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RESEARCH ARTICLE

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What makes an operational farm soil carbon code? Insights from a global comparison of existing soil carbon codes using a structured analytical framework

Helaina I. J. Black[a], Mark S. Reed[b], Helen Kendall[c], Robert Parkhurst[d], Nicola Cannon[e], Pippa J. Chapman[f], Matthew Orman[g], Jenny Phelps[h], Hannah Rudman[b], Sarah Whaley[h], Jagadeesh Yeluripati[i] and Guy Ziv[f]

[a]Ecological Sciences, The James Hutton Institute, Dundee, UK; [b]Thriving Natural Capital Challenge Centre, Department of Rural Economies, Environment & Society, Scotland's Rural Collage, Edinburgh, UK; [c]Centre for Rural Economy, School of Natural and Environmental Science, Newcastle University, Newcastle Upon-Tyne, UK; [d]Sierra View Solutions, LLC, Sierra Madre, California, USA; [e]Royal Agricultural University, Cirencester, Gloucestershire, UK; [f]School of Geography, University of Leeds, Leeds, UK; [g]Sustainable Soils Alliance, Bristol, UK; [h]Farming and Wildlife Advisory Group, Wellington, Somerset, UK; [i]Information and Computational Science, The James Hutton Institute, Aberdeen, UK

ABSTRACT

Soils have the potential to sequester and store significant amounts of carbon, contributing towards climate change mitigation. Soil carbon markets are emerging to pay farmers for management changes that absorb atmospheric carbon, governed by codes that ensure eligibility, additionality and permanence whilst protecting against leakage and reversals. This paper presents the first global comparative analysis of farmland soil carbon codes, providing new insights into the range of approaches governing this global marketplace. To do this, the paper developed an analytical framework for the systematic comparison of codes which was used to identify commonalities and differences in approaches, methods, administration, commercialisation and operations for 12 publicly available codes from around the world. Codes used a range of mechanisms to manage additionality, uncertainty and risks, baselines, measurement, reporting and verification, auditing, resale of carbon units, bundling and stacking, stakeholder engagement and market integrity. The paper concludes by discussing existing approaches and codes that could be adapted for use in the UK and evaluates the need for an over-arching standard for soil carbon codes in the UK and internationally, to which existing codes and other schemes already generating soil carbon credits could be assessed and benchmarked.

KEYWORDS

Agricultural soils; voluntary carbon market; carbon code; MRV

CONTACT Mark S. Reed Mark.Reed@sruc.ac.uk Thriving Natural Capital Challenge Centre, Department of Rural Economies, Environment & Society, Scotland's Rural Collage, Edinburgh, UK

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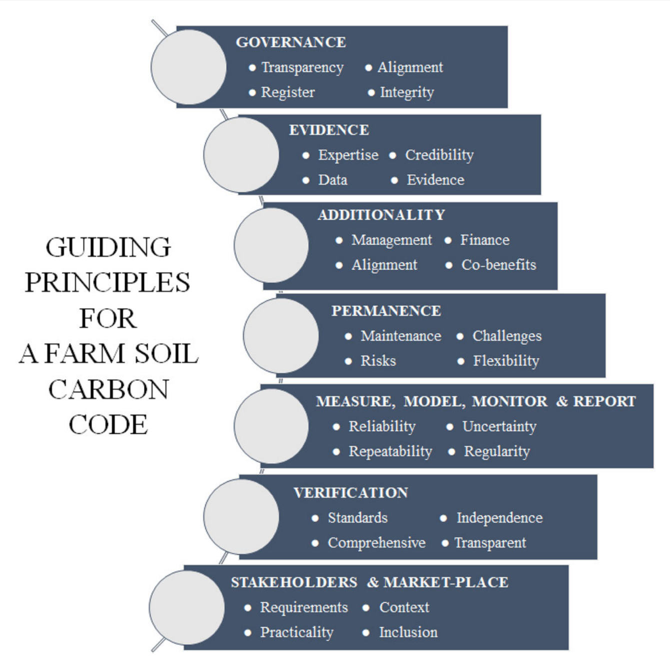
GRAPHICAL ABSTRACT



Introduction

There has been a surge of interest in agricultural soils with the growing urgency to reduce soil greenhouse gas emissions (GHGs) fifty percent by 2030. Soils have the potential to absorb significant volumes of carbon (C), or carbon equivalents (CO_2e), from the atmosphere [1] particularly since long-term agricultural land use and management has resulted in soils severely depleted in carbon [2]. Cropland soils around the world having lost on average 26% of topsoil carbon due to land use change and intensification of farming practices [3].

Numerous agricultural practices are considered effective at increasing soil carbon stocks and/or reducing direct soil GHGs [4, 5]. These reflect different capacities to: (i) reduce soil C losses from residue removal; (ii) reduce soil erosion to reduce soil C losses; (iii) reduce mineralisation of soil C, and associated soil GHGs, particularly N_2O; (iv) balance productivity with soil C retention; and/or (v) add carbon to soils from integrated or external sources [6]. The ultimate effectiveness of any practice will reflect local farming systems in a context of local economic, social and environmental (e.g. soil type and climate) factors [7]. Therefore, objectives to achieve, and sustain soil carbon sequestration will require tailoring to local conditions [8].

An increase in soil carbon content can have additional benefits for soil health by improving soil structure and biodiversity, reducing soil erosion and increasing soil resilience [9]. These co-benefits may encourage the adoption of practices, such as agroecological and regenerative, that encourage carbon sequestration which we subsequently refer to as carbon-positive farming practices. However, widespread adoption of carbon-positive farming practices around the world has been limited to date, reflecting diverse economic, social and environmental barriers [10, 11].

With a growing commitment to climate change mitigation and adaptation by farmers, supply chains, consumers and financial institutions, voluntary markets for natural capital, including carbon, are increasingly being viewed as mechanisms to enable and scale the adoption of carbon-positive farming practices [12]. Several existing "codes" (e.g. programmes or standards) aim to deliver verified soil carbon credits from agricultural land to the voluntary carbon market. However, adapting or translating existing, or developing new, approaches to establish a workable farm soil carbon code in a new country or region is not trivial, since codes must address local economic, environmental and social factors, including farming systems, soil and climatic conditions, regulations, social norms and values.

This paper introduces a novel analytical framework that enables a comprehensive comparison and evaluation of existing and future soil carbon codes from ownership, methods to marketplace, with a focus on agricultural soils. The framework supports the identification of areas of convergence or divergence between individual codes and permits consideration of the applicability of the approaches to different farming contexts. In this instance, illustrating questions about soil carbon markets from farmers and others around the world, we reflect on the UK farming sector where there is growing interest in carbon-positive farming practices and voluntary carbon markets in the context of a reduction in, and major changes to, publicly funded farming subsidy [13].

In the UK, agricultural land covers 17.7 million hectares with conservative estimates of soil C sequestration potential of this land at 1 to 2 t CO_2e ha^{-1} per year [14] which, at a carbon price of £15 per ton, could attract £265 million to £531 million per year of private investment. However, amongst UK farming communities, there is cautious interest in soil carbon markets [10, 15] with concerns that, without proper regulation, these markets might expose farmers and investors to unnecessary financial risks, whilst providing limited climate benefits if, for example, issues of additionality and permanence are not addressed [10, 15, 16]. In response to these and other concerns, an independent UK Farm Soil Carbon Code (UKFSCC) was proposed to help provide assurances for private and public stakeholders involved with soil carbon projects and soil carbon markets in the UK (see https://sustainablesoils.org/soil-carbon-code). The first major task of the consortium working on the UKFSCC was to conduct a comprehensive analysis of existing soil carbon codes from different global regions and contexts to help inform on commonalities and differences between existing methods, standards, rules and guidelines and associated code/programme documents. This paper presents the results from this comprehensive analysis which had the specific aims to:

1. Develop a clear and justifiable framework for the inclusion of existing soil carbon measurement/monitoring, reporting and verification (MRV) methods in the comparative analysis.
2. Establish a comprehensive and replicable set of evaluation criteria for the analysis of existing soil carbon MRV methods and associated codes selected for inclusion.
3. Apply these criteria to identify commonalities and differences in methods, projects, administration and commercialisation and associated code documents.
4. Explore aspects of existing MRV methods and codes that could be adapted for use in the UK.
5. Identify gaps in existing methods and codes for use in the UK.
6. Evaluate the need for an over-arching standard for soil carbon codes in the UK.

Methodology

There is wide variety in the terminology used by organisations involved with the voluntary soil carbon market. For this paper, a "code" is a document, or set of documents, detailing the requirements and rules to establish and run a project that aims to generate verifiable soil carbon credits under the auspices of a certification programme and registry. A glossary is provided in the Supplementary materials which sets out definitions for this review. Given the proliferation of codes that have emerged globally in recent years, including varying levels of detail and rigour at different levels of operational development, it was not practical or useful to include all codes in the comparative review. Therefore, to be included in the review, codes were required to:

1. Provide detailed guidance on methods for measurement (monitoring), reporting and verification (MRV).
2. Be publicly available and open access online.

The analytical framework was developed based on an inductive thematic analysis of codes and the expert knowledge of the authors, many of whom have worked across (and in some cases developed) carbon codes covering a range of land uses and habitats internationally. The framework consists of components and sub-components within key domains that can be used to analyse and systematically compare codes. These domains and components were identified and refined through a two-step process. A preliminary analytical framework was developed using expert knowledge and used in an initial thematic textual analysis of each code, during which additional domains, components and sub-components were identified inductively, based on this first reading. A revised framework, shown in Table 1, was then developed and used to structure a second thematic analysis

Table 1. **Analytical framework showing components and sub-components within domains that can be used to compare soil carbon MRV methods and associated codes.**

Analytical domain	Component	Sub-components
MRV method context	Documentation and status	Official method title, version, approval status free-to-access source of documentation
	Context for MRV method	Overarching Code, Owner organisation Code sponsors, Market approval for code, Code aligned to recognised Standards body
	Method scope	Terminology used, Quantification approach, Intended geographic coverage
	Geographic coverage and active projects	Geographic coverage, number of active projects, location and area of projects
	Project Activity using MRV methods	Active projects, locations, tonnes CO2e, area covered (ha), fields, verified credits issued, credits retired
Project eligibility and rules	Project ownership and rights	Project ownership, project land relationship
	Eligible and ineligible	Eligible land use, ineligible land use, eligible practices/ interventions
	Additionality rules	Types of additionality (common practices, project practices, financial, legal, other)
	Permanence rules	Permanence, reversals and leakage rules
	Other rules/compliance	social or environmental no-harm; regulation or ethical considerations, co-benefits
Project administration	Registration process	Registration review process, costs, URL for open registry
	Project contracting	contract duration, land management strategy required, data ownership, data disclosure policies, allowable changes
	Complaints/disputes	dispute procedures, project disqualifications
Project baselines	Setting the baseline	Type, historical look-back period
	Allowable data sources	regional, farm, modelling, literature data sources
Project reporting	Frequency of reporting	Frequency, data management, responsibility for verification and reporting, certification bodies, standards for certification bodies
	Other aspects of reporting	Templates, data management tools, farmer records, dispute or complaints
Quantification - measurement, monitoring and modelling	Soil sampling	Sampling strategy, min. depth, sampling to depth
	Soil carbon stock measurement	SOC% analytical methods, calculations, bulk density
	Modelling: SOC stock and GHG emissions	Approved models, soil GHGs, non-soil GHGs, model approval, reference datasets, emission factors, calibration, validation, timescales
	Uncertainty	Model, sampling, analytical
Credit issuance and risk mitigation	crediting period	Qualifying payments, start of crediting period
	Retrospective crediting	Past soil carbon credits
	Credit unit	Name
	Uncertainty	Is this reflected in credit issuance
	Buffer/clawback/insurance	Are buffer funds required
Market-place	Buyers	How are units sold, buyer information, know your buyer
Market-value	Price	Carbon prices, how are prices determined, floor price guarantee
	Payment schedule	Payment triggers, project payments
	Project costs	Project registration and operation costs, credit transaction fees, financial support, project account costs, other project costs e.g. farm management

of each code, to ensure systematic analysis of each code.

A single researcher conducted the second thematic analysis to ensure consistency across the codes, and the extracted data was tabulated and managed in Microsoft Excel. Key similarities and differences between the codes with each of the five domains were then identified by comparing each component of the codes in turn. The framework is based on domains and components typically found in codes, and as such the framework may be adapted for use in comparative analyses of codes developed for other land uses and habitats. Following completion of the analyses, code owners were contacted to review content, provide feedback and gap fill if/where appropriate. The initial selection of the code documents started in 2019 and was completed in March 2020. Final selections were reviewed in early 2021 with additional documents added to reflect new geographies and significant revisions to existing code documentation. In total 12 MRV methods were selected for review from 8 different owner organisations. Each of these was allocated a short-hand descriptor which has been used throughout the paper.

Table 2a presents the first analytical domain of the framework which lists the selected MRV methods along with related details including the short-hand descriptor, version and completion status. Documents for the MRV methods and a route to relevant documentation from the affiliated codes were available from the URL links provided. Although terminology varied across the methods and codes, consistent relationships between MRV methods, Codes and the marketplace could be determined which is illustrated in Figure 1 as a

Table 2a. Analytical framework – documentation for the soil carbon MRV methods reviewed.

MRV method: documentation

Title	Version year	Reference	Source URL	Status	Short-hand descriptor for MRV/code
Measurement of Soil Carbon Sequestration in Agricultural Systems) Methodology Determination 2018	2018	[17]	www.cleanenergyregulator.gov.au/ERF/Pages/Choosing%20a%20project%20type/Opportunities%20for%20the%20land%20sector/Agricultural%20methods/The-measurement-of-soil-carbon-sequestration-in-agricultural-systems-method.aspx	Approved	AU1
2021 Soil carbon method: proposed new method under the Emissions Reduction Fund	2021	[18]	https://consult.industry.gov.au/soil-carbon-method-proposed-new-method	Consultation (approved 12/2022)	AU2
Protocol for Measurement, Monitoring, And Quantification of The Accrual of Below-Ground Carbon Over Time	2021	[19]	https://static1.squarespace.com/static/611691387b74c566a67f385d/t/6127d43cbc940c49c7b6cfdc/1630000191203/082621_Metrics_Protocol.pdf	Approved	BC
Soil Enrichment Protocol V1.0 September 2020	2020	[20]	www.climateactionreserve.org/wp-content/uploads/2020/10/Soil-Enrichment-Protocol-V1.0.pdf	Approved	CAR
Soil Organic Carbon Framework Methodology. Version 1.0. Published January 2020	2020	[21]	https://globalgoals.goldstandard.org/402-luf-agr-fm-soil-organic-carbon-framework-methodolgy/	Approved	GS
A protocol for measurement, monitoring, reporting and verification of soil organic carbon in agricultural landscapes	2020	[22]	https://doi.org/10.4060/cb0509en	Approved	GSOC
Carbon Agri Method, September 9, 2019	2019	[23]	www.ecologie.gouv.fr/sites/default/files/M%C3%A9thode%20%C3%A9levages%20bovins%20et%20grandes%20cultures%20%28Carbon%20Agri%29.pdf	Approved	LBC1
Field Crop Method, July 23, 2021, V1.1	2021	[24]	www.ecologie.gouv.fr/sites/default/files/M%C3%A9thode%20LBC%20Grandes%20cultures.pdf	Approved	LBC2
Pilot Croplands Methodology Version 1.2 Last Updated: March 05, 2021	2021	[25]	https://storage.googleapis.com/nori-prod-cms-uploads/Nori_Croplands_Methodology_1_2_5435488110/Nori_Croplands_Methodology_1_2_5435488110.pdf	Pilot	NORI
Adoption of Sustainable Agricultural Land Management. VM0017 Ver.1.0, Sectoral Scope 14	2011	[26]	https://verra.org/wp-content/uploads/2018/03/VM0017-SALM-Methodolgy-v1.0.pdf	Approved	VM17
Soil Carbon Quantification Methodology. VM0021. Ver.1.0, Sectoral Scope 14	2012	[27]	https://verra.org/wp-content/uploads/2018/03/VM0021-Soil-Carbon-Quantification-Methodology-v1.0.pdf	Approved	VM21
VM0042 Methodology for improved agricultural land management Ver.1.0 Sectoral Scope 14	2020	[28]	https://verra.org/wp-content/uploads/2020/10/VM0042_Methodology-for-Improved-Agricultural-Land-Management_v1.0.pdf	Approved	VM42

Y = yes; N = no; – = not stated.

generic operational framework for soil carbon projects using MRV methods and soil carbon codes. A glossary of common terms used by code is included in the supplementary material to aid interpretation of the results.

Results

Code context

Documentation and approval status

Table 2a outlines the MRV method documentation source and approval status. Although the earliest codes date from 2011/12 (VM17&21), the majority have been approved for use since 2018 (9 codes), with 1 code in consultation (AU2) and the majority (6) approved in 2020 and 2021. Prior to approval, the codes have undergone various development pathways which have included evidence reviews and analyses, independent engagement, and, in some instances, field-based pilots [29]. All codes are approved for use under the auspices of an "owner" organisation with approval processes generally including external consultation and stakeholder engagement (Table 2b). Codes are distinctive with respect to their associated structures, processes and documentation. Two codes, GSOC and BC, sit in programmes solely focussed

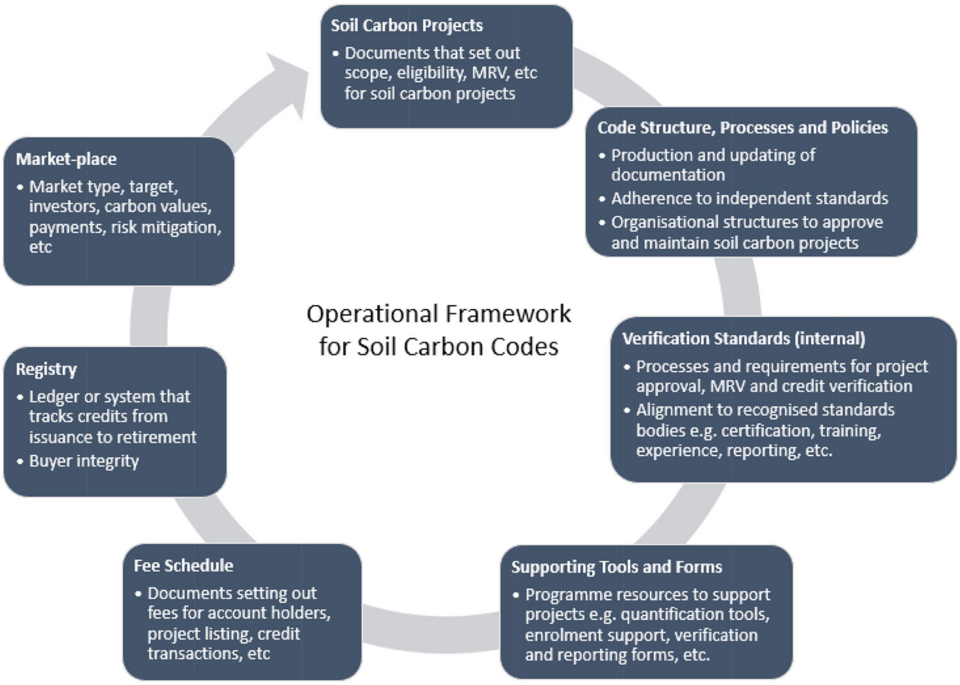


Figure 1. A generic operational framework for a soil carbon code.

on soil carbon sequestration with relatively few additional documents. The remaining codes sit in broader programmes associated mainly with government initiatives (France and Australia) or CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation) approved offset programmes. These programmes all have highly detailed processes and structures with interrelated documentation which often umbrella several codes of which soil carbon is one. For example, the assessment of VM21 alone included 18 interrelated documents.

Ownership, alignment and complaints/disputes

Of the eight owner organisations, for the 12 codes reviewed (Table 2b), 4 were not-for-profit, two were national governments (Australia and France), 1 was commercial (NORI) and another an intergovernmental organisation (UN FAO). Most codes (8) were affiliated to recognised standard setting bodies and aligned with national legislation. Where indicated, organisations used recognised international and/or national standard setting bodies (e.g. ISO, ASEA) with ISO14606 and ISO14044 referenced. It is important to note that these alignments indicate adoption of auditable independent performance standards as opposed to programme “standards” which are widely used to indicate a carbon programme with rules and procedures. Half of the codes provided accessible information on procedures for dispute resolution and complaints, while most codes provided information on conditions for disqualification during the project contract period.

Intended geographic coverage and active projects

Half of the codes were developed for country-specific (5 codes for France, Australia, USA) or regional application (CAR for Mexico, USA and Canada) while the other half were open or globally applicable (Table 2c). By accessing registry information at the time of review, 7 codes had been used by >120 active projects to generate soil carbon credits in Australia (110), France (1), USA (13), South Africa (1), Kenya (1) and India (1). These reflect 3 country (AU, NORI, LBC), 1 regional (CAR) and 3 global codes (VM17, VM42 and BC). Where stated, active projects ranged from several thousand to millions of hectares with 6,700 to 34,700 credits issued. Registries also indicated that there were many more projects in development using the codes reviewed in a variety of circumstances around the world.

Soil carbon scope

Various terms have been used to define the intended scope of the codes (Table 2c), including net abatement, soil carbon sequestration, soil carbon stock gain, and reduction in soil GHGs. The terms reflect, amongst other things, different affiliations, historical contexts, goals, methods and approaches. Gains in soil carbon stocks are treated as soil carbon sequestration while net abatement is the combination of an increase in soil carbon stocks

Table 2b. Analytical framework – context for the soil carbon MRV methods reviewed.

	Context				
MRV method abbrev.	Name of overarching code	Owner organisation	Code sponsors	Market approval for code	Code aligned to recognised Standards relating to emission reductions
AU1	Carbon Farming Initiative	Australian Clean Energy Regulator	National government	Australian Government Carbon Credits (Carbon Farming Initiative) Act 2011	ASAE 3000-3100-3410; ASQC 1; ISO 14064-3:2006
AU2	Carbon Farming Initiative	Australian Clean Energy Regulator	National government	Australian Government Carbon Credits (Carbon Farming Initiative) Act 2011	ASAE 3000-3100-3410; ASQC 1; ISO 14064-3:2006
BC	The BCarbon Standard	Bcarbon Inc.	Not for profit	–	–
CAR	Climate Action Reserve Voluntary Offset Program	Climate Action Reserve	Not for profit	CORSIA, Approved Offset Project Data Registries in California	ISO 14064
GS	Gold Standard for Global Goals	Gold Standard	Not for profit	CORSIA	–
GSOC	RECSOIL	UN-FAO	UN	–	–
LBC1	Label Bas Carbone	Ministry of Ecological Transition, French Government	National government	French Government – 'National Low Carbon Strategy'	ISO 14044 for Livestock Assessments
LBC2	Label Bas Carbone	Ministry of Ecological Transition, French Government	National government	French Government – 'National Low Carbon Strategy'	–
NORI	NORI Carbon Removal Marketplace	NORI Inc. USA	Commercial	–	ISO 14064
VM17	Verified Carbon Standard Program	VERRA	Not for profit	CORSIA, Approved Offset Project Data Registries in California	–
VM21	Verified Carbon Standard Program	VERRA	Not for profit	CORSIA, Approved Offset Project Data Registries in California	–
VM42	Verified Carbon Standard Program	VERRA	Not for profit	CORSIA, Approved Offset Project Data Registries in California	ISO 14064-14065

Y = yes; N = no; – = not stated.

plus a reduction in direct soil GHGs. Therefore, based on MRV details in the documents, eight codes adopted a combined soil C sequestration and GHG approach while two addressed soil GHGs only (VM17 & VM21; although VM17 indicated that soil C sequestration could be included once suitable MRV methods were approved) and two (NORI and BC) focussed on soil carbon sequestration only.

Allowable approaches to the quantification of soil carbon stock included options for the use of Intergovernmental Panel on Climate Change (IPCC) emission factors (GHGs; [1]), measurement (soil C stocks), modelling (soil C stocks and/or soil GHGs) or a hybrid combination of measurement and modelling (soil C stocks and soil GHGs). Four codes stipulated a single approach: modelling (NORI (soil C stocks), LBC1) or hybrid (LBC2 and GSOC). The remaining codes allowed various combinations of measurement, modelling, hybrid and IPCC emission factors. Allowable approaches had significant influence on all aspects of a code from eligibility, measurement, monitoring, reporting through to credit verification. (Table 2c).

Project eligibility

Project ownership and land relationships

Project owners include third party project developers, farmers or landowners (Table 2d) with the common requirement that projects had legal right to the land either through property ownership or contractual obligations between project developers and farmers or landowners. Projects could be implemented by either the landowner or a farmer leasing the land if they had agreement with the landowner for the duration of the permanence contract. In general projects were contracted to the relevant registries to deliver reporting and verification and to ensure permanence and contracted to buyers/investors to deliver verified soil carbon credits.

Eligible land use and practices

Croplands and grassland (often including rangeland) were the most common eligible land uses (Table 2d), whether in a combination (8 codes) or covered by separate methods for croplands and

Table 2c. **Analytical framework – scope for the soil carbon MRV methods reviewed.**

	Scope									
	MRV Scope			Project activity using MRV methods						
MRV method abbrev	Soil carbon impact (terminology used)	Quantification approach	Intended geographic coverage	Active projects	Locations of active projects	Tonnes CO2e	Area covered (ha)	Fields	Verified credits issued	Credits retired
AU1	Net abatement	Measure, model or hybrid	Australia	110	Australia	–	–	–	–	–
AU2	Net abatement	Measure or hybrid	Australia	–	–	–	–	–	–	–
BC	Soil carbon sequestration only	Measure + model	Open	1	USA	–	–	–	34,700	Planned
CAR	GHG (eCO2) reductions	Hybrid	USA, Mexico, Canada	2	USA	–	4.6 million	56,888	Planned	–
GS	Soil carbon sequestration + reduced GHG emissions	Measure / model / emission factors	Global	–	–	–	–	–	–	–
GSOC	Soil carbon sequestration + reduced GHG emissions	Hybrid	Global	–	–	–	–	–	–	–
LBC1	Soil carbon sequestration + reduced GHG emissions	Measure + model	France	1	France	137,936	–	–	–	–
LBC2	Soil carbon sequestration + reduced GHG emissions	Measure + model	France	–	France	–	–	–	–	–
NORI	Soil carbon stock gain	Model	USA	10	USA	–	–	–	>6760	–
VM17	Greenhouse gas emission reductions	Model/emission factors	Global	2	India, Kenya	132,768 pa	22,966	–	Y Unknown N	325,825
VM21	Greenhouse gas emission reductions	Measure/model/hybrid/ emission factors	Global	–	–	–	–	–	–	–
VM42	Greenhouse gas (GHG) emission reductions and removals	Measure/model/hybrid/ emission factors	Global	1	South Africa	1,887,500	4,361,997	–	Planned	–

Y = yes; N = no; – = not stated.

grassland. Additional land uses included: bare fallow (AU1 and AU2), orchards and vineyards (NORI) and agroforestry (GSOC). BC left eligible land uses open to any agricultural land use. Ineligible land uses included forested lands, restored or protected areas, wetlands, and land with histosol (peat) soil types. In some cases, there was also consideration of ineligible land use change e.g. time since conversion to cropland or change from permanent pasture.

The definition of eligible management practices differed across the codes. GS specified a single option of tillage while the Australian codes provided defined lists of practices from which at least one must be adopted e.g. cover crops or reduced tillage. Most codes (9) had a less prescriptive approach with eligible categories where one or more practice or management change was required e.g. fertiliser use, water use, tillage, organic amendments, crop types, rotations. BC had an open approach with no eligibility rules for management practices. Ineligible practices range from specific management practices (e.g. biochar for LBC1 from 2022 and overgrazing, removal of perennial vegetation for GSOC) to default ineligibility if not included on the specified or defined eligible list or if considered negative by other rules (e.g. additionality rules for CAR). Demonstrating that projects would result in "no net harm," or avoidance of social, economic and environmental impacts, was specified in 9 codes (Table 2e). This could be demonstrated in various ways from engagement with local stakeholders to environmental risk assessments. In addition, most codes specified that projects should be compliant with relevant national laws and regulations.

Additionality

In all codes, the objective of additionality (Table 2e) was to demonstrate that carbon sequestration and/or reductions in GHG emission associated with the adoption of new management practices would be greater than "business as usual" and would not happen without incentives from the carbon markets. While there were consistent criteria for additionality across most codes, the details within these varied considerably. Most (10 codes) required that practice(s) be new to the project and not common to a region. Most codes required financial and legal additionality tests (8 and 7 respectively) to show that new practices were not viable without carbon finance or already required by law (CAR, GS, 3 VM, both LBC and GSOC). In some cases, an investment analysis was required to prove that the activity was not economically viable without generating carbon credits (GSOC, VM21 & VM42). Various tools were provided or suggested for this, ranging from bespoke investment analysis tools to approaches such as investment comparison analysis, benchmark analysis or a simple cost analysis. BC took a simpler approach, stating that "if a landowner can prove that they are adding atmospheric carbon to the soil or trees, they have a right to sell that stored carbon," whether they would have made these changes anyway or were compelled to do so by law.

Co-benefits and stacking

Most codes (8) indicated that co-benefits were added value to a project (Table 2e). While CAR allowed stacking of funding from other sources for co-benefits (e.g. improved water quality, reduced flood risk), the other codes did not explicitly state whether they allowed "stacking" of other funds and BC stated that it did not allow stacking. The potential for co-benefits, for example biodiversity gains, water or soil health improvements, job creation, regional dynamism as outlined in the French codes (LBC1 and LBC2), could be used to improve the prospects of project funding. For example, both French codes supported listing of co-benefits in their carbon registry to allow funders to compare projects, with the expectation that projects with significant co-benefits were likely to attract funding more easily. In other instances, there are options for the application of additional certification standards to demonstrate co-benefits which can be marketed and sold in other marketplaces.

Permanence, leakage and reversals

All but one code (BC) addressed leakage and reversals to varying degrees (Table 2e); BC considered leakage and reversals to be unlikely with no rules regarding productivity losses. Leakage and reversal rules ranged from monitoring project areas and activities, for example, movement of livestock, land use change, externally sourced organic amendments, liming, removal of woody materials, soil disturbance and redistribution, irrigation controls and productivity loses. Generally, unintentional carbon reversals were taken from credit buffers unless a reversal was intentional which could require compensation payments by the project. GSOC did not distinguish between intentional and unintentional reversals, only requiring reversals over $>10\%$ of the project area to be reported. For others, there

Table 2d. Analytical framework – eligibility and rules for project relationships, land use and management for the soil carbon MRV methods reviewed.

	Eligibility/Rules					
	Project relationships		Land use		Management practices	
MRV method abbrev.	Project owner	Project-land	Eligible	Ineligible	Eligible	Ineligible
AU1	Open	Legal right	Cropland, grassland, bare fallow	Y	Defined list	Y
AU2	Open	Legal right	Cropland, grassland, bare fallow	Y	Defined list	Y
BC	Farmer, landowner, commercial	Legal right	Open	–	Open	–
CAR	Project developer	Legal right	Cropland, grassland, (inc. managed rangeland or pasture)	Y	Open	Y
GS	Farmer/ project developer	Legal right	Cropland, grassland,	Y	Single (tillage)	Y
GSOC	Open	–	Cropland, grassland, other (agroforestry, etc)	Y	Categories	Y
LBC1	Farmer/ project developer	Legal right	Grassland	–	Categories	–
LBC2	Farmer/ project developer	Legal right	Cropland	–	Categories	–
NORI	Open – farmer preferred	Legal right	Cropland (inc. orchards and vineyards)	Y	Categories	Y
VM17	Project developer	Legal right	Cropland, grassland, rangeland	Y	Categories	–
VM21	Project developer	Legal right	Cropland, grassland, rangeland	Y	Categories	Y
VM42	Project developer	Legal right	Cropland, grassland, rangeland	Y	Categories	Y biochar ineligible from 2022

Y = yes; N = no; – = not stated.

could be credit deductions or discounting if leakage or reversals were significant. CAR determined that the risk of leakage was low but provided protection from two specific scenarios – displacement of livestock and sustained yield decline,

There was a large difference between codes in the requirements for permanence i.e. after the crediting period of a project has ended (Table 2e). Ten codes stipulated that permanence was required for a defined period which ranged from 8 years (GSOC), 10 years (NORI and BC), up to 25 years (AU1 and AU2) and up to 100 years (CAR and all three VM codes), all supported by periodical regular monitoring and reporting (Tables 2f and g). Three codes (GS, LBC1 and LBC2) adopted a different approach where there was no specified permanence period but instead applying specified credit discounts over the project period to account for post-project non-permanence, leakage and reversals; up to 20% for GS or up to 10% for either LBC (Table 2e).

Project administration

Project account and registration

The process of setting up a new soil carbon project typically involved opening an account with a code owner organisation with affiliated registries. This is the case for all codes reviewed except GSOC where there is no associated registry at present (FAO) (Table 2f). After registration, a proposed project would prepare all relevant documentation to demonstrate that the project met eligibility requirements, a reliable baseline had been established and verifiable carbon credits could be generated from the methods used. Two codes (CAR and GS) listed projects publicly after an initial review of eligibility (and submission of a draft project design document and stakeholder consultation report in the case of GS) before projects were formally registered after the first verification report had been accepted.

Project approval

Projects were reviewed and approved (Table 2f) through internal processes (both AU, BC and both LBC) or internal plus independent processes (3 VM, GS, CAR) with all codes assessing project eligibility, defined project boundaries, including "temporal boundaries" (start/end dates), and maps showing boundaries of all eligible land at the start of the project, from entire farms, individual parcels of land within a farm or multiple farms/fields across a region. BC also required these maps to show soil types. In CAR and VM21, project boundaries focussed on GHG sources or carbon pools, rather than physical boundaries, unless these are relevant to the calculation of soil GHGs. Soil carbon stock/GHG emission baselines and intervention scenarios for change were required as part of project approval for all codes. Whether this required modelling with or without measurement (of soil carbon stocks) would depend on the code's allowable approaches and project scope. In all instances, records for past land use and management were required along with details on the strategy for adoption of eligible management. For AU codes, all this information would be contained in a land management strategy (including assessment of limitations and risks), (Table 2f). All codes required details on planned monitoring and record keeping to the end of the permanence period and an assessment of anticipated carbon credits (Table 2g). A pre-implementation additionality assessment typically formed part of the validation processes in all the codes reviewed.

Measurement, reporting and verification (MRV)

The collection of MRV data was a common requirement in all codes. Project MRV costs differed greatly between projects but were difficult to establish in full reflecting, amongst other factors, commercial contracting arrangements, methods used and local economies. However, MRV costs would be greatest for a project with permanence of 100 years compared to a project with permanence of 8 years or a fixed discount. In recognition of the potential barrier from MRV costs, the Australian Government offered grants to support SOC stock baseline measurement costs for projects following both AU codes (see Table 2g).

Baselines

Baselines at the start of a project are the foundation for all MRV activities, whether SOC stocks and/or soil GHGs. There were three generic approaches to setting project baselines across 10 codes: fixed, fixed average and dynamic (Table 2g). Fixed and fixed average baselines were set at the project start prior to new management; fixed baseline (GSOC, AU1, AU2) was determined for each field while fixed average baselines (LBC1, LBC2, GS, VM17) were determined from a sub-sample of fields. Dynamic baselines (VM42, NORI, CAR) would be re-evaluated as part of MRV and revised, if necessary, to reflect changed circumstances in the project or project region. BC did not specify a specific approach for baselines, instead projects would be required to demonstrate that an appropriate approach.

In all cases, setting baselines was reliant upon the amount, quality and period of data available for a field, farm, region and country (Table 2g). Most codes specified that historic data was required, varying from 3, 4, 5 to 10 years prior to project commencement or, for 1 code (VM42), for at least 1 full rotational cycle. For all codes except AU1 and AU2, projects could use other data sources to supplement project specific data in setting baselines e.g. scientific literature and IPCC emission factors. All codes required modelling for baselines and quantification to be calibrated to a project's local conditions.

Project delivery of MRV

Most of the codes (11) required projects to deliver MRV on a regular basis, typically between 1 and 5 years (Table 2g). CAR and GS indicated MRV after a full cropping cycle while NORI required annual, plus a 10 yearly average MRVs. All MRV required farm and field management records as well as quantification of soil carbon stocks and/or soil GHGs. Most codes provided data reporting templates to aid in the collection of data (GSOC, CAR, GS, NORI, 3 VM and both LBC codes.) although for some these were intended to guide reporting and use was not a stipulation. In all cases, aspects of MRV had to be maintained at defined intervals until the end of the contracted requirements which could be the project end (NORI, GS, VM17, VM42, LBC1, LBC2) or duration of the permanence period (AU1, AU2, CAR).

Methods to quantify soil carbon sequestration and/or GHG reductions differed across the codes (Table 2h), partly reflecting allowable approaches and carbon scope in combination with experiences, affiliations, and evidence for using particular techniques, models and analyses. Quantification of uncertainty from measurement and modelling was also addressed to varying degrees and reflected in crediting e.g. buffers, insurance, clawbacks, discounting (as outlined above). Direct measurement of soil carbon stocks was required in all codes except NORI, which used a modelling soil metrics platform alone and VM17 which only quantified soil GHGs. The minimum soil depth for the quantification of soil carbon stocks was predominately 0 to 30 cm. BC specified no set soil depth while GS allowed a depth of 0-20 cm for a particular method. Four methods (GSOC, AU1, AU2, CAR) indicated that a SOC stock depth beyond 30 cm and up to 100 cm was ideal, corresponding to IPCC guidance. Specifications for laboratory analyses for SOC content (%) and bulk density were covered in varying degrees of detail with respect to allowable methods, quality control and measurement errors. For example, the Australian codes allow the use of either combustion or spectral methods with suitable calibration whilst 4 codes recommended dry combustion as the only method for the determination of soil carbon content (GSOC, CAR, VM21, VM42, BC). Three codes indicated that the soil carbon stock could be determined using the "equivalent soil mass" either in addition to (GSOC, BC) or instead of (AU2) the traditional and widely used "fixed depth" method of multiplying SOC concentration by bulk density to a fixed soil depth. The equivalent soil mass method is recommended for comparing SOC stock changes in managed ecosystems, to overcome the effect of bulk density changes that commonly occur from implementing new management practices [30].

Modelling soil GHGs (baselines and potential reductions) and/or potential soil carbon sequestration also varied across the codes (Table 2h). Four codes prescribed the use of specific models or modelling platforms (e.g. RothC for VM17, Soil Metrics for NORI, CAP'2ER® for LBC1 and LBC2). Other codes indicated that the model selection was open to suitable models that met calibration and validation requirements (e.g. CAR, VM42, GS, GSOC and BC). All codes required calibration and validation to local circumstances using suitable data although calibration and validation specifications and model approval varied across the codes. For example, reference datasets were mandated in LBC1, LBC2, AU1, AU2, and NORI while CAR and VM codes specified model calibration. Timescales in modelling to predict potential soil carbon sequestration were indicated in three codes (GSOC, NORI and CAR) and open for other codes. For all codes, modelling at regular intervals was required over the duration of the contract or permanence period.

Commercialisation

Registries, crediting periods and credit issuance

All registries affiliated with codes and code owner organisations issued their own carbon credit units

Table 2e. Analytical framework – eligibility and rules for additionality, permanence and other rules for the soil carbon MRV methods reviewed.

	Eligibility and rules										
	Additionality					Permanence			Other rules/compliance		
MRV method abbrev.	Management in surrounding region	Management in project boundary	other finance options	legal matters	other barriers	period - years or other	Leakage rules	Reversal rules	social or environ-mental harm	regulation or ethical considerations	co-benefits
AU1	Y	Y	–	–	–	25 or 100	Y	Y	Y	Y	–
AU2	Y	Y	–	–	–	25 or 100	Y	Y	Y	Y	–
BC	–	–	–	–	–	10	–	–	Y – social	–	–
CAR	Y	Y	Y	Y	Y – social norms	100	Y	Y	Y	Y	Y – stacking *via* SDG tool
GS	Y	–	Y	Y	–	Fixed 20% buffer	Y	Y	Y	Y	Y – stacking using SDG
GSOC	Y	Y	Y	–	Y	8	Y	Y	–	–	–
LBC1	Y	Y	Y	Y	Y	Other	Y	Y	Y	–	Y – listed co-benefits
LBC2	Y	Y	Y	Y	Y	Other	Y	Y	Y	–	Y – listed co-benefits
NORI	–	Y	–	–	–	10	Y	Y	–	–	Y – listed as other ecosystem C benefits
VM17	Y	Y	Y	Y	Y	100	Y	Y	Y	Y	Y – stacking *via* VERRA
VM21	Y	Y	Y	Y	Y	100	Y	Y	Y	Y	Climate, community and
VM42	Y	Y	Y	Y	Y	Max. 100	Y	Y	Y	Y	biodiversity standard

SDG = sustainable development goals. Y = yes; N = no; – = not stated.

Table 2f. Analytical framework – project administration using the soil carbon MRV methods reviewed.

	Project – registration and contracting										
	Registration process			Project contract and policies						Complaints /disputes	
MRV method abbrev.	Registration review process	Registration costs	URL links to registry	Project contract duration	Land Management Strategy	Data ownership	Data disclosure	Changes allowed during project term	Changes to practices allowed	Procedures for dispute resolution and complaints	Project disqualification conditions
AU1	Internal	–	https://regulatoryportal.asic.gov.au/	Permanence period	Y	–	–	Y	Y	–	Y
AU2	Internal	–	https://regulatoryportal.asic.gov.au/	Permanence period	Y	–	–	Y	Y	–	Y
BC	Internal	Y	BCarbon blockchain registry	Min 10 years	–	–	–	Y	Y	–	Y
CAR	Internal + independent	Y	https://thereserve2.apx.com/myModule/rpt/myrpt.asp?r=111	Permanence period (usually)	–	Y	Y	Y	Y	Y	Y
GS	Internal + independent	Y	https://registry.goldstandard.org/projects?q=&page=1	5 yrs renewable	–	–	Y	Y	–	Y	Y
GSOC	–	–	–	–	–	–	–	–	–	–	–
LBC1	Internal	–	https://www.ecologie.gouv.fr/label-bas-carbone#scroll-nav__3	Min 5 yrs	–	–	Y	Y	Y	–	Y
LBC2	Internal	–	https://www.ecologie.gouv.fr/label-bas-carbone#scroll-nav__3	Min 5 yrs	–	–	Y	Y	Y	–	Y
NORI	Internal	–	https://nori.com/registry	Project duration (10 yrs)	–	Y	Y	Y	Y	Y	Y
VM17	Internal + independent	Y	https://registry.verra.org/	Project duration	–	Y	Y	Y	Y	Y	Y
VM21	Internal + independent	Y	https://registry.verra.org/	–	–	Y	Y	Y	Y	Y	Y
VM42	Internal + independent	Y	https://registry.verra.org/	Project duration	–	Y	Y	Y	Y	Y	Y

Y = yes; N = no; – = not stated.

Table 2g. Analytical framework – project baselines and reporting for the soil carbon MRV methods reviewed.

	Project – baselines								Project reporting					
	Setting the baseline		Allowable data sources						Frequency of reporting			Other aspects of reporting		
MRV method abbrev.	Baseline type	Historical look-back for baseline	Regional data	Farm records	Modelling	Scientific literature	Grants or other financial support available	Project/farm records (years)	Measured SOC stocks	Modelled GHGs/ SOC stocks	Are reporting templates provided	Data management tools provided	Do farmers have to keep records
AU1	Fixed	3–10	Y	Y	Y	–	Y up to AU$5000	1–5	$\leq$5	1–5	Y	–	Y
AU2	Fixed	3–10	Y	Y	Y	–		1–5	$\leq$5	1–5	Y	–	Y
BC	Open	3–10	Y	Y	Y	Y	–	–	$\leq$5	–	–	–	Y
CAR	Dynamic ('matched' or "blended")	Min 3, must include 1 full crop rotation	Y	Y	Y	Y	–	1–5	$\leq$5	$\leq$5, typically after a cropping cycle	Y	Y	Y
GS	Fixed average	Min 5	Y	Y	Y	Y	–	Annual and 5	At performance certification, depending on approach		Y	Y	Y
GSOC	Fixed	3–10	Y	Y	Y	Y	–	5–10	$\leq$5	1–5	–	–	Y
LBC1	Fixed average	4	Y	Y	–	Y	–	5	$\leq$5	$\leq$5	–	–	Y
LBC2	Fixed average	3	Y	Y	Y	Y	–	5	$\leq$5	$\leq$5	–	–	Y
NORI	Dynamic	up to 5	Y	Y	Y	Y	–	1–5	$\leq$3	Yearly and 10-year averages	Y	Y	Y
VM17	Other -model equilibrium	5 for most	Y	Y	Y	Y	–	Annually	–	Part of project sampling plan	Y	–	Y
VM21	Fixed average	–	Y	Y	Y	Y	–	Intervals of $\leq$5	$\leq$5	$\leq$5	Y	–	–
VM42	Dynamic – matched or blended	Min 3, must include 1 full crop rotation	Y	Y	Y	Y	–	Intervals of $\leq$5	$\leq$5	$\leq$5	Y	–	Y

Y = yes; N = no; – = not stated.

Table 2h. Analytical framework – quantification for the soil carbon MRV methods reviewed.

	Quantification – measurement and modelling																			
	Soil sampling			SOC stock baseline and monitoring				Modelling: SOC stock and/or GHG emission baseline and potential change										Uncertainty		
MRV method abbrev.	Defined sampling strategy	Minimum depth (cm)	Sampling (cm) below 30 cm	SOC% analytical methods	Stock calculations defined	Calculations	Soil bulk density determination method	Which models are approved	Direct soil GHG emissions included	Are non-soil GHG emissions sources covered?	How are models approved	Reference databases mandated	Emission factors allowed	Model calibration defined	Model validation mandated	Historical timescale - baseline models (years)	Quantification timescales (years)	Model uncertainty defined	Sampling uncertainty defined	Analytical uncertainty defined
AU1	Y	30	to 100	DC or spectral	Y	FD	C or GR	Defined calculations	CO_2/ N_2O/ CH_4	Y	I	Y	Y	–	–	10	–	–	Y	Y
AU2	Y	30	to 100	DC or spectral	Y	ESM	C or GR	Defined calculations	CO_2/ N_2O/ CH_4	Y	–	Y	Y	–	Y	5	–	–	Y	Y
BC	Y	Open	100	Open[P]	Y	FD or ESM	C	Open	–	–	I	–	–	–	–	–	–	–	Y	–
CAR	Y	30	100 ideal	DC	Y	FD	C	Open	$CO_2/N_2O/CH_4$	Y	I + ID	–	Y	Y	Y	Min 2 (1 crop cycle)	10 or credit period	Y	Y	Y
GS	Y	20 or 30	50 cm pits	DC, spectral or VM42	Y	FD	Open	Open: RothC, Century mentioned	CO_2 /N_2O/CH_4	Y	I	Y	Y	–	Y	–	–	Y	–	–
GSOC	Y	30	100	DC, WB spectral[a]	Y	FD & ESM	C	Open	$CO_2/N_2O/CH_4$	Y	–	–	Y	–	Y	–	20	–	–	–
LBC1	–	–	–	–	–	FD	–	CAP'2ER®	$CO_2/N_2O/CH_4$	Y	I	Y	Y	–	–	–	–	–	–	–
LBC2	Y	30	–	Open[SL]	Y	FD	–	AMG, STICS, MAELIA	CO_2/N_2O	Y	I	Y	Y	–	–	–	–	–	Y	–
NORI	–	–	–	–	–	FD	–	Soil metrics platform	$CO_2/N_2O/CH_4$	Y	ID	Y	Y	–	–	3	10	–	–	–
VM17	Y	–	–	Open[SL]	–	–	–	RothC	$CO_2/N_2O/CH_4$	Y	I	Y	Y	Y	Y	–	–	Y	Y	–
VM21	Y	30	100	Open[SL]	Y	FD	C	DNDC	$CO_2/N_2O/CH_4$	Y	ID	–	Y	Y	Y	up to 5	–	Y	–	Y
VM42	–	30	100 ideal	DC, WB spectral[a]	Y	FD	C	Open	$CO_2/N_2O/CH_4$	Y	ID	–	Y	Y	Y	≥3 + 1 rotation	–	Y	Y	Y

[a]see https://www.fao.org/global-soil-partnership/glosolan/soil-analysis/sops/volume-2-2/en/
WB = Walkley Black; DC = dry combustion; FD = fixed depth; ESM = equivalent soil mass; [SL] = standard lab procedure; I = internal; ID = independent; C = conventional; GR = gamma radiation; [P] = prior approval required. Y = yes; N = no; – = not stated.

Table 2i. Analytical framework – Credit issuance and risk mitigation for the soil carbon MRV methods reviewed.

	Credit issuance and risk mitigation						
	Crediting period		Retrospective crediting	Credit units	Uncertainty	Buffering/Claw back/insurance	
MRV method abbrev.	Period for qualifying payments	What defines the start of the crediting period	Can past soil carbon gains be credited?	Name of credit	Is quantification uncertainty reflected in credit issuance	Are buffer funds required	Discounting arrangements
AU1	25	After baseline	N	Australian Carbon Credit Units (ACCU)	Y	5 or 25% buffer	50%
AU2	25	After baseline	Y; previous methods from 2014		Y	5 or 25% buffer	25%
BC	5	Start of soil carbon sampling	N	–	–	–	–
CAR	10 to 30 (3 credit periods of 10 yrs max.)	Start date	Y – up to 2 yrs	Climate Reserve Tonnes (CRTs	Y	Y	–
GS	10	Start date unless postponed	Y – 2 to 5 yrs	Gold Standard Verified Emission Reductions (VER)	Y	20% fixed buffer	–
GSOC	–	–	–	–	Y	Y	–
LBC1	5 yrs	Project notification	N	Unnamed carbon unit	Y	Option of 10% buffer	–
LBC2	5 yrs	Project notification	N		Y		–
NORI	10	Date NRT agreement signed	Y – up to 5 yrs; pre-2019, verifiable farm records	Nori Carbon Removal Tonne (NRT)	Y	Y	–
VM17	20 to 100	Start date	N	Verified carbon unit (VCU)	Y	Y (VCS AFOLU Non-Permanence Risk Tool)	–
VM21	20 to 100	Start date	N		Y		–
VM42	20 to 100	Start date	N		Y		–

Y = yes; N = no; – = not stated.

(Table 2i). Three codes (both AU, NORI) were involved with the direct sale of soil carbon credits whilst 5 codes were not (CAR, GS and 3 VM codes) with credits sold in the wider marketplace through various mechanisms. BC and LBC worked with multiple intermediaries. Project owners (generally termed "project developers) entered into contracts with investors for the payment of credits, and with farmers for subsequent payments where relevant. Projects maintained separate contracts with codes for project operations and permanence requirements.

The crediting period ranged from 5 years to 100 years, with most codes allowing extension beyond the initial period (Table 2i). VM codes credited between 20 to 100 years while AU codes credited for 7 to 25yrs. Two codes (NORI, CAR) credited for 10 years initially with the option to renew or extend. CAR limited renewed crediting to 3 periods i.e. 30yrs. Three codes credited for 5 years: both LBC codes and BC. Retrospective crediting was allowable in 3 codes (Table 2i); up to 5 years (NORI and GS) or from a specific date relating to preceding MRV method (AU2). For all other codes, retrospective crediting was either not allowable (8 codes) or not considered (GSOC).

With VM and LBC, verified credits could be requested after the initial project validation in the understanding that these could be withdrawn later if verification reports showed that the project had failed to deliver sufficient carbon sequestration. Payments to projects, where indicated, were made at either verification of carbon abatement (AU), when credits units were sold (NORI) or at 5 years or earlier (BC). Risk mitigation was a key aspect of the market with uncertainty in soil carbon sequestration affecting remuneration in different ways. Various tools and approaches were being used to quantify and manage risk, with most codes using buffers to manage this. Some codes operated "know your customer" background checks before buyers were allowed to open accounts e.g. to ensure "good legal standing," (NORI and VM, Table 2j).

Credit units, uncertainty and verification

One t CO_2e (sequestered in soil C stocks and/or from reduced soil GHGs) equated to 1 soil carbon credit unit across all codes (Table 2j). Credits issued by all codes addressed uncertainties in soil GHGs and/or soil carbon stocks. Uncertainties reflected various sources from leakages and reversals to

Table 2j. Analytical framework – Market-place and value with reference to projects applying the soil carbon MRV methods reviewed.

	Market-place					Market – value						
	Buyers			Price				Payment schedule		Project costs		
MRV method abbrev.	How are units sold	Buyers identified	Know your customer	Carbon price at time of review	Information on how carbon prices are determined	Carbon floor price guarantees	What triggers payments to projects?	Payments to the project	Costs for registering and operating a project	Credit transaction fees	Project account costs	Other project costs e.g. farm management time
AU1	Code auction or direct sales	Y	–	1 ACCU = AU $19.00	Y	Y	After each report demonstrating carbon abatement	Nominated accounts	Y	–	–	–
AU2		Y	–	–	Y	Y			Y	–	–	–
BC	Open	–	–	–	–	–	5 yrs (modelling may support interim credits)	–	Y	$0.15 / transaction on blockchain registry	$1 / acre registered per year	–
CAR	Open	Code not involved in selling							Y	–	>$3500	Y – illustration available
GS	Open	Code not involved in selling							Y	–	>$1000	review fees $900 /$1000
GSOC	–	–	–	–	–	–	–	–	–	–	–	–
LBC1	Open	–	–	–	–	–	3 options	–	Y	–	–	–
LBC2	Open	–	–	–	–	–	3 options	–	Y	–	–	–
NORI	FIFO queue	Y	Y	1 -NRT = $15 + 1 NORI token	Y	Y	Selling NRTs in FIFO queue triggers payment	Nominated accounts	Y (only verific-ation)	15% transaction fee on the sale price NRT.	Verification c. $5000	Estimated in project proposal
VM17	Open	Code not involved in selling						–	Y	–	>USD8,000	Y
VM21	Open							–	Y	–	Fees: opening $500, registration levied, capped $10,000, verification	Y
VM42	Open							–	Y	–	>$8,000	Y

Y = yes; N = no; – = not stated.

insufficient scientific evidence, measurement differences, modelling variabilities, etc. Most codes (10) accounted for these through the credit verification process (Table 2i). The simplest approach was the application of a fixed discount to all project credits to account for all and any uncertainties over the duration of a project (e.g. GS, LBC1 and LBC2). All codes except GSOC accounted for uncertainty by using some form of carbon credit reductions using a range of approaches including buffers, risk tools and discounting,. AU1 and AU2 applied temporary discounts to soil carbon credits by reducing initial soil C baselines by 50% or 25%, respectively, based on variability in soil carbon measurements and until more than 2 MRV cycles had been completed. Buffers on credits were generally variable and determined based on local project conditions and using a range of tools including risk mitigation tools (VM codes), project-specific risk rating (CAR) or the MRV methods used (NORI where lower buffers applied to higher quality methods to drive adoption of superior verification approaches). The code operators and registries often retained a proportion of these buffer credits. Credits were generally issued on the basis of MRV at intervals across the contract period and/or permanence period.

All codes required verification prior to the issuance of credits with most codes requiring verification by independent assessors with professional qualifications and accreditation from national or international standards organisations. Generally, a verifier would have no financial, or other, conflicts of interest with the project. Several codes provided a list of approved verification bodies for projects to use. GS operated a separate validation and verification body. For half of the codes, verification audits or summary audits were publicly available (CAR, GS and all VM codes). Quality assurance processes for verification typically conformed to recognised international general standards, such as ISO19011, ISO14064, ISO14065, or national equivalents, as well as IPCC guidance (Table 2b).

Carbon sales and values

Information on the sale, retiral and value of soil carbon credits was inconsistent across the codes, reflecting, in part, different stages of code uptake and implementation and different operations (Table 2j). AU1 and AU2 were run by the Australian Government who ran regular carbon auctions, published previous prices, and allowed units to be resold on secondary markets. NORI ran Dutch-auctions, with a fixed floor price set by the supplier, for pre-qualified buyers and sellers. Other codes made their units available *via* registries which then managed transactions independently of the code (e.g. CAR and all 3 VM codes).

Project costs

The process of setting up a project required payment of various fees at different stages. Each code had a different fee structure while not all fee information was available for all codes and could be adjusted over time (Table 2j). For illustrative purposes, account costs ranged from fixed fees to fees based on project size e.g. $1 per acre registered per year for BC or linked to the number of anticipated carbon units (all VM codes). Account set up fees were $500 for VM codes and CAR, with annual fees $500 for CAR and $1000 for GS. In some codes, there were fees for credit issuance, e.g. $0.19/credit for CAR and $0.14-0.025 for VM codes, and transfer of credits ($0.03/credit CAR). There were additional fees for other services e.g. project variance review ($1350, CAR) and project design review ($1500 GS).

Discussion

The structured framework enabled the consistent collation and summary of details from the extensive documentation associated with MRV methods and associated soil carbon codes in operation around the world. The framework supported useful comparisons of commonalities, divergences, and the reflection on these for adaptation, translation and development of a new code, in this instance the UK Farm Soil Carbon Code. This section discusses the implications of the comparative analysis of existing codes for the development of a new code that could support a growing domestic demand for farm soil carbon projects for different purposes in the context of an established international voluntary carbon market with existing codes and methods.

Governance, ownership and contracting

Deciding who will "own" a code is a vital early step for a new code. Most existing codes are affiliated to owner organisations, with their own registries, which are either independent (for-profit or not-for-profit) or government affiliated. All code owners have common aims to support climate change mitigation using market mechanisms and verified soil carbon credits which are approved through their registries. Therefore, soil carbon codes are developed, approved and operate under the auspices of legally recognised organisations which can maintain governance, assurance and continuity. In the UK, similar structures already exist for the Peatland and Woodland Carbon Codes [31, 32] which use the UK Land Carbon Registry (See https://www.woodlandcarboncode.org.uk/uk-land-carbon-registry) to record transactions from all projects from these codes and provide transparent access to UK-based Woodland and Peatland Carbon Units. These codes operate with financial support from UK Governmental departments and NGOs (and their donors) and are (or in the process of being) affiliated to United Kingdom Accreditation Service (UKAS, https://www.ukas.com/) to support independent, and cost-effective, verification and auditing.

The inclusion of a UKFSCC in the UK Land Carbon Registry would complement existing codes, and codes that are in development, including. Hedgerows, salt marshes, lowland peats, rewilding etc. and would address, in part, concerns over independence, governance and oversight [10, 15]. Farm soil carbon codes supported by national governments in Australia and France are like the UK Peatland and Woodland Codes in that there is a national carbon registry with governance and assurance maintained through national government affiliated organisations. However, opportunities already exist for UK-based farm soil carbon projects to be approved by existing codes and use registries based in the USA (e.g. NORI, VM, CAR, BC). Constraints which limit UK soil carbon projects to a UK registry, with UK-based investment only, could significantly limit the opportunities for farming from the global voluntary carbon market.

A question is therefore why existing codes would engage with the UK Land Carbon Registry. From a government perspective, registering UK soil carbon credits through the UK Land Carbon Registry would enable straight-forward oversight alongside other UK-based ecosystem carbon credits. However digital developments linking global carbon registries will make UK-based credits more accessible through non-UK registries. A specific benefit in linking to the UK Land Registry could relate to financial and legal additionality requirements under the UK public farming subsidy system, in which a farm soil carbon project will have to address relationships between public subsidy and private finance to ensure additionality [33]. Regularly updated advice and assurance through a UK Farm Soil Carbon Code could help soil carbon projects navigate the distinctive and ever-changing UK additionality conditions.

In general, the suitability of existing codes, and associated MRV methods for use in the range of farm contexts found in the UK remains to be established with questions around suitable evidence and data to support the verification of soil carbon credits from UK farming systems [16]. This also reflects wide questions over the universal equivalence of soil carbon credits generated using different methods [34]. In this context, there is a growing need for farm pilots, to trial the application of international codes and generate the necessary publicly available data to provide robust MRV for UK farming systems under these codes, where this proves possible, and to support the development of evidence-based UK soil carbon projects.

This review has highlighted the sheer breadth and depth of documentation, and vast range in terminology, associated with soil carbon codes. Codes have common structures, even if terminology differs. However, the details within documents indicate that there are substantial differences in approaches which, for example, influence the verification of soil carbon units and ultimately the financial viability of soil carbon projects. Project developers have a key role in keeping abreast of relevant documents, processes and procedures to register, approve and run cost-effective soil carbon projects. This is a substantial demand on projects and there may therefore be a role for an independent organisation, such as the proposed UKFSCC, to provide up-to-date information with assurance that relate to UK conditions for soil carbon projects and associated codes.

Project scale and duration

There has been a rapid growth in the development of farm soil carbon codes, with eight codes developed since 2020, and no sign of slowing down. Our analysis indicates that active and planned projects are substantial in spatial scale and/or number of farms involved, delivering economies of scale in project delivery and costs. For example, the two active projects in CAR cover arable farmland which is equivalent to the entire area of UK arable land (c. 4.3 million ha around 25% of all agricultural land in UK. Grassland covers most of the remaining UK farmland along with mixed (grazing and arable) farming which is not explicitly addressed in existing codes. With the average UK farm size c. 86 ha, there is a question over what size of UK soil carbon project is financially viable for a farmer, project developer and buyer. Options to minimise project costs include subsidising the operation of a UK Farm Soil Carbon Code, in a similar way to the Peatland Code and Woodland Carbon Code or broadening of eligibility rules around land use and management to enable farmers with similar carbon aims across different regions to come together in larger scale soil carbon projects.

Soil carbon projects require significant on-going commitment beyond the crediting period. Ultimately, if the UK farming sector is to make a substantial contribution to climate change mitigation, then multi-decadal timescales are essential [35]. Long-term permanence contracts (e.g. 100 years) with registries provide assurances to this contribution of they can be maintained for this long-term commitment. Shorter-term contracts or alternatives to fixed permanence, could be considered if the projects were committed to permanent mitigation pathways, for example through adoption of long-term land management strategies similar to those used in Australia, and have clear methods for mitigating risks of post-project carbon reversals and leakages. A more flexible approach to permanence might enable tenant farmers, a significant proportion of UK farmers, to participate and benefit from soil carbon markets.

Scope and quantification

A combined scope, increase SOC stocks and reductions in direct soil GHGs, would offer the greatest scope for UK farming to contribute to climate change mitigation through a UK Farm Soil Carbon code. This would also ensure that UK agriculture could demonstrate no leakage or reversals from either soil carbon stocks or soil GHGs in a fully accountable contribution to climate change mitigation through carbon-positive soil management. There is considerable scope to reduce direct soil GHGs from UK agriculture since agricultural soils account for 68% of UK's total N_2O emissions Office for National Statisti (ONS) [36] while arable mineral soils are relatively low in soil organic carbon [37] with substantial potential for sequestration [38]. However, the rationale for a combined scope should not be based solely on this potential. The UK farming environment is diverse, with agricultural soil types ranging from lowland peats to mineral soil in arable systems, and a significant proportion of mixed and grassland systems on organo-mineral soil types. The potential to reduce soil GHGs and/or increase soil C stocks will vary greatly depending on how these different soil types might respond to the proposed interventions [39]. Existing soil codes primarily address mineral soils, do not account for organo-mineral soils, and exclude peat or organic soils while agricultural lowland peat soils are currently also excluded from the UK Peatland Code. Therefore, additional work is required to demonstrate how the UK's diversity of soil types and management systems could be accommodated in a UK soil carbon project and by existing MRV methods.

A hybrid approach to the quantification of soil carbon, combining measurement and modelling, integrates soil GHGs and sequestration which can determine auditable verifiable carbon credits by reflecting relevant uncertainties. Crucially, local field and farm measurements can support greater certainty in quantification for individual projects and, as this data resource grows, increase the evidence base to support approval of new soil carbon projects. While technological developments have already increased access to, and reduced costs of, field measurement and modelling [40], strategic funding from public sources, as shown by the Australian example in grants for baselining, could help reduce initial cost barriers in field measurement. Ultimately, the growing demand for soil carbon MRV will need to be met by further development in easy-to-understand, accessible, auditable and cost-effective scientific and technical applications for the specific purpose of accurate MRV at local scale.

Rules

UK agriculture includes a significant proportion of mixed farming and horticulture as well as specialised arable or livestock farms, although there has been a recent resurgence in the integration of livestock into arable systems. Therefore, a universally applicable code would need to address a broader range of eligible land uses than available from existing international codes. Following examples from elsewhere, an option for the UK would be to develop individual agricultural land use modules that operate under a single umbrella of governance, verification and registering. A modular approach would ensure that new land use types could be added as the evidence base develops.

This could follow the approach taken by existing ecosystem carbon markets in the UK (e.g. UK Woodland and Peatland Codes). However, there is a question over whether this would address the greatest need for a UK farm soil carbon code, given the global activity of existing soil carbon codes.

As the evidence base and modelling capacities have developed, the eligibility rules around management in codes have shifted from single and defined towards criteria-based management options, which can include cessation, modification and/or initiation of practices. Given the diversity and dynamism in UK farming, where management in rotations is regularly adapted, modified and altered in response to various drivers, a criteria-based approach, looking to accumulate soil carbon gains over several cropping cycles and contract periods, might be more appropriate with eligibility rules that would support a degree of flexibility and innovation.

A clear challenge will be demonstrating that sufficient additionality in soil carbon gains can be achieved using criteria-based management, where there are various possible outcomes, and if there is scope for flexibility to adapt. All this is likely to place a greater reliance upon empirical data and modelling to support project approvals, reliable quantification, and re-quantification, of verifiable carbon and, potentially, on-going projections for year-on-year decision-making by farmers. To support expanding evidence demands, there is a critical need for field-scale data on the variability and response of soil carbon stocks and soil GHGs under crop rotations typically found in the UK and under management practices that could be adopted by UK farmers.

To date, additionality in most codes indicates that private finance will only be forthcoming where a management change would not occur otherwise, primarily reflecting aims to offset emissions elsewhere. However, if a code scope, and carbon markets are focussed on demonstrating real carbon gains, whether offsetting or (increasingly) insetting, it can be argued that the primary focus for additionality should be on the desired results i.e. demonstration that the proposed management changes will result in additional soil carbon gains over and above business as usual, and, where relevant, these gains could not be met without finance from the voluntary carbon market. Additionality rules which consider whether the proposed management already occurs in a wider region could be too restrictive for UK farming given that different farm types (e.g. organic, regenerative, conventional) exist side-by-side within most regions, and that there may be wider social, economic or political barriers to change [41]. These rules should also consider appropriate look-back periods to ensure that relatively recent carbon-positive management change can be rewarded and to reinforce "no-harm" by preventing inclusion of inappropriate land use change e.g. conversion out of permanent pasture.

Legal additionality tests, where farmers should not be financed for management required by legislation or regulation, are included in all international codes and would be important to address given the environmental protection regulation that applies to UK farming. Ultimately, financial additionality rules could be more flexible than currently outlined by most codes to reflect local circumstances and foster, not constrain, a major transitional change in UK farming at a critical time given the context of Brexit, Net Zero targets and specifically, evolving government farming subsidies. Key will be options for stacking of private finance with public funding, which is not specifically addressed in existing soil carbon codes. For example, the UK Peatland Code allows projects up to 85% public funding for certain expenditures if at least 15% comprises private carbon finance. A range of opportunities exist to blend and stack finance by ensuring that there is clarity in how carbon credits are managed between different funding sources [33]. In addition, there are opportunities to bundle and stack soil carbon with other co-benefits which could attract further finance through alternate verification standards. Stakeholder engagement should help establish which approaches to additionality would be acceptable to UK farmers, investors and governments.

Measurement, reporting and verification (MRV)

Quality of, and access to, empirical data from farms and fields are critical for reliable baselines and MRV. In setting up a project, several years of farm records will be required to quantify the soil carbon stock baselines of the "business-as-usual" management system plus a commitment to data gathering under the new management system for the project contract period and, if relevant, throughout permanence. It is possible to use representative data to supplement project data gaps, although, there must be a clear understanding that using data from other sources generally means greater uncertainty in quantifying the change in soil carbon stock, potentially fewer credits and, on occasions, wider questions over the real carbon benefit of a project. There is an opportunity to provide guidance to UK farmers about what data they could be recording and collecting in readiness for a soil carbon project e.g. field-scale nutrient inputs, livestock grazing, crop productivity, soil carbon stocks to depth, and equally what on-going recording commitments will be required if looking to start a soil carbon project.

Quantification of soil carbon credits relies upon robust baselines for soil carbon stocks and/or soil GHGs prior to the start of a project which supports the fundamental requirement to determine the difference in soil carbon gains between "business as usual" and the new "additional" management. Most codes account for the dynamic nature of soils by using dynamic or fixed average baselining and/or baseline readjustments which may use data from project field monitoring, paired "business as usual" fields and/or regional benchmark sites. Ultimately, if a project can demonstrate that a baseline approach can support reliable quantification, with adequate consideration of uncertainty throughout this process, then any of these baselining options could apply to UK farming. A key question in deciding baselining will be what effort, and therefore cost, is practical for a UK project?

There is growing demand for the measurement and re-measurement of soil carbon stocks to depth at regular intervals to demonstrate that change can be detected and, vitally, to enable local calibration, and recalibration, of models to improve the quantification of carbon credits at a field, farm and project scale. One benefit of this measure and model combination is that further credits can be released as the confidence in carbon gains improves through the duration of a project. With this, regular MRV would be used to release further credits, up to the end of the permanence period and/or contract length. A maximum time interval for MRV could be set e.g. five-yearly, but codes may wish to stipulate shorter periods between verification or at certain points, for example at the start of a project to support successful transitioning and establishment of practices and once practices are well embedded. However, given that MRV requires significant effort and funding, optimal MRV intervals could be informed by outputs from the project's initial and on-going modelling and measurement.

While there is a substantial reliance upon models in all codes for all stages, from project development through to MRV and permanence, specifying the use of certain models may limit the scope of a project, reflecting not only the scope of existing models but also factors such as available technical expertise to run these models, suitable data for model calibration, etc. Ultimately, the suitability of a model should be established with calibration and validation using UK farm and field data before they can be used to predict carbon credits for a UK soil carbon project. However, before the effort and expense of calibration and validation, projects should be able to determine what models would be most appropriate for a new soil carbon project. This would benefit from a comprehensive assessment of existing modelling approaches for quantification to reflect suitability for different farming system, management options, local environments, contract durations, etc. In parallel, there is a question about using multiple models in "ensembles" to provide more reliable illustrations of potential carbon gains and uncertainty [42]. Overarching this is a lack of independent standards against which models, methods and approaches can be compared and assessed [43]

There is broad consensus across the codes on soil carbon stocks measurement with fixed depth sampling to a minimum of 30 cm and ideally up to 100 cm. Equivalent soil mass (ESM) is increasingly being recommended for monitoring change in soil carbon stocks [40] and has been adopted by the Australian and GSOC codes. However, the effectiveness of ESM versus fixed depth still warrants further investigation [44]. Both approaches can be accommodated if soils are sampled to sufficient depth i.e. well below any management influence. Refinement of sampling methods for monitoring soil carbon stocks would greatly benefit from far more extensive datasets on soil carbon content and bulk density at depth (i.e. up to 100 cm) under different management systems and from controlled field experiments to follow change, and rates of change, in these soil properties over time. As with modelling, the suitability of sampling methods and laboratory analyses must be established against standards before they are used in quantifying soil carbon credits for a project [43]. Until universal standards are available and/or widely applied, this means that existing codes will require UK field data to demonstrate the suitability of methods and models.

Independence and transparency

Independent qualified auditors and assessors are essential to the credibility of soil carbon projects with their involvement needed at various points from the start to the end of a project. Most codes specify certification and qualification requirements for individuals and general requirement for audits/ assessments to conform to ISO standards that relate to GHG emission reductions in agriculture. In the UK this would typically involve British Standards Institute standards (ISO equivalent) and accreditation with The United Kingdom Accreditation Service (UKAS). At present, standards in general use reflect project management processes and, as outlined earlier, there is an urgent need for further standards to be developed and/or widely used to support the independent verification of soil carbon gains and reductions in direct soil GHGs [43]. Public access to audits, including standards used and summary assessments, would help build the evidence base for, and trust in, soil carbon projects and could be promoted more widely, unless there are explicit disadvantages, since only half of the codes currently provide public access to project audits and assessments.

Finances and project costs

Substantial project costs under most existing codes favours large projects which can operate cost-effectively given current soil carbon prices. Such costs may limit the viability of soil carbon projects in countries such as the UK where land holdings are relatively small unless substantial scaling can operate across different regions, farming systems and management options which indicates that a UK code would need to adapt existing eligibility rules. There are also opportunities to link public finance to enable soil carbon projects by funding components of a code that also align with public benefits as demonstrated in Australia with grants for baselines. The UK Peatland and Woodland Codes operate with far lower project costs than typically seen in international codes, specifically to support domestic carbon markets. If a similar model could be adopted for a UK Farm Soil Carbon Code, this could help establish a domestic market for soil carbon projects that are not affordable under existing codes, for example catchment-scale farming groups, landscape conservation interests.

Marketplace

Registries and sales

The integrity of a soil carbon market is highly dependent upon how credits are issued, sold and retired from registries, with online access to registries supporting market transparency. Guidelines exist across the codes on "know your customer," money laundering, accounting for carbon credits, contracts and checks on a buyer's wider emission reduction strategy with reference offsets. The market will benefit further from comprehensive and consistent guidance and standards *via* the proposed Carbon Code Principles and Assessment Framework from the Integrity Council for the Voluntary Carbon Market (https://icvcm.org/the-core-carbon-principles/).

Carbon prices and project value

A few codes provide financial illustrations to help projects understanding costs versus financial rewards for current soil carbon prices. With the voluntary carbon market (VCM), the carbon credit price is expected to increase substantially in the next decade and could rise from c.£10 (US$15)/ $tCO2_e$ at the time of this publication, to somewhere in the region of £37-74 (US$50-100)/$tCO2_e$ [45, 46]. UK farmers, project developers and UKFSCC would benefit from cost-benefit illustrations to help understand the potential value of UK soil carbon projects for current and potential future soil carbon prices, and to help inform where a UK Farm Soil Carbon Code could best be used to support UK soil carbon projects and the voluntary soil carbon market.

Critical lessons for developing a new code

This analysis has highlighted that there are now well-established soil carbon codes around the world with a rapidly growing number of active projects using a range of different MRV methods. Codes which have degrees of flexibility around rules and MRV, e.g. criteria-based rules and/or project determined aspects, are more amenable to adaptation for use in UK farm soil carbon projects, assuming that all legal and other obligations could be accommodated.

However, this would not be without significant investment in expertise, time and funds to gather the necessary evidence, conduct the required analyses and revise relevant documentation. As recently indicated by [16], evidence around eligible practices are currently inadequate with an urgent

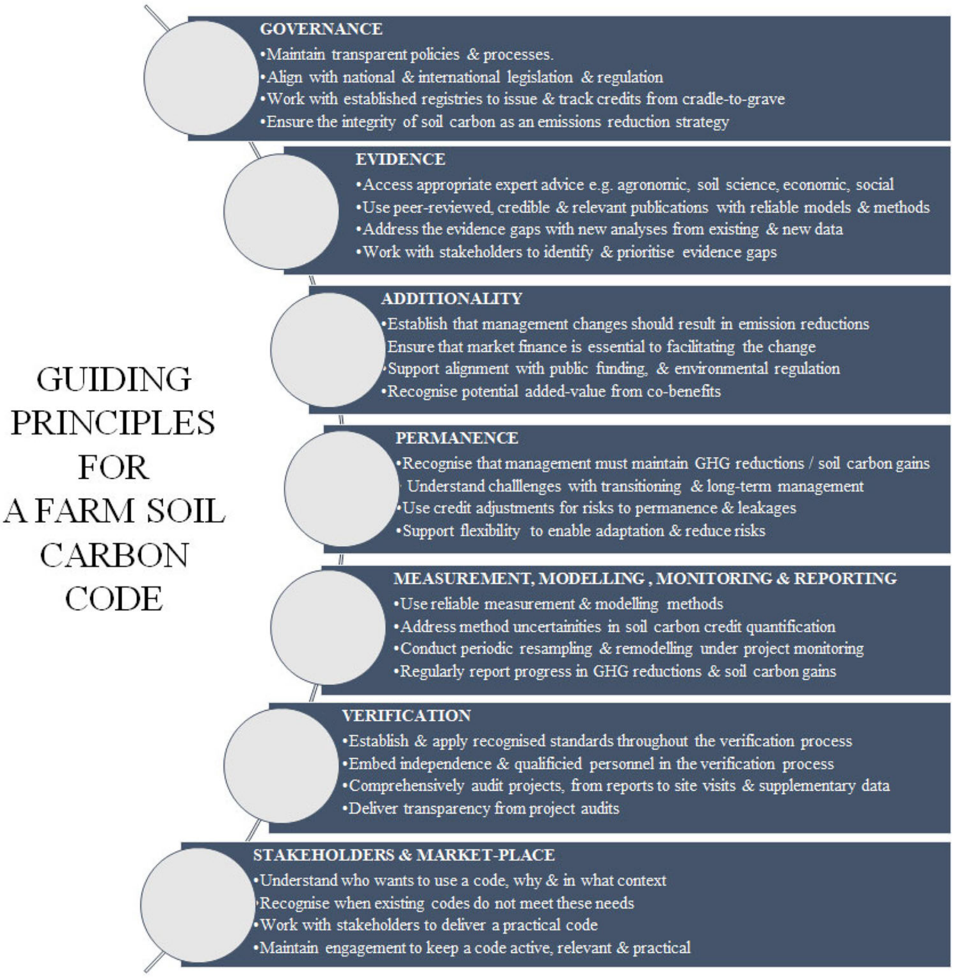


Figure 2. Principles for a UK farm soil carbon code.

need to gather new data that can be used to demonstrate the real potential of various carbon-positive management options across UK farming, including full-cycle rotations, mixed farming and organo-mineral soils. Other distinctive characteristics in UK farming will also need careful consideration. A number of these are illustrated in Figure 2. Rules around financial additionality require specific consideration to ensure that soil carbon projects can accommodate public subsidies alongside carbon market finance to best support UK farming in its transition to Net Zero with reduced reliance on fossil fuels and inorganic fertilisers. Given there is an opportunity to develop a code that could support UK soil carbon projects that may otherwise be excluded from existing codes including costs/economies-of-scale or other barriers, preferences for a domestic market, combined projects with other ecosystem codes in a domestic market and/or other objectives e.g. local authority strategies, business insetting or carbon reductions in supply chains. Ultimately, there is a growing demand for soil carbon codes that can be adapted to new circumstances whilst retaining high integrity in verifiable soil carbon credits.

Conclusion

This paper has demonstrated, with the aid of the structured framework, how governance, scope, rules, methods and marketplace have been addressed by several contrasting soil carbon codes. The framework is now available to help stakeholders better understand and compare different farm soil carbon codes and then to extend this analysis to other farm soil carbon codes as new codes become available. UKFSCC has also initiated work to extend the framework to include other forms of farm soil carbon assessment e.g. carbon certification and carbon audits. Easy to use frameworks, such as the one presented here, can go some way to assist stakeholders – from farms to investors – explore which MRV methods and organisations might best suit their circumstances. A further development of the framework, by extending the criteria, would be to drill into the technical details of MRV, such as sampling procedures, stock calculations and model procedures. These technical details will ultimately determine that there is consistency in the reported soil carbon gains (i.e. CO_2e) from farm soil carbon management across the expanding range of MRV option and, critically, that farm soil carbon is making a significant and permanent contribution to climate change mitigation.

The framework and assembled generic "best practice" principles can now be used to assist in the development of future codes and in further assessments of existing codes for new projects, regions or business-needs. The application of the principles developed from this analysis could help ensure that codes operate in a comparable way and with the highest integrity across different sectors, land uses and practices. While these principles provide high level guidance, the development and new application of soil carbon codes will involve a continual process of adaptation to accommodate the contexts of individual soil carbon projects. Ultimately, the application of code principles through to the delivery of soil carbon projects would benefit from universally recognised soil carbon standards that would ensure comparability and integrity from soil sample to carbon credit.

Different options for a UK Farm Soil Carbon Code have emerged from this analysis. These include: (1) a fully prescriptive approach with a defined MRV that would be similar to existing soil carbon codes but specifically aligned to codes for other UK land uses, perhaps with affiliation to the Land Carbon Registry. This would require substantial investment, and clarity over long-term ownership, funding and organisational commitment; (2) An oversight approach where UKFSCC provides or enables a process of approval and certification for the operation of existing codes in the UK domestic carbon marketplace. This approach could develop and maintain standardised workable approaches for additionality, permanence and other rules in the UK context, and provide criteria for evaluating MRV methods in existing codes seeking to operate in the UK. In so doing, it may be possible to help facilitate a "levelling up" across the soil carbon marketplace if minimum standards in MRV were widely adopted. These could help provide confidence in, and direct comparison of, carbon gains from different MRV approaches whilst enable these to develop and compete within the marketplace. And, help to protect the interests of buyers, sellers, intermediaries and the environment; (3) some combination of the previous two options, with the focus of any a prescriptive approach on small-scale UK soil carbon projects that do not have resources to engage with large-scale global codes or who want to demonstrate integrity in a soil carbon project outside the global soil carbon marketplace. Engagement with stakeholders from farmers, project developers, buyers, supply chain businesses, governments, to advisory organisations will be critical in determining the right pathway for UKFSCC to complement existing codes and address country-specific interests.

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ORCID

Mark S. Reed http://orcid.org/0000-0002-8958-8474
Nicola Cannon http://orcid.org/0000-0001-7956-8747
Pippa J. Chapman http://orcid.org/0000-0003-0438-6855
Guy Ziv http://orcid.org/0000-0002-6776-0763

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