Farm Carbon Toolkit

Supporting accurate measurement of soil carbon through the use of remote sensing and other novel technologies

Prepared by The Farm Carbon Toolkit

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This report was written by staff of the Farm Carbon Toolkit (FCT) and published in February 2023. It has been written to FCT's best knowledge of current understanding in the area of discussion, and is only meant to be used as a reference and point of information, but not necessarily advice. FCT does not claim that the report is accurate or complete. FCT takes no liability for any decisions made upon referring to this document and any consequences thereof.

In preparing this review, FCT has endeavoured to speak to representatives from all the technologies included, FCT has shared the proposed content and received agreement on accuracy of representation, FCT has since conducted edits to reduce elaborate wording. Where contact has not been possible FCT has indicated so and all information has been sourced from content available on the technology companies' websites at the time of writing.

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1.0 Monitoring soil carbon: complexities, inconsistencies and choices

The ability to measure, monitor and verify soil carbon stocks is becoming ever more important, especially for businesses wishing to get involved with the voluntary carbon markets. There is however a key barrier to effective and consistent soil carbon measurement and this is the cost of collection and analysis of soil samples, as well as the duration over which any increases in soil carbon are considered relevant to the carbon balance. To assist with effective UK voluntary carbon market development a set of minimum standards for UK Soil Carbon Codes was issued in December 2022 to help shape the development of agreed standards for investment in soil carbon in the UK. Find it here: https://sustainablesoils.org/soil-carbon-code/minimum-requirements The Soil Carbon Code is set to sit alongside the Woodland Carbon Code and Peatland Carbon Code.

To combat the high cost of collecting soil and analysing it, many remote sensing offers and probe sensors are coming onto the market. It is, however, often difficult to fully understand the metrics being used to establish the data, the protocols they are following and whether the verification claimed is credible, as there are currently no such agreed metrics or protocols in place. For instance, there is very often no way to be certain of the level of accuracy of such sensing results, especially when the source of the reference data used for calibration is not clearly stated and relates to an underground asset. This can make it difficult to effectively evaluate and choose from the growing range of soil carbon remote sensing and probe offers available. Land owners and managers need a measurement they can guarantee will pick up subtle changes in soil carbon stocks over time.

The real question here is - **Are the best remote sensing and probe technologies and services capable of providing an accurate baseline and ongoing monitoring of soil carbon stocks to support future carbon trading?**

This paper seeks to address this question and drawing from the draft UK Farmland Soil Carbon Code suggests the key requirements and protocols which could be put in place to enable greater certainty for all operating in this area.

2.0 Current best practice for soil carbon baselining

Soil Sampling

Current best practice for soil organic carbon (SOC) baselining is through laboratory analysis for SOC content together with bulk density measurements. Field selection is key, with the recommendation to choose fields that best represent the current and historical land use and the management on your farm. Testing every field could be prohibitively costly and time consuming and may not tell you more than sampling representative fields. Where soil analysis is being carried out as a precursor to entering the voluntary carbon market then more intensive soil sampling and analysis is required.

At Farm Carbon Toolkit (FCT) we recommend soil sampling to 50 cm in general, with samples taken at 0-10cm, 10-30 cm and 30-50cm as this is deemed appropriate. The FAO recommends testing soils to a depth of 30cm for carbon analysis (see here). At FCT we also (where soil depth allows) look at what is happening at the 30-50cm depth; indeed some analysis companies are assessing carbon stocks to 1m in depth to get a more complete picture. One sample point is not sufficient for a field estimate of soil carbon. According to the minimum requirements for farmland soil carbon codes a measure of in field variation is required to inform the sampling intensity required for soil carbon baselining.

Bulk Density

Soil bulk density is also required for an accurate assessment of soil organic carbon stocks to be made. Bulk density is a measure of the mass of soil in the field (calculated based on the weight of soil in a known volume). This is crucial for effectively measuring the quantity of carbon stored in the soil in tonnes per hectare. Laboratories will assess soil bulk density for you, however it is important to look at the methodology being used (for carbon markets equivalent soil mass is also required) and stones within the soil must be accounted for within the calculation.

Laboratory methodology

The role of the analytical laboratory itself cannot be underestimated when considering accuracy and consistency of SOC measurement where this is done via soil sampling. Where an accurate calculation of absolute carbon stocks on-farm is required a “Soil carbon by DUMAS” is required. The DUMAS test is a well standardised technique providing consistent results across different laboratories, particularly compared to e.g. loss on ignition (LOI) which can result in rather varied results from different labs. If you chose to use LOI, you must stick to the same laboratory and time of year when conducting repeat samples so as to have confidence in comparing results.

See here for our practical guide to soil carbon sampling.

3.0 Towards a UK Farmland Soil Carbon Code

An evaluation framework was developed to appraise existing soil carbon codes in other parts of the world, standards and schemes according to an agreed set of criteria to cover:

- Credibility
- Additionality to normal farming practice
- Permanence
- Verifiability

Additionally, the framework emphasised the need for any code to be:

- Transparent
- Holistic
- Scalable
- Fair

Soil carbon remote sensing and in field probes could offer more cost effective soil carbon analysis but to do so they will need to provide services which can deliver against the criteria set out in the codes, with an emphasis on:

- **Credibility** - sequestered carbon must be scientifically measurable according to robust, high-integrity methodologies

- **Verifiability** - the approach used, and the changes in carbon stocks claimed must be verified by a trusted, third party organisation

To support the sector we have reviewed the main soil carbon remote sensing and soil probe services being offered in the UK, and further afield against these criteria (specifically methodologies and verification processes), and spoken with them whenever possible. We have based our analysis on the above framework by researching the methodologies and any verification these organisations may have undertaken. We have also spoken with some professionals in the earth observation industry to assist with this analysis.

Some of the companies we have spoken to are verified with Verra. In 2006 Verra launched the Verified Carbon Standard which permits certified projects to turn their greenhouse gas (GHG) emission reduction/removals into tradable credits. You can find out more about the methodology behind their estimation of carbon stocks in soils here and here.

It should be noted that the above criteria are necessary only where there could be an intention to enter the voluntary carbon market. For other purposes' less stringent protocols can be adopted.

4.0 Analysis of novel sensing technologies

4.1 Earth observations/remote sensing:

AgriCircle

Details: A Swiss based organisation offering technologies for more sustainable agriculture, and incentives for climate-neutral farming. They provide performance data on sustainable farming, vegetation, soil moisture, growth, disease, field drivability, and also on carbon storage. In the UK they offer their services via Agrovista.

How it works: A combination of satellite monitoring, soil data, AI and precision sampling.

Information on methodologies deployed to measure soil carbon: Measurement based. AgriCircle combines radar and optical satellite based monitoring with targeted soil sampling. The results are accessed via their standard API, which can easily be integrated into existing systems. Their precision sampling method (where samples are taken on about one 10x10m area per around 3ha to create high resolution soil maps at 10x10m) is based on algorithms developed with >60,000 measurement points to reduce sampling costs and increase scalability. They provide high resolution soil maps developed from optical and radar satellites, soil databases, biomass and topographic measurements in combination with artificial intelligence and their precision sampling. These maps can be used to increase input efficacy significantly (by 15% with current customer base). For sustainability, farmers get data in 6 month intervals on how they have improved and to give an indication on potential soil carbon sequestration.

Approaches used to verify methodology (including any third party verification): Their methodology has had high acceptance, and is backed by science. As a demonstration of this, AgriCircle are currently working with Verra and The University of Aberdeen on a new standard, particularly for soil sampling, whilst also working on data interoperability. They are a partner of ClieNFarms, an innovative project funded by the European Commission to support the European Green Deal and foster climate-neutral and climate-resilient farms across Europe.

Website link: AgriCircle – Macht nachhaltige Lebensmittelproduktion messbar – für Landwirte und Lebensmittelverarbeiter and Carbon Platform – AgriCircle

N.B. Information collected in conversation with an organisation representative and from their website.

Downforce Technologies

How it works: At Downforce Technologies they have developed a platform to measure natural capital at scale, enabling landowners to design, implement and monitor their nature-based solutions. Their approach measures soil carbon at an accuracy of $10m^{2,}$ providing an analysis of the current state of the land, its 6-year history, and its soil carbon potential. They combine local geophysical and environmental data with the latest earth observation data, to provide customers with a 'digital twin' of their land.

Information on methodologies deployed to measure soil carbon: Downforce Technologies' website states that their approach has achieved over 90% accuracy when compared to individual soil sampling.

Approaches used to verify methodology (including any third party verification): Methodology validated independently by Professor Jules Pretty, Chief & Founding Editor of the International Journal of Agricultural Sustainability. Their methodology is aligned with ISO 14064-2 (2019), meaning they quantify, monitor, and report greenhouse gas emission reductions or removal enhancements as per the International Standards for environmental management.

Website link: https://www.downforce.tech/
N.B. Information collected in conversation with an organisation representative and from their website.

Ecometric

Details: UK based, with a global reach, remote sensing, artificial intelligence and model based technologies working with landowners to support revenue from SOC carbon credits. They state they "*remain completely independent to the carbon credit trade itself*" to avoid commercial bias. They are commercially deployed on over 50 projects in the UK, Belgium, France, Germany, Spain, Romania, NZ and shortly USA + Brazil. They state they are the only UK company to have generated measured soil carbon credits that have gone to trade.

How it works: They use physical soil samples to establish a baseline, spatial satellite data and calibrated artificial intelligence assessment to cross check each data point, and embed accuracy and quality. They state with each new soil type tested, their integrated AI system becomes faster and more accurate, requiring less baseline inputs.

- The physical soil samples are taken using a mechanised corer at high densities aiming to capture whole-field SOC variability. They use the DUMAS laboratory method to measure SOC, and the resulting dataset is used both as a physical baseline, but also to improve their AI system.

- The AI system is *'trained on known soil sample results'*. The AI system identifies

mathematical relationships between input data, such as topography, satellite, soil type, weather and known SOC results. Once it has learnt these relationships it uses them to predict SOC remotely.

- Results are reported numerically and as maps to visualise stock change. Baseline analysis is repeated in year two but at a lower on-ground density as the AI system has memory of in-field variation - this creates a stock change figure which reflects the annual production cycle.

Information on methodologies deployed to measure soil carbon: Measurement based. Their AI system has been building data for 18 months (dated: November 2022), but they do also use other datasets. They state that their system performs well at local scale exceeding expectation, with accuracy to within +/-5% of soil sample results.

Approaches used to verify methodology (including any third party verification): Their website states that all methodology "*is subject to external peer review to provide third party scrutiny*". Ecometric's commercial approval has been via Respira - a carbon credit market that 'aligns the interests of carbon credit developers, buyers and capital providers'. Their scientific approval is due to be completed in 2023, and consists of three part (internal, external and global peer review) process:

- Regen Network provides their external review. They are open source with a methodology which ensures the prevention of double counting carbon.
- Three carefully selected peers from the global science community complete the external review of all the methodology with full access to datasets (currently at this stage, Nov 2022)
- A summarised version of ecometric's paper on their methodology is put out on Regen Networks community noticeboard for open access review by the international science community where they must respond to all review comments. This is part of Regen Networks open-source culture to maximise transparency.

Website link: ecometric.co.uk
N.B. Information collected in conversation with an organisation representative and from their website.

Environment Systems (ES)

Details: UK based / working globally. Environment Systems is essentially a data company predominantly used by governments and industries across the UK and the world. They are a science-based environment and agricultural data consultancy who rely on the use of drones, satellites and other sources of spatial data. In conversation, Environment Systems were open in stating that they do not believe Earth observation systems alone can measure SOC to a high enough detail, and expressed there is a lack of accurate data, particularly at the field level. They also stated that you can only go so far with remote sensing and machine learning, particularly when machine learning relies on soil data that is, often at best, from half a century ago.

How it works: Radar technology, Earth observation technology and modelling. e.g. Their project Pastoral (Pasture Optimisation for Resilience and Livelihoods) is developing a pasture optimisation tool for UK livestock farmers to monitor pasture biomass and carbon storage. This platform uses Earth observations to provide biomass quantifications, but the use of models is required to e.g. look at the flows of carbon in the system. The University of Edinburgh provides the carbon flow model in this instance. Dr. Iain Cameron, who has been technical lead on the project, stated that soil sampling is a key part of the process to provide a baseline.

Information on methodologies deployed to measure soil carbon: They have recently completed a national project for the UK government that used existing datasets to map above and below ground carbon that can be used at a local (but not farm) scale. In addition, a summary report on Environment Systems' website 'Sustainable Farming Scheme: Nature & Carbon Benefits Remotely assessing the potential for genuine environmental delivery' states that "it is not possible to model at the farm-scale using only Earth observation".

Their Pastoral project will use carbon flow modelling to improve the understanding of carbon flow through different carbon pools within a field (e.g. root, soil, vegetation, livestock). Verification work for the model has already been published by The University of Edinburgh, and within the project additional verification is being undertaken. It is important to note that the model only evaluates carbon flow; carbon stocks need to be provided by other data such as on the ground soil sampling. They say that there will likely have to be a practical trade-off somewhere, at some point, to allow progress at the expense of 100% levels of confidence in the readings.

Approaches used to verify methodology (including any third party verification): They do not specifically offer soil carbon quantification for individual farmers but from their Pastoral project there are plans to offer carbon flow data to farmers via third party apps in the near future. You can see their affiliations here, to get a sense of the organisation's credibility.

Website link: Home - Environment Systems (envsys.co.uk)

N.B. Information collected in conversation with several organisation representatives and from their website.

Geotree

How it works: London based, Geotree has substantial domain expertise in satellite technology, machine learning and climate finance. They monitor historic and near real-time soil carbon at a granular level, and quantify spatial and temporal distribution as well as associated uncertainties.

Information on methodologies deployed to measure soil carbon: Model based. Through remote sensing they measure the percentage of reflected radiation, normally in 10 spectral bands. Geotree is also working on hyperspectral models that incorporate additional bands of light to pick up more detailed features. This aims to make better SOC estimates and also provide the possibility to measure other metrics. To train their models, Geotree has used existing libraries of spectral soil data e.g. European Lucas. They state they can work in tandem with direct soil sampling but to reduce costs, soil sampling is not currently a mandatory part of their methodology. In a recent pilot study (in the US), Geotree used relatively few soil samples from specified locations for calibration which presented 'excellent' comparable results to intensive on-ground sampling. They argue that what remote sensing misses in terms of the depth profile of carbon is more than made up in capturing variability across entire fields.

Approaches used to verify methodology (including any third party verification): Focus is on Verra agriculture methodology which is still being finalised. Geotree mostly works directly with larger businesses.

Website link: Geotree | Home
N.B. Information collected in conversation with an organisation representative and taken from their website.

Indigo Ag

How it works: USA based 'Carbon by Indigo' aims to support farmers to adopt practices that build farm resilience and offer payments for carbon credit generation.

Information on methodologies deployed to measure soil carbon: Measurement and model based. Soil sampling and advanced modelling at large scale. Indigo's Carbon Experimentation team launched autumn sampling in September 2021 for year 3 of the long-term study the Soil Carbon Experiment (SCX) -. During year 3, [they] are re-sampling over 100 fields currently enrolled in SCX and will perform initial sampling on new fields joining the program – gathering data including on SOC, bulk density and other soil health measures, including some samples down to a 1m depth. These samples come from a mix of regeneratively and conventionally managed fields – including a subset of split-field trials with both management systems. SCX data and case studies help Indigo:

- understand credit generation potential
- minimise grower data burden
- improve unit economics

Approaches used to verify methodology (including any third party verification): Their website states that "Carbon by Indigo's agricultural soil carbon credits are considered the highest quality because net changes in greenhouse gases are credited following MRV, or "monitoring, reporting, and verification," which adheres to IPCC guidelines and best practices". Verified by Verra, AG Data Transparent, and Climate Action Reserve.

Website link: Earn Income with Carbon Farming | Carbon by Indigo (indigoag.com)
N.B. Information taken from their website only as contact has not been possible to establish.

ReGrow Ag (DNDC - DeNitrification DeComposition Soil Carbon Model)

Details: Regrow Ag is a multinational company headquartered in the US. DNDC is operational in the UK, but only if a farmer is part of a bigger project, e.g., if they supply one of Regrow's carbon project customers. DNDC, which stands for DeNitrification DeComposition, is a model backed by an academic community, developed to estimate soil carbon levels and quantify GHG emissions and reductions. Both DNDC and the product it supports, Regrow's MRV, facilitate the development of scalable ecosystem markets for agriculture.

How it works: DNDC from RegGrow is a biogeochemical model calibrated and validated locally using data specific to the location, this includes data from soil samples and scientific journals. As the dataset grows, the model becomes more accurate. The computer simulation model estimates the influence of agricultural management practices on carbon and nitrogen cycling in soils.

Information on methodologies deployed to measure soil carbon: Model based. The ReGrow Ag website states that DNDC is the only scientific model applied, calibrated and validated globally. The model can scale with limited adjustments, providing estimates across global supply areas, with over 100 crop types and a comprehensive range of farm practices. Their remote sensing model, OpTIS analyses images acquired every 3-4 days, which can demonstrate practice changes and drive the model. The historical dataset goes as far back as 2009 allowing a baseline to measure change against.

- Inputs = climate, soil properties & management practices, grower input & publicly available data.
- Simulation = Algorithms that simulate soil processes use model inputs to digitally recreate the effects of farming practices on soil health.
- Prediction = Carbon sequestration & GHG emissions predicted based on simulated in-field denitrification and decomposition rates.
- Validation = Model predictions are verified using field level measurements & peer reviewed studies.
- The ReGrow team feeds their model as new scientific journals are published and with in-field observations. They also have a Manure DNDC model looking at manure emissions and nutrient cycling across whole farm operations (feed, enteric, manure management and land application).

Approaches used to verify methodology (including any third party verification): DNDC has been peer-reviewed in over 500 publications, and states that it is the only scientific model in the industry supported by a global academic network. DNDC is verified with Climate Action Reserve, and is in the approval process with other standards and markets (e.g. ESMC, Verra, American Carbon Registry). ReGrow has joined SustainCert's Value Change Initiative aimed to establish best practice for scope 3 emissions.

Website link: DNDC (regrow.ag)
N.B. Information collected in conversation with an organisation representative and taken from their website.

Quanterra Systems

Details: UK based carbon monitoring for nature based solutions, now operating commercially with early access partners to refine their system.

How it works: Their technology measures flows of CO_2 between an ecosystem and the atmosphere. They use hardware and data processing, which is deployed and managed by Quanterra's team. Data can be provided at a range of temporal resolutions from 30 minutes to monthly. They can also provide information on water and energy exchanges, and are looking to extend their system to include other trace gases, such as methane.

Information on methodologies deployed to measure soil carbon: It is hard to ascertain with certainty if they are model or measurement based, but likely model based. Quanterra developed a prototype service whilst researching at the University of Exeter and founded Quanterra as a "spin-out" in January 2021. It is also unclear how they quantify soil carbon stocks as opposed to soil carbon flows.

Approaches used to verify methodology (including any third party verification): We could not find anything regarding this on their website.

Website link: https://www.quanterrasystems.com/
N.B. Information taken from their website only as contact has not been possible to establish.

4.2 Other technologies e.g. gamma, probes:

AgroCares (SoilCares)

Details: Currently operating across Europe (not yet in the UK), in Africa, Asia and N. America.

How it works: AgroCares offers the Nutrient Scanner which can measure a range of nutrients as well as soil carbon. It uses a Near Infrared Spectrometer – Range: 1300-2550nm, MEMS technology. The resulting scans are compared with the data in their cloud and recommendations are given via your smartphone.

Information on methodologies deployed to measure soil carbon: Measurement and model based. AgroCares combines sensor technologies with analytical data processing techniques such as data mining and modelling. They believe the most suitable technology is spectroscopy: the specific way in which light is reflected by soil as a function of the wavelength in the electromagnetic spectrum. Mid Infrared Reflectance (MIR) and Near Infrared Reflectance (NIR) Spectroscopy can provide detailed information about organic components and texture in soils. While Rontgen (or X-Ray) Fluorescence (XRF) Spectroscopy collects information about concentrations of minerals and trace elements. Machine learning plays an integral role, providing predictions of the soil's chemical properties from sensor data. Instruments in the sensor produce data, which is added to their database, from this they create a number of machine learning models to identify patterns in the data that correspond with the soil's chemical properties. With machine learning, they reduce the influence of moisture in the sensor data, strengthening the accuracy of their predictions.

Approaches used to verify methodology (including any third party verification): The Golden Standard Lab is a vital part of their company. It consists of several researchers, lab analysts and assistants that process all incoming soil samples collected from around the world. These samples are analysed with several analytical techniques, including ICP-MS, HPLC, XRF, FTIR and laser diffraction and the data extracted from the separate techniques is combined into one big database. This database is the reference for the samples by the AgroCares scanner. The company has a research laboratory and a team which improves and develops new sensors and techniques.

Website link: Home - Smart Farming | Nutrient Testing – AgroCares
N.B. Information taken from their website only as contact has not been possible to establish.

Stenon (FarmLab)

How it works: EU based. Sensor on a stick that can be rented. The sensor probe is inserted into the ground and controlled via a touchscreen, the data is then shown in real time via their cloud technology.

Information on methodologies deployed to measure soil carbon: Measurement based. Their sensor technology analyses soil as often as is desired with instant results. Along with SOC, it measures many other metrics, all with GPS points. >5,000 data points processed per measurement. In addition, the analysis is optimised through the use of machine learning models and from these recommendations for farmers can be drawn.

Approaches used to verify methodology (including any third party verification): With their research partner, the Leibniz Institute, Stenon have carried out tens of thousands of laboratory analyses and several hundred thousand FarmLab analyses in recent years in order to validate their technology and demonstrate laboratory-comparable accuracy. These analyses have contributed towards their Gold Award Standard by the DLG (Deutsche Landwirtschafts-Gesellschaft – German Agricultural Society). However the sensor was only tested for:

- NO3-Content in mg/100 g
- NMin-Content in mg/100 g
- Soil moisture in wt. %

Stenon is supported by the European Fund for Regional Development of the European Union, in the project "Farmlab- the Laboratory for Real-Time Soil Analysis"

Website link: FarmLab - Stenon
N.B. Information taken from their website only as contact has not been possible to establish.

Terramap (from Hutchinsons)

How it works: Gamma technology. TerraMap uses passive, gamma-ray detection technology, providing high-definition mapping of all common nutrient properties, organic matter, carbon and various other metrics. The in-field process of collecting the data is carried out in two steps; scanning by driving a lightweight all-terrain vehicle fitted with the sensor over a field, and then taking soil samples to allow for each scan to be calibrated and used to create the individual map layers. The raw scan, soil data and soil samples are then combined and processed to produce up to 27 high-definition soil property layers.

Information on methodologies deployed to measure soil carbon: Measurement and model based. Manufactured by Canadian company SoilOptix, TerraMap's scanning technology is based on a scaled-down version of airborne sensors that originates in mineral prospecting and has been used in other countries. TerraMap uses gamma-radiation detection technology to deliver resolutions of more

than 800 pints/ha, providing high-definition mapping of all common nutrient properties, pH, soil texture (for example, % clay, % sand, % silt), organic matter and cation exchange capacity, as well as elevation and plant available water and now, carbon.

The TerraMap sensor is non-contact and pre-calibrated. It is an entirely passive sensor. The standard field practice is that the scanner is mounted roughly 600-700mm above the ground and the vehicle is driven around 10-12 mph and at 12-metre swath widths. The sensor is measuring gamma radiation that is naturally emitted from the soil. Specifically, it is measuring caesium-137, uranium-238, thorium-232 and potassium-40.

Approaches used to verify methodology (including any third party verification): The consistency and reliability of the results from TerraMap are stated to be reflected in its uptake on more than 35,000ha on UK farms since its launch in 2018.

Website link: TerraMap - Omnia (omniadigital.co.uk)
N.B. Information taken from their website only as contact has not been possible to establish.

Yard Stick

Details: USA based.

How it works: Spectral measurement device that is made available to farmers/growers providing real time data. Currently Yard Stick is still piloting both its spectral measurements device and its project data platform.

Information on methodologies deployed to measure soil carbon: Measurement based. Sensor on a stick. Yard Stick's website says it helps to create an 'agronomically-credible and statistically sound' sampling plan via web-based planning dashboard. A cloud enabled, handheld spectral hardware instantly collects SOC and bulk density measurements up to 45cm depth, which can be used where crops are still standing. The data is accessed via a live dashboard of project measurement data which shows stocks and changes and can be shared with various stakeholders. It is hard to find specifics on how their technology works on their website.

Approaches used to verify methodology (including any third party verification): Yard Stick has co-founding project partners including the not for profit Soil Health Institute, and a few universities in the States and Australia. We could not find anything more about their verification on their website, but they do state in 2020 they were awarded a large research and development grant from the US department of Energy's ARPA-E Smartfarm program, and their outside financing includes "some of the most prestigious climate tech investors in the world".

Website link: Yard Stick PBC: Soil Carbon Revealed (useyardstick.com)
N.B. Information taken from their website only as contact has not been possible to establish.

4.3 A combination of remote sensing and probes:

RETINA Project

Details: RETINA (Dynamic monitoring, reporting and verification for implementing negative emission strategies in managed ecosystems) is a £1.2 million project led by the James Hutton Institute and funded by the Natural Environment Research Council (NERC) and involves the University of Aberdeen and the Centre for Ecology and Hydrology as partner organisations. It is hoped the system will be operational by the end of the project in 2023.

How it works: The RETINA project applies remote sensing, soil temperature and moisture sensors, and high-speed computing with biogeochemical modelling to track, display, and validate fluctuations in soil carbon and greenhouse gas (GHG) emissions in near real-time. Models that factor in recent data from land parcels should give an estimate of changes in soil carbon and GHG and help users make better management choices. This system can be accessed by the public via a web portal and a mobile app. The RETINA app will assist in recording alterations in agricultural management and feed them into the data cycle, making the system dynamic. Models connected to an ongoing data stream will forecast changes in SOC and GHG emissions up until 2050, guiding farmers along their path to achieving net zero emissions. A demonstration of the technology is expected to be available by July 2023.

Approaches used to verify methodology (including any third party verification): Dr Jagadeesh Yeluripati, principal investigator of this project was part of the consortium who drafted the Soil Carbon Code and voiced high regard to issues surrounding validity and credibility of methodology.

Website: *Groundbreaking research to develop soil carbon sequestration monitoring system | The James Hutton Institute* and *GtR (ukri.org)*
N.B. Information collected in conversation with an organisation representative and from their website.

Note: This list of technologies is not exhaustive. We will be updating this document as new information becomes available.

5.0 Conclusions and actions

If you are considering entering the voluntary carbon market to trade increases in the carbon stocks in your soils and looking for appropriate measurement technologies it is important to consider:

- How accurate and up to date are the various data sets being used by remote sensing applications to provide data on likely soil carbon stocks?
- How transparent are the platforms which provide the data sources used for remote sensing?
- How do remote sensing services manage the measurement of bulk density?

The Soil Carbon Code document sets out recommendations for soil carbon baselining and ongoing monitoring including the level of verification required if remote sensing is to be used as an element of soil carbon baselining and ongoing monitoring. This review by Farm Carbon Toolkit should be read in conjunction with these minimum requirements to ensure that any individual service meets them where the voluntary carbon market is being targeted.

Again, for reference, the minimum requirements can be found here:
Report and recommendations on minimum requirements for high-integrity soil carbon markets in the UK Version 1.0

Sources of further information

For more information on issues surrounding ownership of carbon see our Farm Carbon Toolkit article here, and for more clarity on carbon offsetting see here. For more information on the management practices likely to increase SOC and associated trade-offs for farmers with economic, environmental and social targets, see this 2023 article in the Journal of Environmental Management: Carbon farming: Are soil carbon certificates a suitable tool for climate change mitigation? - ScienceDirect