field sampling to achieve this target.

COMMON FRAMEWORKS HAVE A VARIETY OF UNCERTAINTY REQUIREMENTS

Framework / Context	Recommended or required uncertainty limit
IPCC Tier 1	$\pm 50\text{--}100\%$ LSRS Not allowed for removals
IPCC Tier 2	$\pm 20\text{--}50\%$ LSRS Limited use for removals
IPCC Tier 3	$\pm 10\text{--}30\%$ LSRS Required for removals
National Inventory Reporting	95% confidence intervals reported transparently
Verra VM0042	$\leq \pm 15\%$ at 90% confidence (strata level)
Climate Action Reserve	$\pm 10\%$ (90% confidence) preferred
Gold Standard	Requires uncertainty quantification and may cap at $\pm 20\text{--}30\%$
EU Carbon Removal Certification Framework (CRCF, draft 2024)	Proposes transparency + uncertainty $\leq \pm 20\%$ at 95% confidence for certification
Australia's Emissions Reduction Fund (ERF)	Uncertainty to be reported with 90% confidence and if uncertainty $> \pm 15\%$, the credited removals are reduced proportionally
USDA COMET-Farm	$\pm 20\text{--}30\%$
EU LULUCF	$\pm 20\text{--}30\%$



LSRS deliberately does not define fixed acceptable uncertainty thresholds or cut-offs (such as “must be below 15%”). This reflects the reality that land-sector systems differ widely by geography, carbon pool and time horizon.

Instead, it requires quantitative uncertainty assessment and conservative interpretation of removals, with acceptability determined by methodological rigor, appropriateness of the approach and the treatment of uncertainty and how uncertainty is used in decision-making rather than a specific percentage value.

The key LSRS principle of conservativeness means that uncertainty is acceptable only if reported removals are conservative relative to that uncertainty. This means higher uncertainty does not invalidate results, but higher uncertainty requires more cautious interpretation. In practice if uncertainty is high, removals must not be overstated and if uncertainty is beyond an acceptable threshold, removals should not be claimed. Tier-based expectations mean that uncertainty is quantified, there is explicit treatment of variability, calibration and validation is undertaken, and reporting is transparent. Uncertainty must be used not just reported.

COMMONLY OBSERVED UNCERTAINTY RANGES UNDER TIER 3

Category	Uncertainty quantification
Soil carbon stock change:	~10–25%
SOC models with spatial averaging:	~10–20%
High-quality national inventory Tier 3 SOC estimates:	often ~10–15%

These ranges are contextual benchmarks, not requirements. What matters is how uncertainty is handled, not the absolute number.



Downforce Technologies' treatment of uncertainty in relation to LSRS



UNCERTAINTY

"Companies shall provide quantitative uncertainty estimates for removals, including the removal value, the confidence interval for the estimated removal value based on a specified confidence level, and justification of how the removal value does not overestimate removals." (p.67)

GHG Protocol, Land Sector and Removals Standard

<https://ghgprotocol.org/land-sector-and-removals-standard>

REQUIREMENT 1

Companies are required to assess the uncertainty of any removals reported, either qualitatively or quantitatively, including the causes and magnitude of uncertainty.

DOWNFORCE RESPONSE

Downforce Technologies reports SOC uncertainty levels typically ranging from 8–20%.

Uncertainty is expressed **quantitatively** using:

- standard deviations,
- confidence intervals,
- probability distributions.

The **causes of uncertainty** are clearly described (climate variability, soil processes, management, model and measurement limitations).

This directly satisfies the core LSRS requirement.



REQUIREMENT 2

Companies must explain the main drivers of uncertainty and whether uncertainty is reducible or irreducible.

DOWNFORCE RESPONSE

Downforce Technologies distinguishes between inherent and epistemic uncertainty.

Inherent (irreducible) scientific uncertainty includes long-term biogenic processes, climate variability, stochastic environmental drivers.

Epistemic (reducible) uncertainty, includes:

- parametric uncertainty,
- systematic and measurement uncertainty,
- model uncertainty,
- scenario uncertainty.

This distinction is what LSRS expects for land-based removals where not all uncertainty can be reduced.

REQUIREMENT 3

Where uncertainty is quantified, methods should be statistically valid, consistently applied over time, and appropriate to the system being measured.

DOWNFORCE RESPONSE

Downforce Technologies uses:

- **10 m × 10 m pixel-level analysis**, every **10 days**,
- **1-year and 3-year Central Moving Averages**,
- **standard deviation** as the primary uncertainty metric for SOC change.

This shows:

- temporal consistency,
- statistical robustness,
- explicit treatment of short-term variability versus sustained change.

This aligns strongly with LSRS guidance for Tier 3 land-sector methodologies.



REQUIREMENT 4

Companies should outline policies and processes in place to manage and improve uncertainty over time.

DOWNFORCE RESPONSE

Downforce Technologies has multiple quality-control and improvement mechanisms, including:

- regular review of external datasets;
- sensitivity analysis and error propagation testing;
- probability-based treatment of higher-uncertainty inputs;
- field-based calibration and validation against measurements;
- diagnostics using climate and soil indices (e.g. SPEI);
- refinement of land use and management classification.

This exceeds the minimum LSRS expectation, which only requires *an outline* of such processes.

REQUIREMENT 5

Removals require more stringent uncertainty treatment due to higher risk of overstatement.

DOWNFORCE RESPONSE

Downforce Technologies explicitly:

- recognises the heightened uncertainty in **biogenic removals**,
- avoids reliance on single measurements,
- applies **hybrid model-measurement approaches**,
- quantifies uncertainty at fine spatial and temporal resolution.

This is consistent with LSRS's higher bar for removals relative to emissions.



REQUIREMENT 6

Removals must be conservatively interpreted relative to the uncertainty range

DOWNFORCE RESPONSE

Downforce Technologies explicitly:

- recognises the uncertainty range and uses a 3-year Central Moving Average to determine the underlying trend in removals,
- reported SOC removals are conservatively interpreted relative to the quantified uncertainty range, and only sustained changes exceeding natural variability are recognised.

This aligns uncertainty assessment with decision-making, which is the final LSRS test.

In summary, the Downforce methodology is fundamentally designed to capture the natural variation within soils across landscapes and across time. The best available data sources are selected for each assessment location and a QA process is conducted on each assessment to scan for site specific as well systematic issues.



Example Downforce Technologies uncertainty statement for a soil carbon removals project

REMOVAL VALUE

The annual average soil organic carbon (SOC) stock on Project Area B increased from 1,790,790 tonnes SOC (6,572,020 tCO₂e) in FY2020 to 2,263,579 tonnes SOC (8,307,110 tCO₂e) in FY2024. This represents a net increase of 472,789 tonnes SOC over the reporting period, corresponding to 1,734,090 tCO₂e.

Applying the Downforce methodology's temporal smoothing approach, the 3-year central moving average indicates a sustained SOC storage rate of 71,207 tonnes SOC per year (261,258 tCO₂e per year). The most recent annual increase is estimated at 382,303 tonnes SOC, with an associated standard deviation of ±49,699 tonnes, reflecting underlying spatial and temporal variability.

UNCERTAINTY RANGE

Uncertainty has been quantified in accordance with the GHG Protocol LSRS and IPCC Tier 3 requirements. The 95% confidence standard deviation in SOC estimates over the period FY2018–FY2024, based on dekadal analysis and one-year and three-year central moving averages, ranges from 9% to 20%, with a mean uncertainty of 13%.

The multivariate SOC model used in this analysis has:

- an average model error of 0.11% SOC, relative to an average SOC content of 1.139%, and
- a coefficient of determination (R²) of 0.75, indicating strong explanatory power across the project area.

Uncertainty values incorporate both model-related error and observed variability across space and time.



JUSTIFICATION AND INTERPRETATION

The reported SOC removals and associated uncertainty ranges meet the recommended uncertainty thresholds for IPCC Tier 3 methodologies, national greenhouse gas reporting, and leading voluntary carbon and corporate reporting standards. The use of multi-year moving averages, explicit model error reporting, and conservative interpretation ensures that recognised removals represent sustained, statistically robust increases in SOC, consistent with the requirements of the GHG Protocol LSRS for land-based removals reporting.

The types of uncertainty include i) consistent bias in measurement arising from physical monitoring processes especially relating to aggregation, estimation of annual or cumulative removals from sporadic or short-term measurements, and extrapolation of data when scaling up from small plots to larger areas or over longer time periods; and ii) systematic and instrument error due to physical limitations or lack of proper inter/calibration programmes.

Downforce Technologies recognises the need to reduce parametric uncertainty wherever possible and therefore 1. undertakes regular checks of the accuracy of all external data published by government bodies and research organisations, 2. runs sensitivity analyses of the different parameters used in each assessment to examine error propagation, and 3. produces quantification of errors using standard deviations, confidence intervals, and probability distributions with standard deviations.

For geolocation, terrain, local temperature and precipitation, land classification, lithology and earth observation data, uncertainty levels are <5%. Where uncertainty measures for input data are > 5% e.g. soil texture, bulk density, probability measures are used in the Downforce Technologies multivariate model. Downforce Technologies also undertakes field-based calibration and validation studies to test the accuracy of its measurements against field measurements and to test for laboratory bias.

Downforce Technologies maintains data libraries and a Project Information System for Management of Data Quality and Compliance and undertakes regular checks, calibration and validation on the accuracy of external data it uses. Periodic internal audits and technical reviews are undertaken and a list of sources of data provided.



Data category	Source	Parameters	Uncertainty range (1-5) 1. More Uncertain 5. Less Uncertain	Data management process	Ongoing monitoring
Soil layers	<p>Global <u>Soil Grids / ISRIC / WOSIS</u></p>	<p>Soil Organic Carbon</p> <p>Sampling Location</p> <p>Soil Sampling Depth</p> <p>Soil Type</p> <p>pH</p> <p>Soil Texture</p> <p>Coarse Fraction</p> <p>Bulk Density</p> <p>Note, this list is not exclusive</p>	<p>UNCERTAINTY RANGE: 2-4</p> <p>> 250,000 sample points</p> <p>250m resolution</p> <p>What is the % range in these?</p>	<p>The data is analysed, and lower quality observations removed.</p> <p>Each data layer is remodelled using the latest available research and techniques to fit the needs of commercial customers.</p> <p>E.g. customers with a focus on agricultural land uses.</p>	<p>We continually update our soil layers with new information from our own research and customer provided data.</p> <p>With over 100 clients covering 2.2 m commercial hectares this provides us with substantial additional sample information.</p> <p>We conduct calibration and validation sampling in our active locations.</p>
	<p>UK/Europe <u>LUCAS</u></p>		<p>UNCERTAINTY RANGE: 2-4</p> <p>> 80,000 sample points</p> <p>100m resolution</p>		
	<p>Australia <u>SLGA (TERN)</u></p>		<p>UNCERTAINTY RANGE: 2-4</p> <p>> 281,000 sample points</p> <p>90m</p> <p>https://www.sciencedirect.com/science/article/pii/S0016706125000643</p>		
	<p>Africa <u>iSDA</u></p>		<p>UNCERTAINTY RANGE: 2-4</p> <p>> 100,000 sample points</p> <p>30m resolution</p> <p>https://www.isda-africa.com/isdasoil/technical-information/</p>		



Data category	Source	Parameters	Uncertainty range (1-5) 1. More Uncertain 5. Less Uncertain	Data management process	Ongoing monitoring
Earth observation	Global <u>Sentinel 1</u> <u>Sentinel 2</u> SRTM-derived Digital Elevation Model	Sentinel 1 Synthetic Aperture Radar (SAR) 20m resolution Sentinel 2 13 Spectral Bands at 10m resolution Combined to create SWIR, NDVI, NDMI SRTM Digital Elevation	UNCERTAINTY RANGE: 4-5 Uncertainty can arise from Geographic, Radiometric or Sentinel product anomalies Absolute geolocation(s): <u>better than 5 m at 95.5% confidence.</u> <u>Multi-temporal co-registration (same or different satellites), same repeat orbit:</u> <u>better than 5 m at 95.5% confidence.</u> Multi-temporal co-registration, different repeat orbits: better than 5 m. Uncertainty within 5% radiometric accuracy requirement <u>Product anomalies are reviewed on a regular basis (at least once/year)</u>	Multiple sources of Sentinel are reviewed to ensure continuity of coverage. Assessments are not provided where there is no Sentinel coverage.	Satellite mission updates are monitored for issues, e.g. corrections and data reprocessing



Data category	Source	Parameters	Uncertainty range (1-5) 1. More Uncertain 5. Less Uncertain	Data management process	Ongoing monitoring
<p>Meteorological</p>	<p>Global <u>ERA5</u> (0.25o grid)</p> <p>UK HadUK v1.0 (1km grid)</p> <p>Australia SILO (0.05o)</p> <p>Africa CHIRPS v3 (0.05o)</p> <p>USA/Canada DAYMET (1km)</p>	<p>ERA5: Hourly Temperature & Precipitation (1940-Current)</p> <p>HadUK: Hourly Temperature & Precipitation (1960-Current)</p> <p>SILO: Daily Temperature & Precipitation (1957-Current)</p> <p>CHIRPS: Daily rainfall estimates scaled from pentad data.(1981-Current)</p> <p>DAYMET: Daily Temperature & Rainfall (1980-Current)</p>	<p style="text-align: center;">UNCERTAINTY RANGE: 4-5</p> <p>ERA5: Uncertainty is calculated using a 10m set of data ensembles. Variable uncertainty driven by historical availability of meteorological data and complexity of terrain. (9km resolution)</p> <p>HadUK: Uncertainty RMSE: Daily – rainfall 1.23mm, Temp mean/max/min – 0.94/1.06/1.27oC; Monthly – rainfall 16mm, Temp mean/max/min 0.36/0.66/0.45oC</p> <p>SILO: Uncertainty estimates spatially and temporally variable. RMSE: Daily – rainfall 3.8mm, Temp min/max 1.95/1.5oC, Monthly – rainfall 35.9mm. Spatial uncertainty maps</p> <p>CHIRPS: Monthly difference maps produced</p> <p>DAYMET: Spatial and Temporal uncertainty is provided. Access to this: Cross validation, Publication</p>	<p>If data sources and the processing of that data in the bi-annual review process are found not to have changed, then the meteorological data is updated with the additional data and stored.</p> <p>For some products, e.g. DAYMET, HadUK provisional data is provided in NRT, and finalised data may become available after 1-6 months. At the 6 monthly review interval any provisional data is reprocessed and replaced with finalised data. If a new data source is found, all data is reprocessed for the long term and annual time series.</p>	<p>Climate data is reviewed and updated on average every 6 months. At this stage available sources are reassessed to determine if they still offer the highest quality input data. If new data sources are found the old data is archived and kept available for future comparisons. Global data is used in countries where no higher quality meteorological data is found to be available and accessible.</p>



Data category	Source	Parameters	Uncertainty range (1-5) 1. More Uncertain 5. Less Uncertain	Data management process	Ongoing monitoring
Land cover	<p>Global ESA World Cover Open Street Map</p> <p>UK DEFRA Lidar Living England Habitat Priority Habitats Inventory</p> <p>Australia CLUM (Catchment Scale Land Use of Australia)</p> <p>NVIS (National Vegetation Information System)</p>		<p style="text-align: center;">UNCERTAINTY RANGE: 2-4</p> <p>ESA World Cover: Global overall accuracy for v2020 and v2021 is <u>74.4%</u> and <u>76.7%</u>, respectively.</p> <p>DEFRA Lidar: absolute height error < +/- 15cm (RMSE). Relative height error (random error) is expected to be no more than +/- 5cm.</p> <p>Living England Habitat: Overall accuracy of 87%. In addition, 47% of England's area cover is predicted with high to very high reliability (5-level score; from very low to very high) and 10% is predicted with low to very low reliability</p> <p>CLUM: A national government source (ABARES) that compiles different datasets from multiple years and resolutions. There is no single, national overall accuracy percentage for the CLUM.</p> <p>NVIS: A national government source, accuracy varies because it is a compilation of data from different bodies and state sources, scales, and dates. There is no single, national overall accuracy percentage for the NVIS.</p>	<p>Publicly available land cover can be lower resolution, out of date due to changes in land use or in some cases is inaccurate for land cover classes.</p> <p>In selected locations Downforce has constructed bespoke land cover data using a combination of the best available sources and up to date machine learning modelling.</p>	<p>Earth Observation is used to detect land cover change to trigger updates in the model.</p> <p>SOC assessment areas are compared with land cover before being processed.</p>



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