Evaluation and monitoring methodologies for soil carbon balance and recommendations for drafting a low carbon label method. ADEME Report. Convention n*18-03-C0034

Wendtwoin Imelda Gécica W. I. G. Yogo, Hugues Clivot, Taeken Wijmer, Eric Ceschia, Fabien Ferchaud, Suzanne Reynders, Jean-Francois Soussana

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Evaluation and monitoring methodologies for soil carbon balance and recommendations for drafting a low carbon label method

Territorial demonstrators of soil carbon sequestration

Final report - deliverable 1/3

ACKNOWLEDGEMENTS

The authors would like to thank the developers of the methodologies and tools as well as the scientific and technical experts of INRAE teams for their valuable contributions.

HOW TO CITE THIS REPORT

Yogo W.I.G., Clivot H., Taeken W., Ceschia E., Ferchaud F., Reynders S., Soussana J.-F. 2021. Evaluation and monitoring methodologies for soil carbon balance and recommendations for drafting a low carbon label method. ADEME Report. Convention n*18-03-C0034. INRAE DOI 10.15454/BEEA-9S49-EN

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ABSTRACT

*France is facing a major challenge for the agricultural sector: it must aim for a 37% GHG emissions reduction by 2030 compared to the 2005 baseline for all non-ETS (*Emissions Trading Scheme *sectors), including agriculture (Effort Sharing Decision). In addition to this reduction challenge, there is also a sequestration challenge that can provide a satisfactory response to the national aim to contribute to the global effort for climate change adaptation and mitigation. The carbon (C) sequestration potential in French agricultural soils is high: 1008 Mt C for the topsoil, 1360 Mt C for the deep soil (Chen et al., 2018). The restitution of the national study "4 per 1000" in June 2019 highlighted the technical potential as well as an economic evaluation (technical cost) of carbon sequestration in French agricultural soils. In order to participate in the establishment of effective and incentive measures to sequester C in soils, this project funded by ADEME aims first to propose a protocol for the implementation of a low-cost MRV (Monitoring Reporting Verification) method for assessing C sequestration that is robust, simple to implement and replicable in different contexts and on large territories, and to draw its limits. With an associated low-carbon label, C credits could be generated and sold on the voluntary C market, which has great potential in Europe but has been underdeveloped until now. The second objective of the project is therefore to analyze the different business models of C demonstrators allowing for increased remuneration of farmers practicing C sequestration . Thus, in Deliverable 1 (this document), we propose three possible options for C balance evaluation and monitoring with different methodologies, tools and data that can be mobilized, as well as recommendations for the specific case of croplands in France. We highlight the impact of the uncertainties of the input data in the MRV methods on C stock estimates and the advantage of moving towards methods that include remote sensing for a territorial deployment dynamic. Deliverable 2 proposes an analysis of the different types of financing around C sequestration, including value addition within agri-food value chains, citizen financing, and intermediation via organizations or platforms as aggregators that are expanding. The financial value generated by the farmer who stores C must be safeguarded in the face of the MRV and administrative costs associated with the C certification process. Other economic models exist, such as those in connection with various food labels that were not studied in this project. It would therefore be relevant to have an analysis of the contribution of these different models and the possibilities of articulations with the "Label Bas Carbone - LBC" (low carbon label) to effectively ensure positive net income for farmers in transition. Finally, Deliverable 3 identifies the main R&D priorities for the implementation of collective and territorial projects for carbon sequestration in agricultural soils.*

RÉSUMÉ

La France fait face à un défi majeur pour le secteur agricole : elle doit viser 37 % de réduction des émissions d'ici à 2030 par rapport à l'année de référence de 2005 pour l'ensemble des secteurs non ETS, dont l'agriculture (Effort Sharing Decision). A cet enjeu de réduction s'ajoute un enjeu de séquestration qui peut apporter une réponse satisfaisante à la volonté nationale de contribuer à l'effort global d'adaptation et d'atténuation des impacts du changement climatique. Le potentiel de stockage de carbone dans les sols agricoles français est élevé : 1008 Mt C pour la couche arable, 1360 Mt C pour le sol profond (Chen et al., 2018). La restitution de l'étude nationale « 4 pour 1000 » en Juin 2019 a mis en lumière le potentiel technique de séquestration de carbone dans les sols agricoles français, ainsi qu'une évaluation économique (coût technique) de la séquestration de carbone dans le sol. Dans le but de participer à l'établissement des mesures effectives et incitatives visant à séquestrer le C dans les sols, ce projet financé par l'ADEME vise tout d'abord à proposer un protocole de mise en place d'une méthode MRV (Monitoring Reporting Verification) d'évaluation du stockage de C à bas coût, robuste, simple dans sa mise en oeuvre et reproductible dans différents contextes et sur de grands territoires et d'en dessiner les limites. Avec une labélisation bas carbone associée, des crédits C pourront être générés et vendus sur le marché de C volontaire qui a un fort potentiel en Europe mais jusqu'alors peu développé. Le deuxième objectif du projet est donc d'analyser les différents modèles d'affaires des démonstrateurs C permettant une rémunération accrue des agriculteurs pratiquant le stockage de C. Ainsi, nous proposons dans le livrable 1 (ce document), trois options d'évaluation et de suivi du bilan C possibles avec différentes méthodologies, outils et données mobilisables ainsi que des recommandations pour le cas particulier des grandes cultures en France. Nous mettons en lumière l'impact des incertitudes des données d'entrées des méthodes MRV sur les estimations de stocks de C et l'intérêt d'aller à terme vers des méthodes incluant la télédétection dans une dynamique de déploiement territoriale. Le livrable 2 propose par ailleurs une analyse des différents modes de financements autour de la séquestration C y compris la valorisation au sein des chaînes de valeur agro-alimentaires, les financements d'origine citoyenne ou encore l'intermédiation par des plateformes ou organismes agrégateurs en plein développement. La valeur financière générée par l'agriculteur qui stocke du C doit être préservée face aux coûts MRV et administratifs liés au processus de certification C. D'autres modèles économiques existent, notamment en lien avec divers labels alimentaires non étudié dans le cadre de ce projet. Il serait donc pertinent d'avoir une analyse de la contribution de ces différents modèles et les possibilités d'articulations avec le label bas carbone (LBC) pour assurer efficacement des revenus nets positifs aux agriculteurs en transition. Enfin le livrable 3 identifie les principales priorités de R&D pour la mise en oeuvre de projets collectifs et territoriaux de stockage de carbone dans les sols agricoles.

ELEMENTS OF VOCABULARY

Method: The low carbon label is based on the development of emission reduction methods. The methods specify, among other things, how the baseline scenario is to be determined for a given project type and how the project's emission reductions are calculated. The term method is translated into English as "methodology" in the jargon of voluntary carbon markets.

Methodologies: the means by which emission reductions are actually calculated from direct measurements, statistical averages or process models. Methodologies can eventually become methods when they go through a certification process.

In this report we use "method" in reference to the French low carbon methodologies.

1. Introduction

Deliverable 1 describes the methodologies, tools and data that can be used to draft a robust, sufficiently precise and low-cost assessment methodology for the effects of changes in agricultural practices on soil carbon sequestration , agricultural production and the climate (greenhouse gas – GHG balance).

In the remainder of this document, the following will be presented:

- An overview of the dynamics created around the project will first be presented, as well as the impacts on the organization of stakeholders for the writing of a cropland method in the framework of the low carbon label (LBC).
- the results of the literature review with a description of the methodologies and their potential and limitations.
- recommendations based on recent simulations for the sectors for the drafting of the low-carbon label method for croplands.

2. Dynamics generated by the project

In line with the activities initially planned for the conduct of the study, we organised and facilitated several meetings jointly with I4CE and ADEME.

Two meetings directly related to project objectives 1 and 2:

- 24 June 2019, 18 participants: this meeting mainly made it possible to identify the holders/developers of methodologies and tools including underlying models and to have an overview of the state of research on the subject.
- 3 September 2019, 82 participants: this second meeting attracted a great deal of interest from project leaders and potential funders who were able to express their willingness to get involved in the development of a method for the Low-Carbon label.

Following these initial meetings, four meetings bringing together the various stakeholders interested in writing a method for the Low-Carbon label were organised at INRAE's headquarters. These meetings made it possible to initiate the reflection with the objective of pooling efforts and limiting the multiplicity of methods on overlapping perimeters:

- 23 October 2019, 11 participants: grassland working group
- 29 October 2019, 26 participants: croplands working group
- 30 October 2019, 18 participants: working group on hedges/agroforestry/arboriculture/viticulture
- 12 December 2019, 20 participants: working group on grassland and croplands

All of these exchanges created a dynamic among the sectors, which came together in a consortium to pilot the writing of a low-carbon label method for croplands with the logistical support of the company Agrosolutions.

Other LBC methods are being developed, in particular hedge-CARBOCAGE (piloted by the Pays de Loire Chamber of Agriculture), agroforestry (piloted by the APCA), fruit (piloted by the Compagnie des Amandes, currently being validated) and legumes (piloted by Agrosolutions).

The numerous bilateral exchanges have led to questions about the propagation of uncertainties and to the creation of a dedicated working group at INRAE:

- 11 December 2019, 7 participants: identification of issues related to the assessment of model uncertainties and the propagation of input data uncertainties.
- 2 April 2020, 10 participants: proposal of a protocol for calculating the propagation of uncertainties.

3. Literature review of GHG balance and carbon sequestration monitoring methodologies

The bibliographic analysis made it possible to identify a non-exhaustive list of 20 methodologies (Table 1), tools, models and data that can be used to monitor carbon stocks and GHG emissions developed in France or internationally for different types of crops, soils and climates. We present these results from a global point of view before developing our analysis for the specific case of France and for croplands.

3.1. Procedure and results of the literature review

The identification was carried out first, with a focus on methodologies and tools including models to assess emissions of at least one of the three main greenhouse gases (GHG) (CO_2, N_2O, CH_4) and/or carbon sequestration in soil and above-ground biomass, with different calculation bases. The underlying calculation types include models (empirical, soil-plant, soil dynamics, agro-meteorological), IPCC Tier1 (default values) or Tier2 (regional/national values) emission factors and the use of satellite data. Second, we considered methodologies and tools with various application scopes to better represent the diversity of the agricultural world. Thus, we considered perimeters covering croplands, grasslands, livestock, hedgerows, forests etc. represented at different scales (plot, farm, agricultural operation) (Table 1).

Table 1: List of 20 methodologies, tools, models and mobilizable data in France and internationally

Name	Type	Scale	Precision of carbon sequestration calculation	Certification	CO2	N2O	CH4
STICS	Soil-plant model	Plot	Tier 3	no	yes	yes	no
FullCAM	soil model	Plot	Tier 3	no	yes	yes	yes
Rock'Eval	tool	Plot	Tier 3	no	yes	not	no
VCS (SALM)	GHG methodology	Plot	Tier 3	yes	yes	yes	yes
SAFY-CO2	Carbon budget methodology	Plot	Tier 3	no	yes	not	no
AMG	soil model	Plot	Tier 3	no	yes	not	no
CarSolEl project metamodel	Statistical metamodel	Plot	Tier 3	no	yes	yes	no
RothC	soil model	Plot	Tier 3	no	yes	not	no
COMET-Farm Tool	GHG methodology	Plot	Tier 3	no	yes	yes	yes
VCS VM0042	GHG methodology	Plot	Tier 3	yes	yes	yes	yes
MAELIA	GHG methodology	Plot	Tier 3	no	yes	yes	no

ABC'Terre	GHG methodology	Territory	Tier 2 except soil model (Tier 3 - AMG)	no	yes	yes	no
Australia-Methodology determination 2018	GHG methodology	Carbon estimation areas defined according to the protocol	Tier 2	yes	yes	yes	yes
Alberta (CCP)	GHG methodology	Carbon estimation areas defined according to the protocol	Tier 2	yes	yes	yes	yes
CAP'2ER	tool	Livestock or plant production system	Tier 1	yes	yes	yes	yes
CarbonAgri method	GHG methodology	Livestock or plant production system	Tier 1	yes	yes	yes	yes
Hedge method-CARBOCAGE	GHG methodology	Agricultural operation	Tier 1	no	yes	no	yes
Cool Farm Tool	GHG methodology	Agricultural operation	Tier 1	no	yes	yes	yes
CARBON EXPERT	Composting methodology	Territory	Tier 1	no	yes	yes	yes
CARBON Navigator	GHG methodology	Agricultural operation	Tier 1	no	yes	yes	yes

A quick look at the data enables us to distinguish between two main groups, namely methodologies certified by a national or international body and those not yet certified. Six methodologies are already linked to a certification framework at **national level** (4 in total: the *CarbonAgri* method *and the Haie method* in France, the *Alberta Conservation Cropping Protocol* in Canada and the *Measurement of Soil Carbon Sequestration in Agricultural Systems Methodology determination 2018* in Australia) or **international level** (2 in total: the *Verified Carbon Standard (VCS) - Adoption of Sustainable Agricultural Land Management and the VM0042* Methodology for Improved Agricultural Land Management).

It can also be noted that all the methodologies and tools, including the models that can be applied at the plot level, are based on Tier 3 approaches, as understood in the guidelines for national inventories, based upon the use of process-based models. Among these, more than half (9 out of 11) are not yet certified. This observation can be explained by the fact that methodologies including process models are often under active development, particularly concerning user interfaces.

The latest methodology approved by the VCS is promising in terms of taking into account the soil carbon stock and provides an additional protocol for the choice of models for establishing the GHG balance according to the most accurate approach "Quantification approach 1". This is the internationally applicable "Methodology for Improved Agricultural Land Management" VM0042. The company Indigo Ag Inc., which is very active in the United States, participated in the development of this methodology and uses it for the certification of its projects, but the calculation methodology chosen is not known, which limits the transparency of the process. Overall, carbon credit certification methodologies are developing internationally at a rapid pace thanks to the strong expansion of the voluntary carbon market.

In Annex VI- Annexes methodological sheets.

20 detailed sheets corresponding to these methodologies, tools and data are available at the end of the document with their descriptions and uses, general information (e.g. spatial and temporal scale, GHGs concerned, etc.), input and output data as well as the underlying databases when applicable. The calculations are not always detailed for better clarity but are available at the links mentioned.

3.2. Developments achieved and in progress in the French context

We were particularly interested in the methodologies, tools and data that could be mobilized to assess GHG balance in croplands, with a particular focus on soil carbon sequestration. In fact, a national study[1] conducted by INRAE recently highlighted the potential (31 MtCO2 eq of additional soil C sequestration per year, on average for 30 years) that the adoption of new agricultural practices with constant land use would represent in France. The main measures identified in terms of potential concern croplands (86% of the additional sequestration potential), with the development of intermediate crops, the increase in the place of temporary grasslands in crop successions and intra-plot agroforestry.

Thus, a first summary table presents the advantages, disadvantages, degree of maturity and implementation costs, where possible, of promising methodologies or those already labelled as low-carbon in the cropland sector (Table 2). A second summary table presents the tools, including models and data that can be used to support a low carbon label method (Table 3).

[1] Sylvain Pellerin and Laure Bamière (scientific pilots), Camille Launay, Raphaël Martin, Michele Schiavo, Denis Angers, Laurent Augusto, Jérôme Balesdent, Isabelle Basile-Doelsch, Valentin Bellassen, Rémi Cardinael, Lauric Cécillon, Eric Ceschia, Claire Chenu, Julie Constantin, Joël Darroussin, Philippe Delacote, Nathalie Delame, François Gastal, Daniel Gilbert, Anne-Isabelle Graux, Bertrand Guenet, Sabine Houot, Katja Klumpp, Elodie Letort, Isabelle Litrico, Manuel Martin, Safya Menasseri, Delphine Mézière, Thierry Morvan, Claire Mosnier, Jean Roger-Estrade, Laurent Saint-André, Jorge Sierra, Olivier Thérond, Valérie Viaud, Régis Grateau, Sophie Le Perchec, Isabelle Savini, Olivier Réchauchère, 2019

Stocker du carbone dans les sols français, Quel potentiel au regard de l'objectif 4 pour 1000 et à quel coût? Synthesis of the study report, INRA (France), 114p.

Table 2: Summary of the advantages, disadvantages, degree of maturity and implementation costs of promising or already labelled low-carbon methodologies in the cropland sector

Soil C measurement methodologies	Main advantages	Main disadvantages	Case of applicability (Scale/Culture/Soil type)	Cost (excluding human time for implementation)	Level of maturity/examples of application
ABC'Terre approach with the SIMEOS-AMG tool (http://www.agro-transfert-rt.org/abcterre)	• Enables the integration of a soil C balance and a GHG balance of the territory's cropping systems into a PCAET (Plan Climat Air Energie Territorial or Territorial Climate Air and Energy Plan in English) by taking into account the cropping practices, the soil types of each cropping system and the territory's agri-environmental issues. •Is based on the mobilization of the territory's agricultural actors to build the action plan with them •Allows a fine allocation of cropping systems (rotation x cropping practices) to the soil types of the territory in which they are located (the Soil Typological Units - UTS). These UTS are divided into one or more Soil Map Units (UCS) that can be located on the territory. •Is based on the simple and robust AMG model (Andriulo et al. 1999), which is validated for a very wide range of crops, cover crops, soil types and climates, covering the territory of mainland France and beyond. The methodology therefore has a good potential to predict soil organic carbon evolution under different scenarios (climate, soil, practices) in the long term (30 years). •Existence of guides and implementation of processes to facilitate and automate future applications of the approach and to optimize its appropriation by the territory	• Legal conditions for access to certain input data (from databases) still under study •Sensitivity to the determination of initial carbon and the ratio of stable carbon to total carbon. •Methodology that requires the use of field expertise to reconstruct agricultural practices • No direct characterization of cover crop biomass •High uncertainties when applied to generic cropping systems, reduced uncertainties when the model is parameterized with farm data.	• Scale of application: the territory •Arable crops (no simulations via SIMEOS -AMG of changes in C for permanent grassland, long-term temporary grassland, > 3 years, hedges or agroforestry) • Consideration of C stocks under permanent grassland (long-established) on a flat rate basis •Calculation scale: "reconstituted cropping system by soil type" (= combination "Cropping system x Soil type x Corg content") in each SCU •Parametrization still needed for soils with high OM, hydromorphic soils	•Software with a fee-based license (several hundred euros per year) • Paid training for the implementation of the approach (max. 500€ for 2 days) •Different levels of support are possible by Agro-Transfert.	• Currently being tested in five experimental territories in France, as part of the ABC'Terre-2A project (3 in Hauts-de-France, 1 in Alsace and 1 in Nouvelle-Aquitaine to test the application of the methodology to different soil and climate contexts): http://www.agro-transfert-rt.org/abcterre/publications-abcterre/ • An adaptation of ABC'Terre has been carried out in a territory of the Gers (South-West France) by the SolAgro consultancy agency to test the impact on soil C sequestration of various territorial projects under study (bioeconomy). Prospects are ongoing.

	stakeholders (users of the methodology, farmers, local authorities, etc.)				
MAELIA platform (http://maelia-platform.inra.fr/)	• Each parcel and each farm of a territory is represented and simulated according to its specificities • Dynamic simulation of current and future scenarios on a daily time step and representation of the spatiotemporal dynamics of technical operations •Daily and interannual water, N, C interactions over the course of the cover crops x practices x years •Coupling with inventory tools (mes p@rcelles) to mobilize information directly in the field - •Agroforestry model under development (Yield SAFE) •Impact of climate on space-time dynamics •Possibility of constructing an indicator of the variability of the carbon stock over a few decades	•Acquisition of data on crop management strategies (decision rules) •Need to parameterize specific crops •Interfacing to be adapted as needed to operationalize	• Scale of the "territory": from the fine scale of the farm to several thousand km2 •Croplands, grasslands, herd dynamics module and agroforestry under construction •Any type of soil	•Free software • Free training for its implementation (7 to 15 days)	- Depending on the data available, the application of MAELIA on a study site can take from one to several weeks. It has been used in research, research-action, R&D and discussions are ongoing to allow its use by agricultural development (CRAGE) and for the design of agri-environmental policies (Switzerland)
CarbonAgri method with the	•Modulable soil C component: awaiting the work of CarboCage, 4p1000, EFESE and	•The soil C component is not well developed in the method	Several scales:	•The CARBON AGRI method is based on the use of the certified CAP'2ER® level 2	It is a Low-carbon label certified method

CAP'2ER ® tool (https://cap2er.fr /Cap2er/)	CarSolEl projects to integrate more practices and associated factors • Consideration of nitrogen loss during carbon removal (IPCC equation, 2006)	•A list of practices is provided with additional sequestration factors: conversion from crop to permanent grassland, conversion from permanent grassland to crop, extending the duration of temporary grassland, planting hedgerows.	•The scale of the farm operation, •The scale of the livestock production system: the herds and the areas they use (forage area and self-consumed grain area), •The scale of the plant production system: areas of the farm where harvested crops are sold.	tool, available under license (~35€ per diagnosis) • Support arrangements have been put in place via the France CARBON AGRI association (https://www.france-carbon-agri.fr/)	
Methodology based on the SAFY-CO2 model	•Independent assessment of regrowth/cover crop biomass and main crop biomass using satellite data (Sentinel 2) •Calculates the change in C stocks between two periods in relation to the change in practice	• The initial absence of a soil module representing the evolution of OM in the model -> greater uncertainties in the estimation of medium-term C balances. Coupling with the AMG model in progress. • Complementary data to be collected on agricultural practices (straw export, organic fertilization) • Satellite data limited by cloud cover (use of radar data under development)	• Accessible regional scale (plot, farm, region) • Croplands: parametrized for wheat, maize, sunflower and rapeseed • Any type of soil	• Cost of data hosting and processing	• The Naturellement Popcorn project (in conjunction with the company Nataïs), which aims to pay farmers in the network who implement cover crops. In the long term, the use of satellites would make it possible to have a payment proportional to the biomass of the cover crops planted and therefore proportional to the carbon sequestration. - H2020 NIVA project "New IACS Vision in Action": development of agri-environmental indicators based on remote sensing and that can be used in the framework of the future CAP. The project focuses on three indicators: carbon balance, nitrate leaching risk and biodiversity. **hal-03190579, version 1**

Table 3: Summary of the advantages, disadvantages, degree of maturity and costs of implementing tools or databases for improving soil characterisation in arable farming methods

Tools including models and data that can be mobilised to feed a method	Main advantages	Main disadvantages	Case of applicability (Scale/Culture/Soil type)	Cost	Level of maturity/examples of application
Thermal analysis of soil C using the Rock-Eval® tool	• Allows the assessment of the biogeochemical stability of soil organic matter and reduces the error related to the initialization of C stocks (Cs/C0) in AMG • Measurement of organic and inorganic C in a single sample • Could be implemented in a simple and quick way for applications on a territorial scale (e.g. MAELIA/ABC'Terre), in particular via the creation of a national map of stable C stocks on a century scale (work in progress in conjunction with the GIS Sol).	• Research instrument (no research or analysis office equipped in France to carry out these measurements in series; under development by Vinci Technologies and IFPEN) • Not yet validated for other models (will be done with other soil C dynamic models (Roth-C, possibly Century) in the framework of the ANR StoreSoilC project).	• Fine scale, on site • Any type of soil (to be consolidated, uncertainties to be assessed on some soils rich in metals or carbonates)	• Cost of the machine around 250,000 euros. Awaiting the implementation of an economic model allowing the profit-sharing of analyses laboratories	• Operational with the AMG model
Remote sensing of soil organic C	• With remote sensing we can stratify the space, obtain direct estimation with updating, maps with uncertainties, and adapt the methodology according to the region. • Land use spatialization: the farming history can be reconstructed • Can be a solution to collect information for inputs to other models	• Conflict between the interest of covered soils and the better accuracy of measurements on bare soil • Need for calibration data sets • Measures can only concern the first millimeters of bare soil, and must be associated with a good knowledge of practices (e.g. tillage having an impact on carbon redistribution)	•Variable scale •Any type of soil	• The cost of soil analyses to validate the update maps	- Spectral models for remote sensing of soil organic carbon: Work on the Versailles plain (221 km2) • Satellite remote sensing (Europe): little previous work until Sentinel-2. Work on Sentinel-2, models from this satellite; predictive models with an average RPD (Ratio of Performance to Deviation) are obtained

	• Deployable over large regional areas while allowing for intra-plot variability				
Available soil data (www.gissol.fr)	Several programs with data available: RMQS program "Réseau de Mesure de la Qualité des Sols » (Soil Quality Measurement Network) • Public funding and operation, coordinated by INRAE • Information on agricultural practices on each of the points • Reliable and robust analyses BDAT program "Base de Données des Analyses de Terres" (Soil Analysis Database) to capitalize on the soil analyses carried out for farmers in France IGCS programme "Inventaire Gestion et Conservation des Sols" (Inventory of Soil Management and Conservation) capitalizing on soil surveys carried out in France and associated properties	• It is complicated to open up soil data and practices: Data are increasingly geo-referenced and can be considered as personal data making them legally "private property", requiring conventions for research application. • BDAT analyses are prior to 2014 but a new agreement for data collection is being negotiated • ¾ of IGCS data are prior to 2000 (there is no obsolescence of soil data but biological activity data such as pH or organic matter vary over time)	• Fine scale, direct measurements	Public funding	Soil databases are used for national inventories and model calibration

The diversity of approaches applicable to croplands is encouraging but suggests a recurring problem, which is the lack of information on the impact of the accuracy of input data on the calculated/estimated data. It is important to have accurate calculation methodologies for a reliable assessment of soil carbon stock, particularly in the context of the Low-Carbon label. Indeed, the economic valuation of the stored carbon is necessary and contributes to the incentive to reach a greater part of the sequestration potential in croplands. Valuing the sequestration at 55 €/tCO2e (the level initially planned for the climate-energy contribution for 2019) would make it possible to align farmers' interest in changing their practices with public objectives for about half of the potential (i.e. 14.7 MtCO2e) at a relatively low cost compared to the CAP budget in France (159 M €/year, for a CAP budget in France of 9.1 Bn € for the period 2015-2020). The development of emission reduction projects in the framework of the LBC could mobilize the sequestration and conservation of carbon stocks, which can constitute an economic opportunity for farmers providing that there is a return on investment between the implementation of emission reduction levers, the cost of measuring carbon sequestration and emissions and obtaining carbon credits.

However, LBC methods to monitor and verify carbon sequestration in agricultural soils are still under development. The available options, their advantages, disadvantages, and their compatibility with the low-carbon label are discussed in the third part of our analysis.

4. Approaches and recommendations for estimating and certifying soil organic carbon stock change

There are several elements to consider when building viable business models for emission reduction projects. In this section, we present the possibilities for determining sequestration potential, the different options for assessing and monitoring soil organic carbon balance, the lessons learned from a sensitivity analysis of the AMG model to input data and the principles of the low-carbon label to consider when setting up an emission reduction project to obtain carbon credits. The choice of the AMG model is explained by its simplicity of use and the fact that it has been validated for a very wide range of crops, cover crops, soil types and climates, covering the territory of mainland France (Clivot et al., 2019).

4.1. Preliminary analysis of sequestration potential at farm level

When designing a project to store carbon in agricultural soils, an initial assessment of the practices to be implemented, their soil carbon sequestration potential and their cost can be carried out thanks to the national coverage of the 4 for 1000 study (INRAE, 2019). Carbon sequestration was assessed in this study for different practices in croplands and permanent grasslands using the STICS and PASIM models. The CarsolEl project's meta-model[2], built from the database containing the simulations carried out in this study for the whole of France, will provide references for the main carbon-storing practices and for the main crop and livestock systems in mainland France. This first step is simple to use, thanks to a limited number of input variables, and could make it possible to obtain an order of magnitude at farm level. However, this meta-model does not make it possible to represent all the diversity of combinations between cropping systems, carbon-storing practices, soils and climates. It cannot therefore provide a sufficiently accurate estimate of organic carbon stocks in the soil for a given farm or plot. On the other hand, it could be used to guide the choice of carbon-storing practices and to evaluate *ex-ante* the potential storage level of a project.

A first version of the meta-model and its user interface is currently being tested. After validation, this tool will make it possible to guide the choice of levers to be implemented on a farm and to have an initial idea of the expected organic carbon stocks.

[2]https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjClbXt0ZfqAhUvx4UKHWZMBdoQFjAAegQIAhAB&url=http%3A%2F%2Fwww.agro-transfert-rt.org%2Fwp-content%2Fuploads%2F2019%2F01%2F12_Colloque_SoleBIOM-AMG_Atelier1_Resume_CarSolEI.pdf&usg=AOvVaw3pnjzqFVhDRPzTgOHzJH3h

4.2. Options for assessing and monitoring the organic carbon balance of a cropland soil

First of all, it should be remembered that it is not possible in practice to directly determine the variation in soil organic carbon stock of a plot a few years after the introduction of carbon storing practices. In a series of European cropland sites, Schrumpf et al. (2011)[3] showed that, the minimum detectable difference was 1.05±0.28 tC ha-1 for a very large sampling effort (100 core samples down to 50 cm, with measurement of bulk density and carbon content of several horizons per sample). If we consider the target of 0.4% carbon sequestration in the soil per year for an initial stock of 50 tC/ha, the difference in stock after 4 years is only 0.8 tC/ha. The detection of this sequestration would only occur after 6 years, assuming a measurement effort (100 samples per plot) which is in reality impractical for a farmer. With a still important measurement effort (10 samples per plot), significant sequestration would only be detected after 24 years, which would not allow projects to be funded.

To date, some international methodologies have been validated by private actors, such as the methodology (SALM) which has been approved by VCS[4] (Verified Carbon Standard) and which frames the assessment and monitoring of the carbon balance for projects adopting carbon-storing practices such as the application of organic amendments, the introduction of cover crops (e.g. intermediate crops), tree planting, etc. This methodology is based on a theoretical modelling approach, as it estimates the differential between the soil carbon stocks with and without the introduction of carbon-storing practices. This methodology is based on a theoretical modelling approach, as it estimates the differential between equilibrium soil carbon stocks with and without the introduction of carbon-storing practices. The RothC model (for soil carbon dynamics simulation) is used for this purpose. However, there are several approximations in this methodology: i) the soil of a plot is not necessarily in equilibrium and the initial value of the carbon stock may be significantly different from the equilibrium hypothesis made by the model; ii) After the introduction of a new carbon-storing practice, it takes 20 years or more to reach a new equilibrium and the dynamics of carbon accumulation during this period are not linear (which is neglected in the methodology); iii) the contribution to the soil of the carbon-storing practice must finally be estimated, but the methodology is not very precise on this point. Another reason for not directly applying a soil carbon balance methodology developed in another region of the world (such as Australia or Alberta) is the lack of parameterization for French pedoclimatic conditions. Finally, we propose several complementary options that could be used in the development of a low-carbon label method for croplands.

4.2.1. Option 1: Simeos-AMG with an ABC'Terre extension for the complete GHG balance

The AMG model (Andriulo et al. 1999) is a simple semi-mechanistic model with three compartments. The first compartment, of incoming fresh organic carbon, comes from residues and organic waste products (PRO). Then, two compartments of soil organic carbon are distinguished: one called "active" while the other is considered "stable" for at least 100 years. Three major parameters are to be considered: the humification coefficient of residues or k1, the annual mineralization coefficient of active soil organic carbon or k2 and the partition coefficient between active and stable C. For the latter, it is possible to use a default value or to estimate it from a Rock-Eval® thermal analysis[5] (Barré et al., 2020).

Table 4Inputs, outputs and databases for the AMG model

Input	Output	Databases
Initial organic carbon (0-30 cm) Soil data (clay, limestone, pH, C/N)	Soil organic carbon stock and evolution (+30 years)	Calibration database compiling French long-term trials (soil, climate, crops and cropping systems)

[3] https://doi.org/10.5194/bg-8-1193-2011, 2011.

[4] http://verra.org/wp-content/uploads/2018/03/VM0017-SALM-Methodolgy-v1.0.pdf

[5] https://www.afes.fr/wp-content/uploads/2020/07/EGS_2020_27_Barre_305-320.pdf

Data on farming practices, crop rotations, types of cover crops, yields, organic amendments Irrigation data, local climate	Distribution of organic carbon in the soil profile (0-30cm) Plant biomass flux returned to the soil and associated humified organic carbon (mean.ha^{-1}.yr^{-1})	Allometric characteristics of the crops to determine root inputs

The AMG model, derived from the Hénin-Dupuis model, can simulate the evolution of soil organic carbon stock with a low relative error *RRMSE=5*.3% and comparable to the error of measured data (median CV = 4.3% for 386 stock measurements with 4 replicates on average, depth 20 to 30 cm: median = 28 cm, Clivot et al., 2019) on long-term experimental sites in France. In addition, improvements to the model (AMGv2) reduced the root mean square error for soil organic carbon stock (RMSE) to 2.6 tC/ha, a value slightly lower than the initial version (AMGv1 RMSE = 3.2 t C. ha^{-1}, Clivot et al., 2019). It has also been shown that an initialization of the AMG model using the Rock'Eval© tool (determination of soil organic matter stability) with a statistical model improves the prediction capabilities of the model (Cécillon et al. 2018). Like most carbon dynamics models, however, the AMG model is not adapted to organic soils (andosols, former peat bogs, etc.).

Since this deterministic model was calibrated on a database that is fairly representative of the soil and climate conditions of croplands in France, and since its prediction error for the soil carbon stock is comparable to the experimental error, it can be used to predict the evolution of the stock as a function of practices, as long as all of the model's input variables can be provided with sufficient precision. A study of the model's sensitivity to the uncertainties of the input variables is presented in Part 3 in order to assess the resulting uncertainty on the evolution of the soil carbon stock with constant practices, on one hand, and on the stock differential with and without carbon-storing practices, on the other hand.

At the territorial level, the ABC'Terre methodology makes it possible to assess changes in soil organic carbon stocks (using the Simeos-AMG tool) as well as emissions of other greenhouse gases based on IPCC emission factors and other databases (Agribalyse, EcoInvent). In the current version, Simeos-AMG works with typical rotations of 3 to 6 years repeated over time, which is an IT constraint of the Simeos tool, which is not linked to the AMG model itself and therefore this constraint could be lifted. There may be a difference between the practices envisaged at the beginning of the project and those actually implemented. This is true for all practices (crop succession, introduction of intermediate crops (IC), inputs of organic waste products (PRO), etc.). The case of ICs is special because their production must be entered into the AMG model, as this determines the input of organic carbon to the soil. A verification of the presence of these covers and an estimation of their production, for example by satellite remote sensing, is therefore desirable.

The use of the AMG model could be recommended from now on, with a desirable adaptation of the SIMEOS tool to more diversified cases of rotations. Moreover, remote sensing validation of the presence of intermediate crops and their development would make it possible to secure the methodology, avoiding the counting of intermediate crops that have shown defects in emergence or growth.

4.2.2. Option 2: SAFY-CO2 and remote sensing canopy monitoring

SAFY-CO2 (Pique et al., 2020) is an agro-meteorological model assimilating optical remote sensing data (leaf area index maps, LAI) to estimate crop production and carbon balance components. It uses the Monteith approach to calculate GPP. Autotrophic respiration (Ra), i.e. by plants, is separated into maintenance and growth respiration. The net primary production (NPP, which is the difference between GPP and Ra) is then divided between above-ground and below-ground parts. Above-ground biomass is calculated from the carbon content of the above-ground parts and converted into leaf area index and yield at the end of the growing season using a harvest index (HI). Soil respiration (heterotopic respiration, Rh) is estimated in this version using a simple temperature response function (Q10 exponential function). The carbon balance (NEE) is calculated at a daily time interval taking into account GPP, Ra and Rh, and then aggregated to an annual scale (cropping year) taking into account the amount of carbon exported at harvest (yield).

Table 5: Inputs, outputs and databases for the SAFY-CO2 model (https://www.cesbio.cnrs.fr/la-recherche/activites/modeliser-codes-et-modelisation/liste-et-descriptif-des-modeles/modspa/)

Input	Output	Databases
LAI and land cover maps Global radiation, temperature (and rainfall for the version coupled with a water module: SAFYE-CO2) Information on whether or not straws are exported, the amount of C provided by organic fertilization.	Photosynthesis, autotrophic and heterotopic respiration, biomass, LAI, NEE, yield, C balance (evaporation and transpiration when coupled with a water module) including soil carbon stock evolution	Sentinel 2 for LAI assimilation SAFRAN data (Météo France), ERA5 (ECMWF) Global Soil Map RPG Land cover maps from remote sensing

SAFY-CO2 has been developed and calibrated from CO_2 exchange data measured by the turbulent fluctuation method (flux towers) between the atmosphere and cropland plots. In its initial version, it does not include a model of organic matter decomposition in the soil, which is a major limitation. Indeed, at the same temperature, Rh can vary according to the initial soil carbon stock, the soil type and the water balance. On the other hand, the assimilation of satellite data makes it possible to have a diagnostic approach of the carbon balance week after week. In particular, the carbon stock differential with and without carbon-storing practices can be estimated over time, taking into account the satellite-observed growth (Sentinel 2, resolution of about 10 m twice a week under clear skies) of main and cover crops. The prediction of the carbon balance is therefore largely dependent on independent data from remote sensing, which will be increasingly available in the near future. For example, a COPERNICUS program is expected to provide an open access Sentinel 2 product[6] on the dynamics of the leaf area index of agricultural land, as well as the nature of the crops, by the end of 2020. In addition, farmers' activities are reported via the Land Parcel Identification System (LPIS) showing fields and their margins as part of the Common Agricultural Policy's IACS[7]. The Integrated Administration and Control System (IACS) can also provide valuable data on cropping systems and management practices at plot level via the Land Parcel Identification System[8]. However, for soil carbon monitoring purposes, there are gaps in the CAP declarations, including the presence or absence of cover crops and the management of crop residues and organic fertilizers.

The calibration of the model for the different crops (croplands, intermediate crops) requires field campaigns to estimate the relationships between above-ground biomass, leaf area and crop residues. The root mean square error of the model (RMSE) for the soil carbon balance reaches 0.77 tC/ha[9] . The analysis of the propagation of uncertainties in this model is underway and will be available from the 3rd quarter of 2020.

The SAFY-CO2 methodology facilitates simulations on a regional scale, since it is possible to simulate the carbon balance of a small agricultural region, provided that the yields, the fate of crop residues and the organic fertilisation for each plot are entered. These regional-scale simulations are being developed in the Horizon 2020 NIVA project, which foreshadows the monitoring tools that should be implemented as part of the modernisation of the CAP.

> This second option is interesting for the future and should at least allow the estimation of the emergence and growth of intermediate crops as a complement to option 1. However, it is incomplete due to the absence of a soil organic matter decomposition model.

[6] Remote sensing of phenology, NDVI, faPAR, fcover (see COPERNICUS phenology products, to be released in 2020 for the EU)

[7] https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/financing-cap/financial-assurance/managing-payments_en

[8] https://www.eca.europa.eu/Lists/News/ NEWS1610_25 / SR_EN.pdf

[9] G. Pique, R. Fieuzal, A. Al Bitar, A. Veloso, T. Tallec, A. Brut, M. Ferlicoq, B. Zawilski, J.F., Dejoux, H. Gibrin, and E. Ceschia (2020). Estimation of daily CO2 fluxes and annual carbon budgets for winter wheat by the assimilation of Sentinel 2-like remote sensing data into a crop model. Geoderma, in press.

4.2.3. Option 3: SAFY-CO2 - AMG coupling, spatialization of soil carbon stock at the surface

Because of the complementarity between AMG and SAFY-CO2, the coupling of these two models was recently carried out within the framework of the EIT KIC Climat project '*Soil carbon farming*' and the coupled version is currently being evaluated. This new version could also benefit from the computer developments carried out by SIMEOS-AMG and ABC'Terre, as well as from the satellite image calculation chain developed by SAFY-CO2. A priori, the coupled version could be applied to different soil types without the need to re-calibrate the heterotrophic respiration for each soil type.

Finally, also within the framework of this KIC Climate project, different methods of initializing soil carbon stock and soil properties were tested (Global Soil Map, Soil Grids-ISRIC). The uncertainties of the soil parameters (organic C, clay and CaCO3 content, pH and C/N, see Table 6) would be quite high (RRMSE = 18-118%, median = 46%) if "low resolution" soil products (e.g. SoilGrid, GSM, Lucas) were used as input to the model in comparison to measured field data. Using the median values per canton of the BDAT (soil analysis database, GIS Soil), the results would be better (RRMSE = 7-26%, median = 18%, with a correction to be made to the clay values in calcareous soils because the AMG model uses the true clay contents as input). It can be assumed that the uncertainty on analyzed soil samples is lower (around 10%, depending on the representativeness of the plot and the sampling method), with the coefficient of variation between replicates of the same trial being, for example, 4.3% for the organic C stock (Clivot et al 2019). An alternative, currently under development, would be to use remote sensing to evaluate the spectral properties of bare surface soil (first few millimeters) (Sentinel 2, 10 m resolution) in order to obtain high-resolution maps that would make it possible to spatialize these properties on a sub-parcel scale, in comparison with the determination of reference properties on a few samples covering the 0-30 cm horizon. This work is planned in a project submitted to the ESA Worldsoils AAP and is also being developed by a Swiss partner (AgriCircle) in a project funded by the EIT Climate-KIC[10].

This option 3, more comprehensive than option 2, still needs further development, but should provide an advanced methodology for croplands for the low carbon label.

4.3. Sensitivity of the carbon balance estimated by the AMG model to the propagation of uncertainties on the input variables and model parameters

The prediction error of the three options analyzed above depends largely on the propagation of errors. This prediction error is currently being analyzed for options 2 and 3. We present here first results of prediction error for the AMG model. In any deterministic model, such as AMG, the prediction error on the output variables increases with the uncertainty on the input variables and on the parameters. We first analyze the relative uncertainty on the carbon stock in an optimistic scenario of fine measurement of input variables, and then a scenario concerning the propagation of uncertainties in a pessimistic scenario where only regional data would be available.

4.3.1. Propagation of uncertainties in input variables and model parameters under two input data scenarios (fine measurements or regional data)

The sensitivity of the AMG model was studied by Clivot et al. (2019) (Figure 6 of Clivot et al.). For an optimistic scenario where input variables are finely measured (soil properties, yields, etc.), the variation after 5 years of the carbon stock of a soil with median properties was derived from this sensitivity analysis. Two data scenarios were contrasted: an optimistic scenario (fine measurements of input variables) and a pessimistic scenario (simulated or interpolated regional data, no field measurements). For the optimistic scenario, the soil organic carbon stock differential after 5 years varies in half of the cases (interquartile) within a range of ±16% (with extreme variations of ±60%; IV- supplementary figures, figure 7). For the pessimistic scenario, where only regional data (IV- supplementary figures, figure 8) would be available, this differential varies in half of the cases by ±40% (with extreme variations of ±100%).

[10] Carbon Farming: Experimenting Soil Carbon Sequestration Deployment in Farming Systems

4.3.2. Comparison of scenarios without and with carbon storing practices (introduction of intermediate cover and input of organic waste products)

We selected 12 trials from 12 sites in the long-term sites database (AIAL) corresponding to the dataset of Clivot et al. (2019). This allowed us to reduce and attempt to balance the dataset, although it is still somewhat unbalanced for soil lime content (few soils above 200 g CaCO3 kg-1). Two practice scenarios were considered: the cropping system of each site without additional carbon-storing practices; the cropping system with the addition of intermediate crops and the application of residual organic products (PROs, 2.5t C/ha every 2 years). Considering that only regional data would be available, the sensitivity of the soil carbon stock after 5 years was analyzed for each input variable of the AMGv2 model for the negative uncertainty bound and for the positive uncertainty bound. This analysis was carried out for each of the practice scenarios (Figure 2), on the one hand, and for the difference in carbon stock with and without carbon-storing practices (Figure 3).

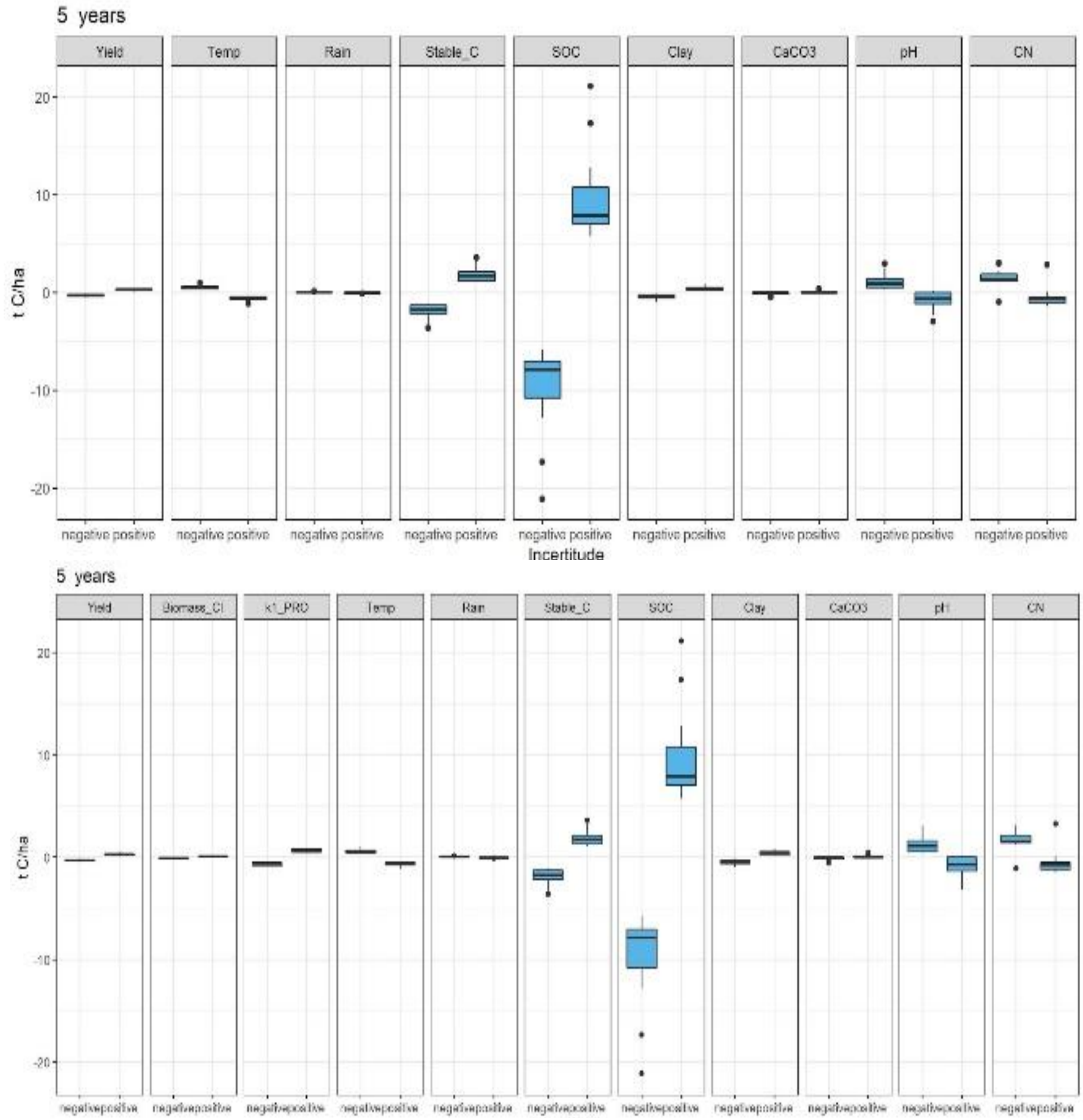

Figure 1. Sensitivity analysis of the final soil C stock after 5 years for 2 practice scenarios: without (top) and with (bottom) intermediate crops and PROs (residual organic products) applications. Influence of the relative uncertainties (negative bound, positive bound) of the input variables and parameters of the AMGv2 model on the C stock. Each box shows the variability of the results for the 12 sites analyzed. The final stock is highly dependent on the initial stock (high sensitivity to the SOC variable).

These data indicate a very high sensitivity of the final soil carbon stock to the initial stock value used to initialize the model, a high sensitivity for soil data such as pH, C/N and stable carbon fraction. A lower sensitivity is observed for the other variables.

In the differential between the two practice scenarios, the sensitivity of carbon sequestration to initial variables and model parameters is strongly reduced in comparison to the results for each practice scenario. In particular, the uncertainties on the initial C stock (SOC) and on the fraction of stable carbon (Stable_C) have no influence on the differential of carbon sequestration between practice scenarios (Figure 3).

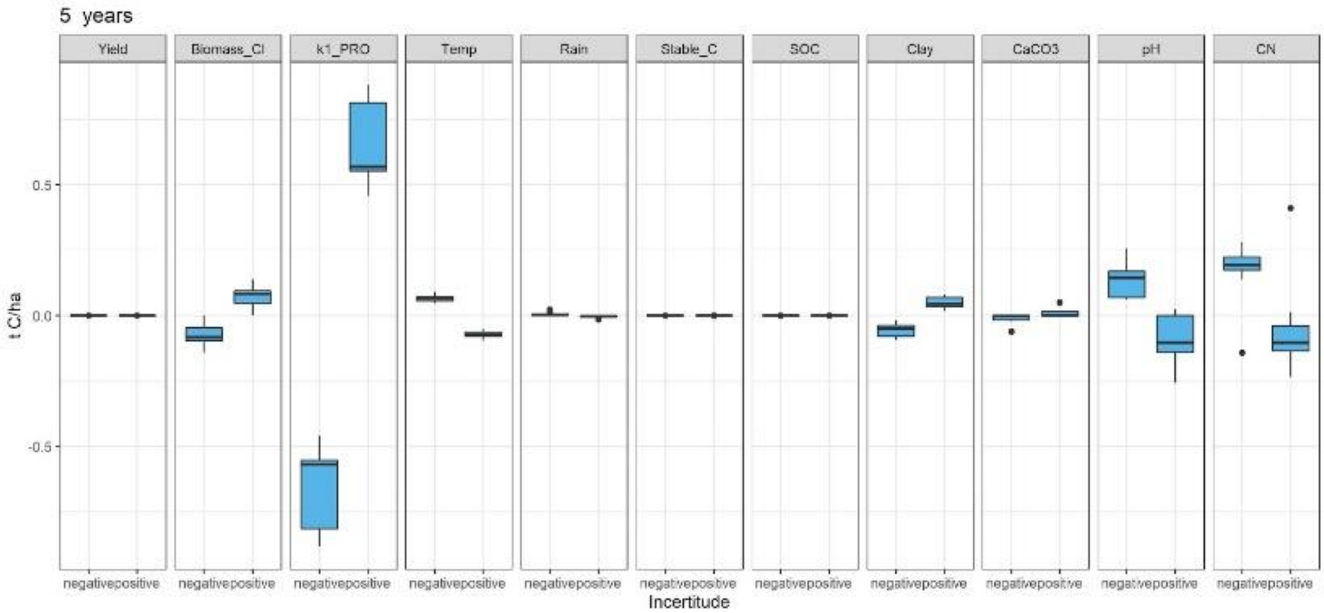

Figure 2. Sensitivity analysis of carbon sequestration after 5 years resulting from the application of carbon storing practices (C.I. and PROs, difference between the two practice scenarios). Influence of the relative uncertainties (negative bound, positive bound) of the input variables and parameters of the AMGv2 model. Each box shows the variability of the results for the 12 sites analyzed.

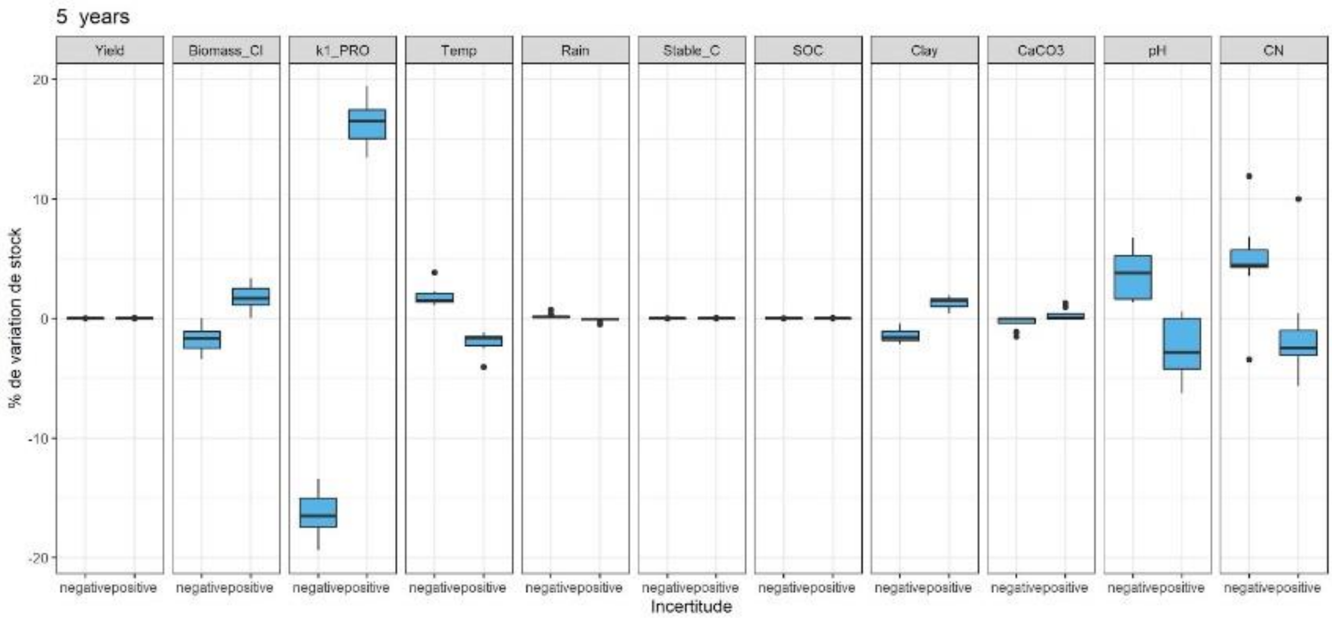

Figure 3Results of Figure 3 expressed as % change in initial C stock. Sensitivity analysis of carbon sequestration after 5 years resulting from the application of carbon storing practices (I.C. and PROs, difference between the two practice scenarios).

For the differential of carbon stocks in the practice scenarios, the effects of the uncertainties on the biomass of intermediate crops and on the humification coefficient of the PROs 'K1pro' are finally the most important on the model outputs (Figure 4); the uncertainty on the yields does not have any influence here because the yields of the main crops are assumed to be identical in the two

scenarios. However, it should be noted that carbon storing practices (such as nitrogen supply) influencing the primary productivity of the main crops and yields would give more weight to the uncertainties on yields in the two practice scenarios.
The other influential variables are those modulating the rate of mineralization of active soil SOM (pedoclimatic factors). The influence of these pedoclimatic input variables (temperature, precipitation, clays, CaCO3, pH and C/N) is about 10 times less on the differential analysis than when the sensitivity analysis is done on absolute C stocks.
We can summarize the main findings of this study with recommendations for data acquisition in Table 6 below.

Table 6. Recommendations for the acquisition of input data for the AMGv2 model. A) to minimise the uncertainty on carbon sequestration resulting from carbon storing practices (difference in stock between practice scenarios). B) to minimise the uncertainty on the absolute value of carbon stock after 5 years in each practice scenario.

input parameters or variables	A) Effect of uncertainties on the difference in C stock at 5 years	A) Recommendations for data acquisition for a stock differential	B) Effect of uncertainties on absolute carbon stocks at 5 years	B) Recommendations for data acquisition for the simulated stock in absolute terms
Initial carbon stock	Low	Regional data with at least one representative soil analysis of the plot	High	Precise measurements of the carbon stock of the surface horizon (0-30 cm)
Stable C fraction			Medium (high in the longer term)	
Rainfall			Low	Regional statistical data
Temperature	Medium (high in the longer term)	Continuous measurements close to the site	Low (medium to longer term)	Measurements close to the site or regional statistical data
pH, clays, CaCO3, C/N ratio	Medium (high in the longer term)	Representative soil analysis at plot level	Medium (high in the longer term)	Representative soil analysis at plot level
Biomass from cover crops	High	Evaluation by calibrated remote sensing on the soil	Low	Remote sensing assessment
Amount of carbon in PROs and its stability (K1_PRO)	High	Precise measurements	Low (medium to longer term)	Average data by product type

Two studies have compared the performance of AMGv2 to simulate C stocks in absolute or differential terms with pairs of reference treatments *vs.* carbon storing practices:

- In the case of PRO applications, the AMG model simulates the carbon stock with an average RMSE of 4.3 t C/ha for the PRO treatments (RMSE = 2.77 t C/ha for their controls). The average RMSE for stock differentials between PROs and controls is lower, at 3.0 t C/ha (Levavasseur et al., 2020). Thus, there is less error in the stock differential between two practices compared to the error in the absolute C stock estimate.

- For the restitution of straw and cover crops, new simulations with AMGv2 of part of the data from Saffih Hdadi and Mary 2008 (H. Clivot, personal communication) show that, on average, the model's error is also smaller for simulating a C stock differential between two practices (average RMSE = 1.7 t C/ha) compared to the error on the C stock (RMSE = 2.4 t C/ha for treatments with straw or ryegrass cover, RMSE = 1.95 t C/ha for the control modalities)

In both cases, the model error (RMSE) is reduced by 30% when estimating a stock differential between 2 practices rather than C stocks.

4.3.3. The error on stock changes for systems with high C sequestration compared to a control system

For trials that allow the model to be initialized with precise site measurements and that have an average carbon stock greater than 1 tC /ha, the relative error (RRMSE) of the model for carbon sequestration resulting from carbon-storing practices is on average 29% for trials with straw or cover restitution (H. Clivot, personal communication) and 28% for PRO inputs (Table 1 in Levavasseur et al.

2020), i.e. an error of about 30% on the difference in stock with versus without carbon-storing practices. The carbon storing practices simulated in the model's sensitivity analysis compared to the baseline scenario show a strong increase in carbon stock after 5, 10, 20 and 30 years (Figure 5). The annual variations in C stocks reach +0.5 to +0.8 tC/ha/year compared to the control systems (Figure 5). Figure 6 shows the relative error of the model (RRMSE) compared to these stock variations.

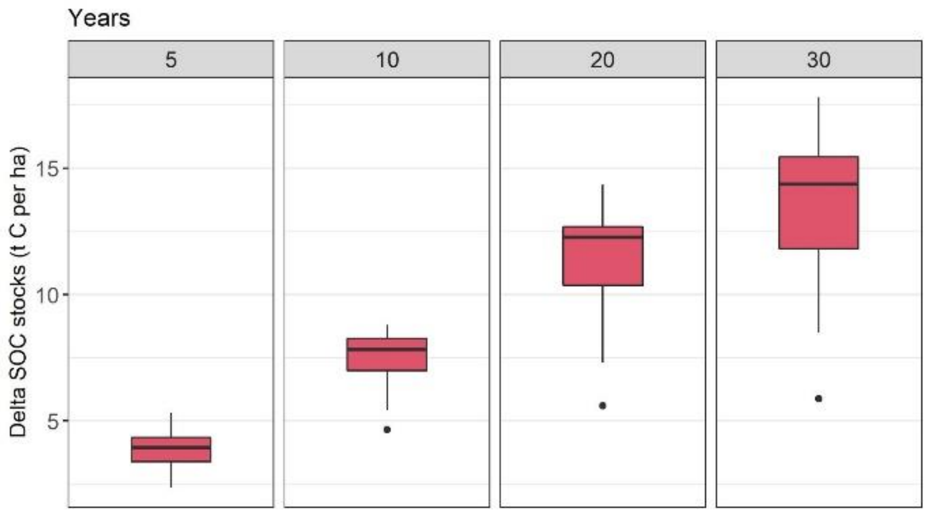

Figure 4: Variability of simulated stock variations for carbon storing systems (I.C. + PRO 2.5 t C/ha every 2 years) on the 12 sites selected in the AIAL database, compared to controls without carbon storing practices at 5, 10, 20 and 30 years.

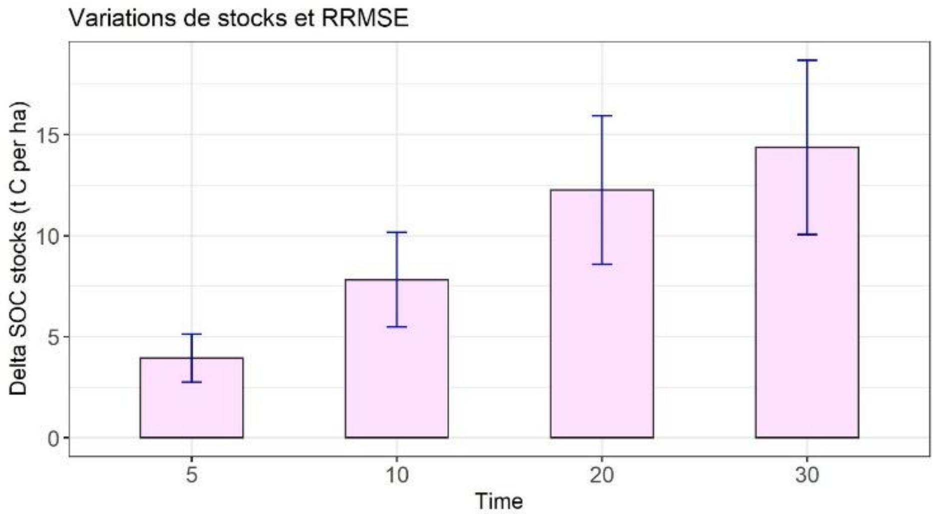

Figure 5: Median values of simulated stock changes (carbon storing systems vs. controls). The error bars correspond to the relative error of the model (RRMSE = 30%) at 5, 10, 20 and 30 years.

In conclusion, these sensitivity and uncertainty analyses lead to recommendations concerning the measurements and data to be used as input to the AMGv2 model (Table 6) in order to reduce the uncertainty either on the evolution of the soil carbon stock or on the carbon sequestration resulting from the application of carbon-storing practices. In the most favourable cases (practices allowing high sequestration, measurements and initialization data following these recommendations), the uncertainty on the sequestration resulting from the application of practices would reach about 30%. This uncertainty is much smaller than the uncertainty on the absolute value of the carbon stock for a given scenario of practices. The use of a differential between the baseline scenario and the scenario with carbon storing practices also makes it possible to encourage carbon storing practices in all situations, including for farmers whose soils are losing C but less than the baseline.

4.4. Integration of the principles of the low carbon label for the writing of a methodology

To qualify for the Low carbon label (LBC[11], an emission reduction project must comply with a method approved by the Authority - the DGEC of MTES. Point III.B of the LBC reference framework defines the mandatory fields of a method, which are detailed in a pedagogical guide [12]built by I4CE in partnership with the MTES. Any natural or legal person can propose a method to the Authority, which will be responsible for its approval. Based on the results of the literature review on existing methodologies in France and abroad, we propose recommendations for writing a method when applicable.

4.4.1. The scope

The scope of a method informs the type of projects to which it applies. It includes:

- The practices covered
- Emissions linked to these practices and which are accounted for (direct, indirect, anticipated emissions)
- The list of GHGs taken into account.
- Any innovation that achieves emission reductions

A method with a broad scope, covering a large number of practices and concerning the main GHGs linked to agricultural activity is desirable (CO_2, N_2O, CH_4, etc.). This will make it easier for project leaders to choose a method and will enable them to identify more easily the levers that concern them.

4.4.2. Practices and their combinations

The results of the national study conducted by INRAE (formerly INRA) with regard to the 4p1000 objective have made it possible to identify carbon-storing practices in arable farming:

- Insertion or extension of intermediate crops
- Insertion and extension of the time spent on temporary grassland
- The mobilization and supply of additional exogenous organic matter to the soil
- The development of intra-plot agroforestry
- Planting of hedges and grassing of inter-rows in vineyards

The additional sequestration potential linked to the adoption of carbon-storing practices is greater in arable crop systems, which account for 86% of the total additional carbon storage potential. The practices with the highest carbon sequestration potential in croplands are:

- Extension of intermediate crops (35% of total potential)
- Intra-plot agroforestry (19% of total potential)
- Insertion and extension of the time temporary grasslands are present (13% of total potential).

A recent simulation complementary to[13] the study's synthesis showed that the simultaneous implementation of three carbon-storing practices (extension of intermediate crops, insertion and lengthening of temporary grasslands, mobilization of new organic resources) allows, on average, an additional sequestration of +184 kgC/ha/year on the 0-30cm horizon.

The results of the simulation study also highlighted the drivers of carbon storage variation: the initial carbon stock, the composition of the cropping sequence, the soil texture and pH, and the climate. A low initial carbon stock is often associated with a higher sequestration potential because carbon-storing practices are generally not well developed. The lowest stocks are observed in several lowland areas

[11] Décret n° 2018-1043 du 28 novembre 2018 créant un label « Bas-Carbone » et arrêté du 28 novembre 2018 définissant le référentiel du label « Bas-Carbone ».

[12] Guide pédagogique du label bas-carbone: https://www.ecologie.gouv.fr/sites/default/files/LabelBasCarbone-GuidePedagogique-Mai2020.pdf

[13] Julie Constantin, Camille Launay, Sylvain Pellerin, Olivier Réchauchère, Olivier Thérond, 2020. Effet du changement climatique sur le stockage de carbone dans les sols de grandes cultures. Complément au rapport « Stocker du carbone dans les sols français : quel potentiel au regard de l'objectif 4 pour 1000 et à quel coût ? »

(Paris Basin, Aquitaine Basin, Rhone corridor, Alsace). However, areas where the practice of intermediate crops is little or not used have a significant sequestration potential despite high initial stocks (e.g. insertion of intermediate crops in Poitou-Charentes)

The simultaneous implementation of compatible carbon-storing practices can increase the additional sequestration of soil carbon, especially when local conditions are favourable (carbon-storing practices are not well developed), and several additional practices are possible

The method must specify the maximum period of validity of the Project. If this is longer than 5 years, the particular conditions of application over the chosen period must appear in the method.

The accounting period for emission reductions may be longer than or equal to the project's validity period. Indeed, it is possible that the crediting period be longer than the validity period of the Project provided that emission reductions are achieved beyond the validity date of the project. (Point IV.C. of the baseline).

The crediting period for emission reduction projects at the international level is highly variable (5 to 100 years) and tends to be between 10 and 30 years for projects taking into account carbon sequestration.

4.4.3. The baseline scenario

Each method needs to define a baseline scenario and demonstrate the additionality of the emission reductions.

The baseline scenario is what would have happened in terms of emissions without the project, in other words, it is the *status quo* or continuation of trends. It can be specific to a project or generic for a type of project. In the latter case, a discount will be applied (point III.C.2.b of the LBC baseline). The baseline scenario can be determined from the scientific literature giving the most recent sequestration /emission rates in relation to a given perimeter (IPCC default factors, data from national studies such as the national study conducted by INRAE or from soil databases (e.g. RMQS, BDAT, etc.).

The baseline scenario must also take into account the legal obligations already in place to encourage better practices and to encourage further emission reductions (III.C.1 of the standard). This implies that emission reductions that would have taken place in the absence of the project being labelled cannot be recognized in the framework of the label. Moreover, the label only takes into account emission reductions resulting from actions undertaken after the notification of the project to the Authority in order to ensure the condition of additionality of projects. The term "additionality" therefore refers to what the labelled Project will bring in addition in terms of emission reductions and only when it goes beyond what is required from a regulatory point of view compared to the baseline scenario. This additionality rule may therefore be penalizing for those who have put in place emission reduction levers before the LBC appears or before the project is notified to the Authority. However, it could be considered that the maintenance of carbon storing practices can be encouraged, since their cessation would create a rapid loss of soil carbon.

The method could consider that the practices voluntarily put in place in the 10 years preceding the project are additional. This would allow the efforts put in place before the label appeared to be taken into account.

4.4.4. Discounts for non-permanence risk :

Various discounts are identified in the LBC's baseline and should be included in the method. They are intended to compensate for the risk of overestimating emission reductions:

- The discount related to the degree of uncertainty in the variables affecting the estimates. The degree of uncertainty for the influential variables integrates the intrinsic uncertainty on the value of the variable (e.g. measurement uncertainty) and the uncertainty on the representativeness of the variable used for the Project. However, the characteristics for determining a low, medium or high level of uncertainty are not described in the LBC reference framework, so they could be done in a quantitative way (see part 3) or by expert opinion depending on the case.

After determining the degree of uncertainty, a discount is applied according to the criteria in Table 2 below:

Table 7: Levels of uncertainty and corresponding discounts to be applied under the LBC

Degree of uncertainty	Discounts to be applied
Low	No
Medium	Discount to be determined so that in 80% of cases emission reductions are underestimated
Fort	Discount to be determined so that in 95% of cases emission reductions are underestimated

The method of allocating uncertainty discounts in the SALM methodology may be a source of inspiration for method writers to submit to the LBC. The details of the calculation of the *UNCt* uncertainty (equation 15, page 27[14]) are provided for the Roth C model only. However, these principles are applicable to another model (such as AMG) if it has some or all of the parameters listed in the methodology.

The emission reductions (ER) of the project are adjusted (RE-adjusted) according to the *UNCt* uncertainty. In summary:

- $UNC_t < 15\%$.
  No discount

- $15\% < UNC_t < 30\%$:

Discount = ER x (UNC_t -15%)
RE-adjusted = RE-discount

- $UNC_t > 30\%$: the project owner should increase the sample size of the input data until the uncertainty is better.

The risk of non-permanence of emission reduction activities can be addressed in one of two ways:

- For any type of emission reduction accounted for, the application of a discount of at least 10%.

- For anticipated emissions, it is possible to consider a "hazard scenario" in which accidental/natural hazards that could reduce long-term sequestration are taken into account. The change in the long-term average carbon stock with this 'hazard scenario' is then reduced by the long-term average carbon stock change in a reference scenario (with continuation of trends). The reference framework does not specify the implementation modalities; they must be made explicit in the method.

For the risk of non-permanence, a discount of at least 10% is recommended, following the example of other methods with discounts of up to 20%. Example of Alberta with a range of 7.5 to 12.5% (based on the probability of non-permanence of sequestered carbon) and 20% in Australia (based on the cost of restoration of the project in case of non-permanence).

[14] https://verra.org/wp-content/uploads/2018/03/VM0017-SALM-Methodolgy-v1.0.pdf

4.4.5. The verification procedure

Different methods with various degrees of accuracy and cost may be used for verification depending on the activities undertaken to reduce emissions.

Initially, the verifications can be done on a declarative basis. They also make it possible to identify the inputs used to calculate carbon balance: application of organic or mineral amendments, biochar, export or not of straw, etc. The case of biochar is particular, because the models are not yet or only slightly parameterized for this type of product and if they are, the parameterizations are based on little data. This leads to a high degree of uncertainty, which should be reflected in the method.

For the verification of the presence or absence of plant cover, a staggered approach throughout the accounting period can be proposed. Indeed, the project leader can indicate the presence or absence of plant cover, which will be confirmed by satellite imagery at periods predefined in the contract. In addition, the verification can be more precise with the calculation of the leaf area index (LAI), again via satellite.

It is prudent to have soil sampling followed by laboratory analysis at least once during the project. Such a measurement at mid-term and according to an ISO standard, for example, could be decisive in confirming the viability of the project. However, it should be remembered that the evolution of soil carbon stock is slow with carbon storing practices (in the order of +1 to +2% after 5 years). This slow evolution will not be detectable by direct analysis of the soil carbon stock, the order of magnitude of the uncertainty on the stock being 4 to 5%, even with precise measurements on the site.

It is prudent to have sampling followed by laboratory analysis at least once during the project. Satellite monitoring could be a good alternative to confirm the presence or absence of vegetation cover. A draft standard for measuring soil C (and N) stocks is underway and could serve as a reference (ISO/DIS 23400
Guidelines for the determination of organic carbon and nitrogen stocks and their variations in mineral soils at the plot scale)

ADDITIONAL FIGURES

Parameters and input variables considered for the simplified analysis: yield, temperature, rainfall, percentage of active soil carbon, clay content, pH, C/N ratio and calcium carbonate content CaCO3.

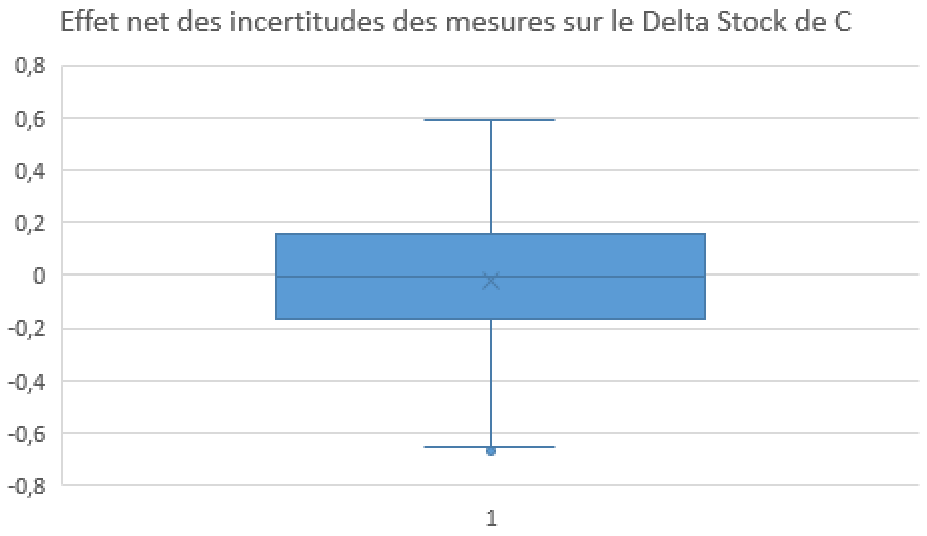

Figure 6: Net effect calculated from 100 random draws. 1st quartile = -0.167; 3rd quartile = 0.157

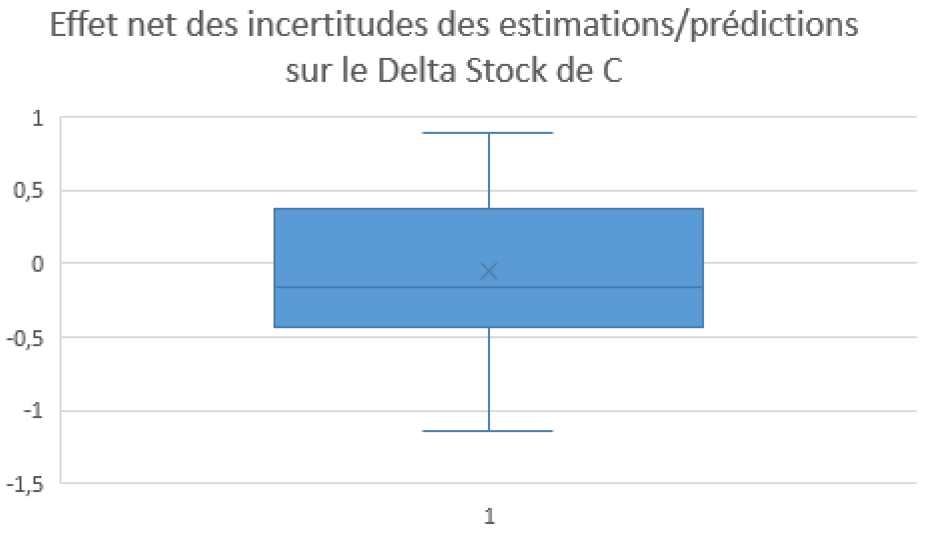

Figure 7: Net effect calculated from 100 random draws. 1st quartile = -0.434; 3rd quartile = 0.367

5. Conclusion

The creation of the Low-Carbon label is an opportunity for the development of emission reduction projects in the French agricultural sector. This framework requires scientific rigor that guarantees the economic, environmental and social reliability of labeled projects. As a result, the choice of methodologies for calculating emission reductions, and in particular for carbon sequestration in the soil, requires great attention to the nature of the input data, the uncertainties associated with them and the impact of these on the outputs. With the example of the AMG model, we were able to highlight, on the one hand, a very high sensitivity of the final soil carbon stock to the initial stock value used for the initialization of the model, a high sensitivity for soil data such as pH, C/N and the fraction of stable carbon, and a lower sensitivity for the other variables. On the other hand, by comparing the performance of the AMG model to simulate C stocks in absolute or differential terms with pairs of reference treatments vs. carbon storing practices, the model error (RMSE) is reduced by 30% for an estimation of a stock differential between 2 practices rather than of C stocks. Indeed, in the most favourable cases (practices allowing high sequestration , measurements and initialization data following our recommendations regarding the sensitivity of input data in (Table 6) and simulating differential carbon stocks, the uncertainty on sequestration resulting from the application of the practices would reach about 30%. This uncertainty is significantly lower than the uncertainty in the absolute value of the carbon stock for a given practice scenario. Moreover, the use of a differential between the reference scenario and the scenario with carbon storing practices makes it possible to encourage carbon storing practices in all situations, including for farmers whose soils would destock C but less than the reference.

It is therefore important to take field measurements into account in the calculation methods in order to reduce uncertainties. From this perspective, the methodology based on the Rock-Eval® tool for predicting the proportion of stable soil organic carbon on a century scale could be deployed on the RMQS soil samples (planned for the Centre Region as part of the ANR StoreSoilC project). This will enable a national map of stable soil organic carbon stocks on a century scale to be produced; this map could be used to systematically initialize the size of the stable carbon pool of soil carbon dynamics models (Barré et al., 2019) on a territorial scale (MAELIA/ABC'Terre). In addition, the monitoring and verification procedure inherent in the method chosen by the project leader should contain at least one direct measurement during the project's validity period to ensure the effective carbon sequestration into the soil. On another note, data acquired by satellite remote sensing can provide information on the quantities of above-ground biomass produced by different crops (cash crops, cover crops) which will also make it possible to refine the parameterization of the models. This is what we propose with the SAFY-CO2/AMG coupling in option 3 of our recommendations (part III), which is also the most compatible with European ambitions to move towards large-scale carbon balance assessment and monitoring methods. Even if this coupling is still in the test phase, this new perspective could eventually facilitate the verification of carbon balances over time (between t0 and tx) in a logic of monitoring, reporting and verification from the plot to the farm and over large areas.

Our results were submitted to the working group developing the LBC method for croplands, which took a number of our recommendations into account, and discussions are ongoing to serve the common interest in the development of a voluntary carbon market in France.

6. Annexes Methodology sheets

6.1. Data sheets on tools (notably models) used to assess and monitor carbon footprints in France and abroad: AMG, STICS, RothC, FullCAM, Rock-Eval ®, CAP'2ER ®.

6.1.1. AMG

Use: Simulation model of the dynamics of organic carbon in the soil under the influence of agricultural practices and according to soil and climate characteristics.

General information
Origin: France
Author: INRAE, Laon.
Publication: v1 1999, v2 2019
Spatial scale: plot, homogeneous soil unit
Time scale: annual
GHGs concerned: CO_2
Model type: soil carbon dynamics
Applicability: 146 crops (main, catch crops and intermediates), 30 types of organic waste products (PROs)

Monitoring of the model by the consortium of partners INRAE, Agro-Transfert-RT, Terres Inovia, Arvalis.

Description
The AMG model is a simple semi-mechanistic model with three compartments. The first compartment, of incoming fresh organic matter (MOF), is made of residues and organic waste products (PROs). The humified organic carbon (C) in the soil is made of two compartments: one is said to be "active" and decomposable, fed by the MOF, while the other is considered "stable", i.e. inert on the scale of the duration of a simulation (a few decades at least). Three major parameters must be considered: the humification coefficient of the C inputs over time (depending on the type and quality of the SOM), the annual mineralization coefficient of the active organic C in the soil (depending on the soil and climate conditions) and the partition coefficient between active and stable C at the beginning of the simulation (depending on the history of practices and land use or estimated by the Rock-Eval® method; *see the* "Rock-Eval® " sheet).

Data

Input	Output	Data sources
- Soil data (C org. content, clay, CaCO3, pH, C/N, bulk density, coarse elements) - Annual climate data (temperature, potential evapotranspiration, precipitation) - Data on agricultural practices (irrigation, tillage), crop rotations, yields and/or measured input biomass	- Soil organic C stock and concentration - Fluxes of biomass returned to the soil, associated humified organic C and decomposed active soil organic C (ha-1.year-1)	Allometric characteristics of crops Humification coefficients of crop residues and PRO

For more information: https://www6.hautsdefrance.inrae.fr/agroimpact/Nos-dispositifs-outils/Modeles-et-outils-d-aide-a-la-decision/AMG-et-SIMEOS-AMG
Andriulo A. et al, 1999[3], Clivot H. et al, 2019[4]

6.1.2. STICS

Use: Simulation model of plant growth and nitrogen, carbon and water fluxes in the soil-plant system, under the influence of climate and agricultural practices.

General information
Origin: France
Author : INRAE
Publication: 1996, latest standard version in 2019 (v9.1)
Spatial scale: plot, homogeneous soil unit
Time scale: daily
GHGs concerned: CO_2, N_2O
Applicability: arable crops, temporary grassland
Type of model: soil-plant

Description
STICS is a soil-plant model that simulates the carbon (C), water and nitrogen (N) balances of the soil-plant system on a daily time step and can simultaneously estimate agricultural and environmental variables (e.g. crop yields, N content of harvested cereals, soil water and mineral N content, N leaching and soil organic carbon dynamics) taking into account the impact of soil, crop and management practices (e.g. mineral and organic fertilization, irrigation, tillage and residue management). It has been designed as a generic model that can be easily adapted to various types of crops and environmental conditions. It can be used to simulate a cropping period or a cropping succession over several years. The formalisms used to simulate the evolution of soil organic carbon are similar to those of AMG.

Data

Input	Output	Data sources
- Soil data (C and N content, clay, CaCO3, pH, C/N, bulk density, HCC, HPF, coarse elements) - Daily climate data (minimum and maximum temperature, precipitation, potential evapotranspiration, global radiation) - Cultivation data: sowing and harvesting dates, species and varieties, density and depth of sowing, date and dose of irrigation, date and depth of tillage, date, nature and dose of nitrogenous fertilization, straw management	Agricultural variables: yield, biomass, quality of harvested organs (oil and N content) Environmental variables: soil organic C and N stocks, H2O balances (drainage, real evapotranspiration), nitrate leaching, CO2, N2O, NH3 and N2	

For more information:
https://www6.paca.inrae.fr/stics/Qui-sommes-nous/Presentation-du-modele-Stics
Brisson et al, 2003 [5] ; Coucheney et al, 2015[6]

6.1.3. CarSolEl project metamodel

Use: The metamodel developed in the CarSolEl project is intended to predict variations in soil organic carbon stock for permanent grassland systems and crop rotations with or without temporary grassland. It is a simple model to use: its input variables are limited in number and designed to be available in operation; and it has an interface that facilitates input.

General information
Origin: France
Year of design: ongoing (CarSolEl project - expected delivery end 2021)
Author : IDELE-INRAE
Spatial scale: plot, homogeneous soil unit
Time scale: annual average over 30 years
GHGs concerned: CO_2, N_2O
Model type: Statistical metamodel
Applicability: permanent grassland, arable crops, temporary grassland
Underlying model: Stics and Pasim.

Description
The CarSolEl metamodel is a summary of the Stics and Pasim models for soil carbon sequestration, obtained statistically from the national 4p1000 study database. Basically, this metamodel is a set of six random forests, corresponding to two soil depths x three types of cover: permanent grassland, arable crop rotations only, and rotations with temporary grassland. Depending on the type of cover, the model takes as input between 20 and 25 parameters corresponding to the soil and climate conditions and the management of the areas.
The metamodel can be used to calculate changes in carbon stocks either
i) directly under the free software R (faster for a large number of input parameter sets)
ii) through the Rshiny application, which facilitates the entry of input of data, in particular with the possibility of selecting a geographical area to propose a default parameterization of pedoclimatic conditions. Eventually, the Rshiny application will be available through a simple web browser, without knowledge of R.
A first version of the metamodel and its interface has been developed and is being tested.

Data

Input	Output	Data sources
- Climate: type of climate, minimum and maximum temperature, rainfall - Soil: initial organic C stock, depth, coarse material content, pH, limestone content, clay content, sand content, texture - Soil cover: permanent grassland / croplands / grassland-crop rotation, length of rotation, share of grassland in rotation, share of intermediate crops - General management: mineral nitrogen fertilization, organic fertilization (quantity and type), irrigation - Grassland management: mowing/grazing, annual dry matter mowed, number of grazing passes, and annual grazing pressure (days*UGB)	Average soil organic C change per year (kg $C.ha^{-1}.year^{-1}$, calculated over 30 years) : - on the 0-30 cm layer - on the total depth of the soil (maximum 1m)	The input data (entered manually on the interface or in files) can have various sources; everything can be entered from the farmer's data (practices, soil analyses, etc.). The interface also gives the possibility of using the pedoclimatic data of the 4p1000 study: geographical database of French soils (BDGSF, from INRAE Infosol), Météo-France SAFRAN data (processed by INRAE Agroclim).

For more information: CarSolEl project; laure.brun-lafleur@idele.fr; Helene.Chambaut@Idele.Fr

6.1.4. Rothamsted Carbon: Roth-C

Use: The main purpose of the model is to calculate changes in soil organic carbon stock in relation to carbon inputs, for cropping systems and forests. It can be used to predict past or future long-term carbon changes in relation to climate change. The model requires the specification of soil carbon inputs and therefore does not include a biomass production module. In reverse mode, it is used to find out what quantities of carbon entering the soil would be needed to reach a given level of carbon stock. It is a very simple model to use and has a small number of input variables and parameters. The model has been used extensively around the world since the 1990s, and this wide use has, over time, provided evidence for the validity of the model in different contexts.

General information
Origin: England
Author: IACR **-** Rothamsted (Coleman and Jenkinson)
Published: 1990
Spatial scale: plot
Time scale: monthly
GHGs concerned: CO_2
Type of model: soil organic carbon dynamics
Applicability: croplands, grasslands, forests

Description
Roth-C is a simulation model of soil surface organic carbon dynamics (except for wet soils, organic soils and andosols) taking into account soil type, temperature, moisture and vegetation cover. The model was originally developed to calculate carbon emissions/sequestrations for the implementation of particular agricultural practices. It is a compartmental model, one of which represents inert soil organic carbon (with a very high residence time). The other four compartments represent carbon derived directly from plant residues (RPM and DPM), contained in microbial biomass (BIO) and humified forms of organic matter (HUM). In the agricultural context, most of the practices are represented by modulations of carbon inputs into the soil, in quantity and quality. Only the practices that determine the periods of soil cover and irrigation have an impact on the levels of carbon mineralization.

Data

Input	Output	Data sources
-Temperature, precipitation, evapotranspiration - Irrigation - Nature of cover (croplands, grasslands, forests) - Soil data (percentage of clay, depth of sampled soil layer), initial organic carbon stock (and proportion of inert carbon). -Soil cover (bare or covered) - Monthly input of plant residues (including carbon released from roots during crop growth) - Input of organic amendment - Composition of the organic material supplied (amendments and crop residues)	- Total organic carbon (t. ha^{-1}) - Carbon in the different compartments including microbial biomass (t. ha^{-1}) - $\Delta^{14}C$ (from which the radiocarbon equivalent age of the soil can be determined)	The input data (entered manually on the interface or in files) can have various sources; everything can be entered from the farmer's data (practices, soil analyses, etc.).

For more information: https://www.rothamsted.ac.uk/rothamsted-carbon-model-rothc

6.1.5. Fully integrated Carbon Accounting Model: FullCAM

Use: FullCAM is a model for assessing and monitoring greenhouse gas emissions and carbon stock changes related to different management practices. It can estimate and predict all biomass, waste and soil carbon stocks in agricultural and forestry systems. It can also be used more simply to examine the results of smallholder land-use projects. For national inventories, Fullcam provides the ability to model on a national scale while having fine spatial resolution.

General information

Origin: Australia

Published: 1997

Author: Australian Government, Dpt. of the Environment

Spatial scale: 25 m

Time scale: monthly

GHGs concerned: CO_2, N_2O, CH_4

Type of model: soil carbon dynamics

Applicability: forests, croplands, grasslands

Description

FullCAM consists of 3 models that can be run individually in isolation or in any other combination depending on the output data required:

- CAMfor (Carbon Accounting Model for Forestry Models carbon cycling in a forest, including the trees, debris and soil. Forest growth can be included as yield curves, empirical growth formula, or process modelling).
- CAMAg (Carbon Accounting Model for Agriculture Models carbon cycling in an agricultural system, including the crops, debris, soil, minerals, and agricultural products. Includes both cropping and grazing.)
- Roth C (Rothamsted Institute active soil Carbon model →Models the carbon cycle in active soil).

Data

Input	Output	Data sources
• Data to be entered by the user according to the objectives • Default data available by species and management practices	• Carbon stock • Carbon fluxes • Sensitivity analysis (via Monte Carlo approach)	

For more information: https://publications.industry.gov.au/publications/climate-change/climate-change/climate-science-data/greenhouse-gas-measurement/land-sector.html

6.1.6. Rock-Eval

Use: Originally, the Rock-Eval® tool is a thermal analysis technique standardized in the oil industry to estimate the petroleum potential of a mother rock. For the past twenty years, this tool has also been used to characterize soil organic matter and more recently to determine the amount of stable organic carbon at the century scale in the soil (Cécillon et al., 2018; Biogeosciences). The amount of stable soil organic carbon estimated by this method can be used to initialize the partition coefficient between active and stable C in the AMG soil carbon dynamics model (*see* 'AMG' sheet), which improves the accuracy of AMG simulations.

General information
Origin: France
Manufacturer of the Rock-Eval® analyser: Vinci Technologies
Authors: Cécillon et al (2018; Biogeosciences; https://doi.org/10.5194/bg-15-2835-2018)

Description
Method based on the rapid thermal analysis (about 45 minutes/sample) of a sample in 2 phases: a pyrolysis phase and a second phase in the presence of oxygen, with monitoring of the gases evolved during both phases.
At the end of the analysis, the organic and inorganic C concentrations of the soil sample are obtained. Information is also obtained on the bulk chemistry (O and H content of the organic matter) and the thermal stability of the organic matter in the sample. Recent work shows that some Rock-Eval® parameters are strongly correlated with the biogeochemical stability of soil organic C (Barré et al., 2016; Biogeochemistry).
A statistical model (Cécillon et al., 2018, Biogeosciences) using a series of Rock-Eval® parameters of a soil sample as inputs allows to estimate the amount of stable organic C on a century scale in this sample.
The amount of stable soil organic carbon estimated by this method can be used to initialize the partition coefficient between active and stable C in the AMG model (*see* 'AMG' sheet) at the beginning of the simulation, which improves the accuracy of simulations of the evolution of soil organic carbon stocks in cultivated soils (demonstration on 10 long-term agronomic trials in France; ANR StoreSoilC project, Eva Kanari's thesis; EGU communication Barré et al. (2019)).

For more information: Barré, P., et al., 2016[7]; Cécillon, L. *et al.,* 2018[8]; Barré, P. *et al., 2019*[9]

6.1.7. Automated Calculation of Environmental Performance in Ruminant Farming: CAP'2ER®.

Use: Calculation tool for evaluating the environmental impacts on the scale of a ruminant farm and by production system (dairy cattle, beef cattle, beef sheep) with the aim of raising awareness and implementing action plans. CAP'2ER® also makes it possible to link environmental, technical and economic performance.

General information

Origin: France
Author: Institut de l'élevage (IDELE)
Design year: Excel format (2012), computerized tool (2015)
Spatial scale: farm, livestock/plant production systems
GHGs concerned: CO_2, N_2O, CH_4
Applicability: ruminant farms
Type of tool: based on emission factors, empirical data and carbon storage/loss packages from the literature.

Description

Calculation principle similar to a life cycle analysis (LCA) up to the farm gate with the inclusion of emissions linked to inputs. The analysis can be done at two levels: by production system (level 1, to raise awareness) or at the farm level, taking into account several production systems (level 2, for the implementation of an action plan). For a production system generating several products, an allocation of environmental impacts is made for them.

Data

Input	Output	Data sources
Details of the different emission sources in the methodological guide (see link below)	• Direct energy consumption (fuel oil, electricity used on the farm) and indirect energy consumption (manufacture and transport of inputs) • Greenhouse gas emissions contributing to climate change • Water quality (nitrogen and phosphorus losses, eutrophication potential) • Air quality (air acidification) • Carbon sequestration and net carbon footprint (grasslands and crops with and without rotations) • Biodiversity (indicators for maintaining biodiversity) • Nurturing performance	• IPCC Tier2 factors, 2006 • Dia'Terre version 3.45 (2014) • Ecoinvent (2012) • Agribalyse version 1.1 (2014) • EMEP Corinair, 2013 • Dollé et al, 2013 • Mondferent (2013)

For more information: http://idele.fr/no_cache/recherche/publication/idelesolr/recommends/guide-methodologique-cap2er.html

6.2. Fact sheets on methodologies developed or being developed in France and abroad for the evaluation and monitoring of emission reductions:

6.2.1. CarbonAgri

Use: Method of accounting for emission reductions for additional projects wishing to obtain the Low-Carbon Label.

General information
Origin: France
Author: IDELE
Publication: September 2019
Spatial scale: farm, production system (animal or plant)
Time scale: annual
GHGs concerned: CO_2, N_2O, CH_4
Underlying tool: CAP'2ER ®.
Applicability: mixed-farming system

Description
Method for monitoring emissions reductions in cattle and cropland farms approved by the Low-Carbon Label. The method's levers concern six sources of emissions, namely herd management and feeding, animal waste management, crop management, fertilizer and energy consumption, and carbon sequestration by soils and biomass.

Data

Input	Output	Data sources
• Livestock data • Surface area data • Energy consumption data • Corresponding emission factors	Net emission reductions	IPCC Guidelines, 2006 Agribalysis IMPACT ADEME's carbon database Study results : • "What is the potential for the 4p1000 objective and at what cost? » • GESTIM+

For more information: https://www.ecologique-solidaire.gouv.fr/sites/default/files/M%C3%A9thode%20%C3%A9levages%20bovins%20et%20grandes%20cultures%20%28Carbon%20Agri%29.pdf

6.2.2. SAFY-CO2, Simple Algorithm For Yield and $_{CO2}$ flux estimates:

Use :

- Estimation of above-ground and below-ground biomass, yield,
- Estimation of C balance variables: CO_2 flux (photosynthesis, soil and plant respiration), C export at harvest
- Estimation of water balance components in coupled mode with the water module (SAFYE-CO2 version; see Veloso 2014)
- ➔ Model to test the impact of certain standard practices (intermediate cover, straw export) on the flows and balances, in particular of C.

General information

Origin: France

Author: Cesbio, Toulouse

Publication: SAFY-CO2 and SAFYE-CO2 2014[1], SAFY-CO2 2020[2]

Spatial scale: plot (or even 10m)

Time scale: daily

GHGs concerned: CO_2

Type of underlying model: agro-meteorological

Applicability: croplands (wheat, sunflower, maize, rape) and intermediate crops/shrubs/weeds

Description

The SAFY-CO2 model is an agro-meteorological model operating at a daily time step assimilating optical remote sensing data (dynamic LAI maps) to estimate crop production and carbon balance components at an annual time step. It uses the Monteith approach to calculate gross primary production (GPP). Autotrophic respiration (Ra) is separated into maintenance and growth respiration. The net primary production (NPP, which is the difference between GPP and Ra) is then divided into aerial and root fractions. The dry above-ground (DAM) and root biomass are then calculated from the above-ground and root NPP considering the carbon content of the tissues. The above-ground biomass is then converted into 1) LAI through a leaf partitioning function and 2) into yield at the end of the growing period through a harvest index (HI). Soil respiration (heterotrophic respiration) is calculated using a simple Q10 function of temperature. There is no module simulating the evolution of soil organic matter in the current version of the model (coupling with AMG in progress). The NEE is calculated at a daily time step taking into account the GPP, Ra and Rh, and then aggregated to an annual scale (cropping year). The annual carbon balance is calculated taking into account the annual NEE and the amount of C exported at harvest (yield).

Data

Input	Output	Data sources
LAI and crop maps Global radiation, temperature (and rainfall for the version coupled with a water module = SAFYE-CO2) Information on whether or not straws are exported, the amount of C supplied by organic amendment.	Above-ground and below-ground biomass, LAI, yield, photosynthesis, autotrophic and heterotrophic respiration NEE, C-balance (evaporation and transpiration when coupled with a water module).	RPG or crop map produced by remote sensing for land use LAI product THEIA for France or Copernicus for Europe Climatic data SAFRAN (Météo France) for France, ERA5 (ECMWF) for Europe In coupled mode with soil water balance, need soil data (texture, depth) from Global Soil Map or Soil Grid.

For more information: https://www.cesbio.cnrs.fr/la-recherche/activites/modeliser-codes-et-modelisation/liste-et-descriptif-des-modeles/modspa/

6.2.3. CarbOn Management Evaluation Tool for whole FARM GHG accounting : COMET-Farm

Use: Comet-Farm Tool is a tool that allows a complete GHG assessment of the whole farm with the possibility to evaluate management practices at a time t and in various pre-designed or user-determined practice change scenarios.

General information
Origin: United States of America
Author: USDA, NRCS and CSU, NREL
Published: 2005
Spatial scale: plot/farm
Time scale: daily
GHGs concerned: CO_2, N_2O, CH_4
Underlying model: DayCent
Applicability: croplands, grasslands, agroforestry, vineyards/orchards, livestock

Description
The tool works by combining process simulation models (DAYCENT for CO_2 and N_2O), empirical models, IPCC default emission factors, and peer-reviewed research results. The interface allows the user to enter information down to the plot level.

Data

Input	Output	Data sources
- Location(State, county), parcel -Soil data - Cultural ecosystem Past, current and future management practice data (drop-down menu) - Default values are provided for input and fuel use but can be changed by the user.	- Complete GHG balance for the whole farm detailed by type of plot, livestock and energy consumption (and production) - GHG emission intensity (e.g. per unit of yield) - Uncertainties quantified using an empirical approach (observations and simulations analyzed with a linear model) in addition to a Monte Carlo approach	- SSURGO soil maps - NCDC climate map - USDA National Agricultural Statistics Service (NASS) - USDA ERS Cropping Practices Surveys - NRCS NRI data - Agroecosystem soil database (CSU-NREL) - Tree biomass data (FIA, Jenkins et al., 2003 model)

For more information: http://comet-farm.com/

6.2.4. VCS - Adoption of Sustainable Agricultural Land Management: SALM

Use: GHG assessment and monitoring methodology for emissions reduction projects in agriculture through the adoption of sustainable land management practices (SALM) in agricultural ecosystems.

General information
Origin: International
Author: Neil Bird, the BioCarbon Fund
Spatial scale: plot
Time scale: months
Underlying model: Roth C
GHGs concerned: CO_2, N_2O, CH_4
Applicability: croplands, grasslands, forests excluding wetlands.

Description

The methodology is based on analytical models validated by the scientific community (Roth C for the current version) for the estimation of soil organic C for each of the identified management practices;
The uncertainty assessment and the Activity Baseline and Monitoring Survey (ABMS) protocol is so far only adapted for the Roth C model.
For other GHGs :

- N_2O emissions from fertilizer use and C stocks in woody perennials are based on the UNFCCC calculation methodology "A/R CDM project activities".
- N_2O emissions from nitrogen-fixing species, residues, and N_2O and CH_4 emissions from combustion are calculated using Tier 1 (IPCC default factors) or Tier 2 (country-specific data) equations

Data: See Roth sheet C

For more information: https://verra.org/methodology/vm0017-adoption-of-sustainable-agricultural-land-management-v1-0/

6.2.5. VCS VM0042 - Methodology for Improved Agricultural Land Management

Use: Protocol for accounting for GHG emission reductions and soil carbon stock for the generation and delivery of carbon credits associated with improved cropland management.

General information
Origin: International
Author: David Shoch and Erin Swails (TerraCarbon LLC) & Indigo Ag Inc.
Year of publication: 2020 (version 1)
Spatial scale: sampling unit (e.g. farm)
GHGs concerned: CO_2, N_2O, CH_4
Underlying model: unspecified, choice of models according to criteria, empirical and default data
Applicability: croplands and grassland (without change of land use) excluding wetlands

Description
The VM0042 methodology is flexible and offers three assessment approaches including:

1) the use of models (Quantification approach 1). The model must meet calibration, validation and verification criteria specified in a dedicated protocol VMD0053 - *Model Calibration, Validation, and Uncertainty Guidance for the Methodology for Improved Agricultural Land Management*. This protocol is intended to test the performance of the model as a component of the carbon credit quantification procedure.
2) the use of direct measurements before and after the project (Quantification approach 2). At present this approach cannot be implemented as it relies on regional baseline performance criteria not yet identified and agreed by Verra.
3) and calculation from default data at country or region/state level (Quantification approach 3).

Monitoring parameters are collected and recorded at the scale of the sample unit and emission reductions are estimated independently for each of them. The main objective of the monitoring is to quantify the change in soil organic carbon stock and CO_2, CH_4 and N_2O emissions resulting from the project scenario during the crediting period and before each verification. In particular, the methodology includes the consideration of soil organic carbon and above-ground and below-ground biomass carbon (optional). A non-exhaustive list of practices covered by the methodology includes reduced fertilization, improved irrigation and tillage management, return of crop residues to the soil, improved seed and harvest management (cover crops in rotations, relay cropping, etc.) as well as grazing systems.

For more information: https://verra.org/wp-content/uploads/2020/10/VM0042_Methodology-for-Improved-Agricultural-Land-Management_v1.0.pdf

6.2.6. Mitigation of the agricultural greenhouse gas balance integrating soil carbon, on a territory: ABC'Terre

Use

ABC'Terre is a spatialized method designed to quantify, on a territorial scale, the impacts of cropping practices on the long-term variation of organic carbon stocks in the topsoil (using the AMG model) and to include this variation in a GHG balance of the cropping systems of a territory.

General information

Origin: France

Author: Agro-Transfert Ressources et Territoires

Spatial scale: cropping systems of a territory (and soil map unit for mapping)

Time scale: year

Underlying model: AMG

GHGs concerned: CO_2, N_2O

Applicability: croplands, temporary grasslands (< 3 years), permanent grasslands

Description

The ABC'Terre method consists of five steps:

(1) Reconstitution of rotations by type of soil and by type of farm using the RPG-Explorer tool;

(2) Assignment of the organic C content of the topsoil from the Land Analysis Database (BDAT) to the soil types of the Regional Pedological Reference System (based on a method developed within the framework of ABC'Terre);

(3) Reconstitution of agricultural practices for each rotation by soil type and by type of farm;

(4) Simulation of long-term SOC evolution using the Simeos-AMG tool;

(5) Calculation of the GHG balance of the cropping systems reconstructed on the territory, using IPCC factors, Agribalyse (mainly) and Simeos-AMG input and output data.

Data

Input	Output	Data sources
-See AMG input data -In addition: technical itineraries per crop and inputs	-Initial carbon stocks by soil type and soil map unit (SMU) ; - Evolution of SOC stocks for each reconstructed cropping system by soil type ; - Plant biomass flux returned to the soil and associated humified SOC on average.ha^{-1}.$year^{-1}$ - GHG emissions of each cropping system reconstructed at different scales (of each crop, each cropping system and the territory)	RPG RRP (or Typterre) BDAT Agribalysis

For more information: Marion Delesalle, Olivier Scheurer, Philippe Martin, Nicolas Saby, Thomas Eglin, Annie Duparque. 2019[10].

6.2.7. Modelling of socio-Agro-Ecological system for Landscape Integrated Assessment: MAELIA

Use

Multi-agent modelling and simulation platform to assess the environmental, economic and social impacts of changes in agricultural activities, natural resource management (e.g. water) and/or global changes (demographics, land use changes and climate change).

General information

Origin: France

Spatial scale: plot, farm

Author: INRAE

Time scale: daily

Underlying models: AqYield-NC, SWAT®...

GHGs concerned: CO_2, N_2O

Applicability: croplands, grasslands, agroforestry and future herd dynamics

Description

The platform enables a dynamic simulation of the C cycle in each plot of a "territory" according to the specificities of the plots (soil, climate), the cropping systems and the operating constraints of the farm. The AqYield cropping system model is used to simulate the daily interactions between the dynamics of the water cycle (water available in the soil, evaporation, transpiration and drainage), the nitrogen cycle (absorption, leaching, volatilization, N2O), the development of plant cover (crops and intermediate cover) and finally the dynamics of soil organic carbon over the course of the year for each plot in a territory. The main indicators evaluated are related to the water, nitrogen and carbon cycles, the physical and biological quality of the soil, the semi-net margins and the nature and quantities of work, from the plot scale to the territory scale. It is possible to carry out simulations of current situations (diagnosis) or under climate scenarios, changes in cropping systems, prices, etc.

Data

Input	Output	Data sources
-Soil properties (clay content, soil water holding capacity and soil depth, pH, Caco3, DA, C/N, initial Corg), -Daily climate data (mean temperature, precipitation and baseline), -Crop management decision rules for tillage, seeding, fertilization, irrigation, harvesting.	-Yield -Organic carbon dynamics and final carbon stock -Nitrogen leaching, -GHG emissions, -Soil water status, nitrogen and water stress -Quantity and nature of work -Semi-net margin	-National or local databases (1:1 000 000, 250 000, 50 000) -SAFRAN weather data (8*8 km2 grid) or climate projections -Spatial coverage of farms via the anonymized graphical parcel register (RPG). - INRAE database for crop sequences - Expert advice on crop management rules

For more information: http://maelia-platform.inra.fr/

6.2.8. Hedge method - CARBOCAGE

Use: Methodology for emission reduction projects to obtain a low-carbon label for the establishment of hedgerows. It aims to account for the emission reductions achieved by increasing carbon sequestration in soils and biomass through the sustainable management of hedgerows on farms in France.

General information

Origin: France
Author: Pays de la Loire Chamber of Agriculture
Publication: In progress,
Type of method: Empirical
Applicability: Local, non-invasive and diversified hedgerows.

Spatial scale: Farm
Duration of projects: 15 years
GHGs concerned CO_2, CH_4 (optional)

Description

The method is based on the experimental results of the CARBOCAGE project, including a measurement protocol for assessing soil carbon sequestration. This basis was used to establish a correspondence between the additional carbon stock and the initial age of establishment of hedges in the Grand-Ouest (alternatives are proposed for projects located outside the Grand-Ouest territory). After an initial diagnosis, a management plan and a management guide are proposed to the project leader. The guide includes a list of management practices that optimize carbon sequestration in the biomass and the maintenance and conversion itineraries for each typology (6 types of hedges in accordance with the national typology). In addition, each itinerary is assigned a sequestration potential per compartment (aerial, root or soil). The method also establishes the list of discounts in accordance with the requirements of the National Low-Carbon Label.

Data

Input	Output	Data sources
For the Grand-Ouest: additional carbon from the results of the Carbocage project For other regions: correspondence coefficient based on soil and climate conditions per major region	Additional carbon stock by age of hedge establishment (teqCO_2/ha/year)	Soil GIS Carbocage protocol for the establishment of local references

For more information: https://pays-de-la-loire.chambres-agriculture.fr/publications/publications-des-pays-de-la-loire/detail-de-la-publication/actualites/projet-carbocage-valorisez-le-carbone-stocke-par-les-haies-sur-vos-territoires/

6.2.9. Measurement of Soil Carbon Sequestration in Agricultural Systems Methodology determination 2018

Use: Methodology for assessing emission reductions from agricultural projects for Australian Carbon Credit Units (ACCUs). It has been approved under the National Emission Reduction Fund (ERF).

General information
Origin: Australia
Spatial scale: Carbon Estimation Areas (CEAs), see supplement. VO.1.0 - January 2018
Author: Minister for the Environment and Energy, Australia)
Publication: Authorised Version F2018L00089 registered 07/02/18
GHGs concerned: CO2, N2O, CH4
Applicability: Croplands, pasture and horticulture
Type of method: based on national emission factors

Description
This methodology allows the determination of a carbon stock differential between a reference situation and a project that has adopted one or more new practices (compared to the reference). The change in soil organic carbon (associated with a 60% probability of exceedance) for a given project period is first calculated. The creditable carbon stock is then determined by adjusting this variation and the average annual difference in emissions between the baseline and the project. The emission sources considered are soil, livestock, synthetic fertilizer application, lime application, tillage activities, soil landscape modification activities, residues and energy used for irrigation. Verification is carried out in several stages throughout the project through audits, sampling, spectroscopic analysis and declarative monitoring of implemented practices.

Data

Input	Output	Data sources
• For the calculation of carbon stock change : Soil mass Soil thickness Mass of coarse material Organic carbon • For other GHG emissions: Consideration of emission sources and associated factors.	Delta of emissions from identified sources between the baseline and the project validation period (See details of the calculations on page 52 of the method).	National Greenhouse Accounts Factors, published by the Department of Environment and Energy. Sampling protocol provided in the complementary documents of the methodology

For more information:
http://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

6.2.10. Alberta Carbon offset system - Quantification protocol for conservation cropping: The Conservation Cropping Protocol (CCP)

Use: Quantification protocol for project developers and farmers implementing conservation agriculture offset projects in dry grassland and parkland ecozones.

General information
Origin: Alberta**,** Canada
Time scale: annual
Author: Alberta Environment and Water, Climate Change Secretariat
GHGs concerned: CO_2, N_2O, CH_4
Publication: April 2012
Applicability: dry grassland and parkland ecozones.
Type of method: based on national emission factors

Description
Since 2007, the Alberta government has been regulating emission reductions for industries that emit more than 100,000 tons of CO2 eq. per year. To achieve this, a number of sector-specific emission quantification protocols have been established. The PPC specifically quantifies emission reductions from the following three activities:

- Additional annual carbon sequestration in agricultural soils
- Reduction of N2O emissions from no-till soils
- And the emission reductions associated with reduced fossil fuel consumption due to fewer passes per field.

The CCP uses an empirical methodology based on Alberta-specific emission factors. Quantification begins with the calculation of total baseline emissions (3 years pre-project). These are then subtracted from the total emissions calculated over the life of the project.

Data

Input	Output	Data sources
• Type of tillage equipment, measurements and date of purchase; • Tillage management practice used; • Area of the field; • Type of crop; • Title deeds and, if applicable, landlord-tenant leases; • Classification of ecozones; • Irrigation data (if applicable) • In addition for projects with summer fallow, specify the practice	Delta of emissions at the baseline and the period of validation of the project (See details of the calculations on page 30 of the method).	Emission factors from the Canadian National Inventory

Pour en savoir plus : https://open.alberta.ca/dataset/b99725e1-5d2a-4427-baa8-14b9ec6c6a24/resource/db11dd55-ce34-4472-9b8b-cb3b30214803/download/6744004-2012-quantification-protocol-conservation-cropping-april-2012-version-1.0-2012-04-02.pdf

6.2.11. COOL FARM TOOL

Use: A tool for calculating greenhouse gas emissions that also assesses biodiversity and water resource management.

General information
Origin: England
Spatial scale: farm, agricultural holding
Author: Cool Farm Alliance
GHGs concerned: CO_2, N_2O, CH_4
Publication: first version in 2010
Applicability: all types of crops (except soilless crops), grassland, livestock
Type of method: open-source Excel document

Description
The Cool Farm Tool assesses the greenhouse gas emissions and carbon footprint of a farm based on standard farming practice data that is readily available to the farmer. For livestock farms, calculations are based on herd size, manure management, feed and energy consumption. Cool Farm Tool also includes a biodiversity metric, which quantifies how the farm's management contributes to biodiversity, and a water use metric, to inform crop irrigation requirements and assess water footprints (blue and green). The calculation methodology is based on emission factors, an empirical model, and equations from the literature or the IPCC report (Tier 1 or Tier 2).

Data

Input	Output	Data sources
• Details of crop management (type and amount of fertilizer, change in land use over the last 20 years; etc.) • Details on the management of the livestock production system (type and number of animals; manure management, diet, etc.) • Details of energy use at the site	• CO2eq emissions for the whole farm/operation, broken down by source and by GHG (expressed as total emissions per unit area or per unit crop) • Activity data for energy use	• N2O emissions based on an empirical model built from an analysis of over 800 generic data sets. These datasets refine the IPCC Tier1 emission factors by taking into account applied mineral N, soil carbon, soil texture, soil moisture and soil pH. • The soil carbon data are derived from research results based on more than 100 data sets.

For more information: https://coolfarmtool.org/

6.2.12. Carbon Navigator

Use: Calculation tool for improving environmental performance on Irish beef farms.

General information

Origin: Ireland

Author: Teagasc and Bord Bia

Published: 2017

Underlying tool: Emission factors (Tier1)

Spatial scale: farm scale

Time scale:

GHGs concerned: CO_2, N_2O, CH_4

Applicability: Multi-crop farms

Description

Based on the information entered by the farmer, the Carbon Navigator tool compares the performance of the farm in question with other similar farms and highlights the potential cost and GHG emission reduction impact of the targets set. The tool quantifies the environmental gains that can be made on each participant's farm by setting targets in key areas such as grazing season management, average calving rate, etc. Each farmer can therefore examine for themselves the changes that can be made to their farm and then illustrate what that change will mean in terms of reduced GHG emissions from their livestock and the associated financial return.

Data

Input	Output	Data sources
• Farm data: selection of county, region, soil type and quality (this allows the length of the grazing season to be assessed) • Enter the cultivated and grazed area • Average number of suckler cows at time t • Average number of pups up to one year old	• Herd management data: length of grazing season, age at first calving, calving rate, live weight performance, nitrogen efficiency, manure application schedule	National agricultural databases (not specified)

For more information: https://www.icbf.com/wp/?p=9091

6.2.13. CARBON EXPERT

Use: CARBON EXPERT is a tool for accounting for GHG emissions and avoided emissions related to the use of a composter.

General information

Origin: France
Author: Agriculteurs Composteurs de France and Trame
Design year: 2009
Applicability: farms with a composter
Type of tool: empirical, based on emission factors

Spatial scale: territory
GHG concerned: CO_2, N_2O, CH_4

Description

The approach is similar to that of a life cycle analysis with a quantification of all the material and energy flows entering and leaving the waste from their collection to their valorization. The scope of the study covers three main emission sources:

- Waste collection
- Composting
- Recovery of compost and screenings

GHG emissions from the composting activity that take place outside the composting facility are also accounted for.

The methodology is not public
For more information: Association Trame (Stéphanie Bonhomme s.bonhomme@trame.org)

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Territorial demonstrators of soil carbon sequestration - deliverable I

With the aim of participating in the establishment of effective and incentive measures to sequester C in soils, this ADEME-funded project first aims to propose a protocol for setting up a low-cost MRV (Monitoring Reporting Verification) method for assessing C sequestration that is robust, simple to implement and replicable in different contexts and over large areas, and to define its limits. In Deliverable 1, three possible options for assessing and monitoring the C balance are identified, with different methodologies, tools and data that can be used, as well as recommendations for the specific case of croplands in France. We highlight the impact of uncertainties in the input data of MRV methods on C stock estimates and the interest of moving towards methods that include remote sensing in a territorial deployment process.

To assess a soil carbon sequestration project in cropland, it is recommended to:

1. *rely on scientifically validated modelling tools (e.g. AMG, SAFYE-CO2).*
2. *account for the carbon sequestration differential between the project scenario and a baseline scenario, not the gross sequestration for each scenario.*
3. *assess the overall GHG emissions associated with changing practices.*
4. *use satellite data (e.g. Sentinel 2) to estimate carbon inputs from plant cover and to guide carbon stock sampling for verification purposes.*

INRAE
147 rue de l'université
75338 Cedex 07
Tél. : +33 1(0) 42 75 90 00

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