CARBONCHANGE METHOD

1. Introduction

Climate change represents one of the greatest challenges that humanity will have to face in the near future. Fighting rising temperatures, melting glaciers, pollution, the increased frequency of droughts and floods is now an imperative requirement even in primary production.

The new sustainability concept for the agricultural sector must deal with the **increasing needs of global production and productivity**, in order to ensure a substantial part of future food security, through a continuous **adaptation** process to new agro-climatic conditions via methods which also contribute to climate change **mitigation**[1] and biodiversity conservation efforts.

The reduction of the environmental impact of production processes on agricultural ecosystems is now a priority on the global political agenda and in the collective consciousness, resulting in a growing interest in tools and methodologies that can control and enhance sustainable approaches to agricultural production.

By adopting appropriate soil management and crop production techniques, farmers **can remove carbon dioxide from the atmosphere** through a "nature-based solution"[2], storing it in the soil as organic carbon. Techniques that farmers can employ to fix CO2 in soils are often referred to generically as **regenerative**[3], sustainable, low-carbon, or climate-positive agriculture.

The **carbon sequestration**[4] provided by "sustainable" agricultural practices represents **one of the key environmental services** of agro-silvo-pastoral systems and agro-industrial supply chains. In particular, a large part of the **mitigation potential** of the effects of climate change that is provided by agricultural ecosystems **is concentrated in soils.**

It is important to properly assess the carbon sequestration capacity of agricultural soils, of agro-forestry and of pastoral systems, **through reliable methodologies and limited costs**, in order to, among other benefits, facilitate access to possible incentives.

[1] Taking action to soften the impacts of climate change by limiting global warming and its related effects. This involves reductions in human emissions of greenhouse gases and practices to reduce their concentration in the atmosphere.
[2] The International Union for Conservation of Nature (IUCN) defines NBS (Nature Based Solution) as the set of alternative solutions to conserve, sustainably manage, and preserve the functionality of ecosystems.
[3] Agricultural technique aimed at recovering soil fertility through the harmonious management of its natural balance and without the depletion of resources.
[4] The process of capturing and storing carbon from the atmosphere in terrestrial reservoirs such as plants, soil, wetlands, etc.

2. Intended purpose of the method

The **CARBONCHANGE** method enable the quantification of the soil organic carbon storage resulting from a change in agricultural activity or management technique that is connected (given the scientific evidence available at this time) to a clear-cut removal of CO_2 from the atmosphere. This removal is quantified by applying CARBONCHANGE in two alternative scenarios (i.e., the **baseline scenario**[5] and the optimized scenario characterized by the most "sustainable" management) for each area under analysis and is expressed in tons of equivalent CO_2[6] .

While quantifying the removal attainable passing from the baseline scenario to the optimized one, CARBONCHANGE possibly considers the emissions of greenhouse gases (GHG) that are attributable to the adoption of sustainable practices. This phenomenon is called **leakage**.

In summary, the change in GHG emissions/leakage due to sustainable business practices represents the number of emissions that have been reduced and the **CO_2eq stored in the soil** regardless of its initial carbon content.

3. The CARBONCHANGE method

The CARBONCHANGE method evaluates the **mitigation potential** of sustainable farming systems by comparison with traditional farming practices in the reference area or "baseline scenario". Such a sustainable farming system is therefore **additional** [7]to the baseline scenario if the GHG emissions from farming operations (offset) with soil organic carbon storage are overall lower than the emissions that would occur in the absence of the virtuous activities developed by the farm.

The CARBONCHANGE method allows the assessment of the mitigation potential of agricultural practices through a **process analysis conducted with a dynamic model on a physical basis** that allows a significant reduction in application costs, compared to sampling and soil analysis, and therefore facilitates access even to small and medium-sized farms.

The methodology is designed to ensure a complete, consistent, transparent and conservative quantification, and possible certification by authorized parties, of carbon removals resulting from the adoption of regenerative agricultural practices in crop fields. The system is configured with a **Software as a Service approach**[8] that is delivered through the operation of a **"Carbon Calculator"** based on the **peer-reviewed model "ARMOSA"** (see point 5 below), developed by the University of Milan researchers, calibrated and validated in many Italian and European farm case studies. The ARMOSA crop systems simulation model is a software that represents, through a series of equations, the **dynamic processes of the agroecosystem** and how they vary in response to

[5] The baseline scenario represents the total anthropogenic greenhouse gas emissions that would result if no sustainable agricultural management practices were in place.
[6] A unit of measurement that enables different greenhouse gas emissions with different climate-changing effects to be weighed together. For example, a ton of methane, which has a climate-changing potential 21 times greater than CO_2, is counted as 21 tons of CO_2 equivalent. The climate-changing potentials of the various greenhouse gases have been developed by the Intergovernmental Panel on Climate Change (IPCC).
[7] The implementation of the intervention leads to an environmental improvement compared to the baseline scenario.
[8] Cloud computing service model available via the internet.

agricultural management, climatic and soil conditions. The model calculates on a daily basis the variables related to soil (organic carbon content, nitrate and ammonia nitrogen, leaching, CO_2 and N_2O emissions) and crops (yield, aerial biomass, nitrogen content).

Thus, the "Carbon Calculator" assesses the carbon sequestration capacity of the soils of the project's baseline scenario and quantifies **the incremental emissions of CO2 and the carbon storage in the soil** due to regenerative practices.

The CARBONCHANGE method is applied to the set of practices that increase the soil organic carbon stocks of agricultural systems; it complies with the assessment and accounting principles and, subsequently, of possible certification of greenhouse gas reduction/sequestration expressed in CO_2eq.

The assessment carried out by the CARBONCHANGE method includes:

- the roadmap and procedures through which carbon removal projects can be defined;
- the project eligibility rules;
- the modalities by which carbon removals resulting from projects are estimated, monitored, reported, and verified;
- the basic project scenarios for carbon enhancement, removal, and conservation;
- the record keeping requirements.

As the method estimates the increase in soil organic carbon stocks by comparing two scenarios (i.e., baseline vs regenerative), **historical information on agricultural practices** is requested to define the baseline scenario for soil organic carbon: crop planting dates; fertilizer and nutrient applications; irrigation practices and water use; crop yields and uses; crop residues; and tillage practices.

Input data consists of: daily weather data (minimum set of variables: maximum and minimum temperature, rainfall), initial soil properties (provided layer by layer, sand, silt, clay, organic carbon content, bulk density), information on cropping systems (crop type, crop rotation, sowing and harvesting date, crop residue management, fertilization, irrigation, tillage). Relative to fertilization, soil operations, and residue management, an accurate description of the operation is possible allowing for a distinct representation of different cropping systems such as conventional, organic, or conservation agriculture.

The method requires that sufficient historical and continuous operational data be imported **through a web interface** to allow the creation of the baseline scenario and to produce annual updates of estimated changes in soil organic carbon stocks. The methodology includes the ability to present additional data (e.g., soil sample test results, satellite imagery and its interpretations, and tractor-mounted, handheld, or underground sensor data) to integrate internal estimates where possible.

Changes in soil organic carbon stocks from year to year are difficult to estimate accurately, even using the most precise measurement tools available (e.g., soil sampling and testing). For this reason, the method involves the use of simulation models to record the trend of variation over time and derive annual values from these trends.

Through the model, climate (precipitation, temperature, and other data) and crop information are integrated, building dynamic, normalized estimates of carbon stock changes for each project application, even for cases where soil organic carbon allocations may vary from year to year due to factors beyond the control of the farm.

By applying this dynamic basis, the methodology ensures that farmers are not penalized or rewarded for changes in soil organic carbon stocks that are natural in origin and not a function of the project. This differentiates us from methods in which CO_2 removals derived from the change are calculated relative to the baseline scenario.

The choice of basing the operation of the calculator on the developments of the ARMOSA model allows CARBONCHANGE to apply a transparent method, which is **continuously reviewed**, updated and capable of linking the estimated changes in carbon stocks to changes in management and production practices. In fact, the model has been developed since 2005 and frequent applications allow for updates and integration of new modules. A description of the model is provided in the **scientific publications** Perego et al. (2013) and Valkama et al. (2020).

The technical documentation defines the requirements that must be met when certification of compliance with the **CARBONCHANGE** method is sought through the **assessment and accounting** of the change in soil organic carbon content within the agro-ecosystem[9] taken as a reference.

The planned activities of assessing and accounting for the mitigation potential of agricultural practices are based on principles and calculation structures applicable in different climatic regions and agro-ecosystems **that focus on increasing soil organic carbon.**

The CARBONCHANGE method is applicable to farms oriented towards the sustainability of their production systems that involve the application of sustainable greenhouse gas mitigation practices and are subject to the following **applicability conditions:**

a) The farm's fields are dedicated to agricultural crops.
b) The farm is not located in wetlands or paddy fields.
c) The farm's fields have been subjected to traditional and/or intensive farming practices in the past, leading to a gradual decrease in soil organic carbon and biodiversity content.

This methodology has a global reach and applies to a wide range of agricultural activities that increase soil organic carbon storage and/or reduce net CO_2 and N_2O emissions compared to a traditional baseline scenario. Examples include **regenerative agriculture practices** including: soil conservation, no-till, minimum tillage, crop rotation, improved residue management, temporary grassland and/or cover crops, organic fertilization, nitrogen loss reduction, precision farming, and organic farming.
All eligible management changes for regenerative agriculture are currently contemplated by the method and include:

- alteration or expansion of crop rotations and cropping intensity;
- introduction of cover crops and/or shift from annuals to perennials;

[9] A geographic area with similar characteristics of soils, morphology, climatic conditions and agro-forestry management.

- reduction in the number and intensity of tillage and/or adoption of new crop residue management;
- adoption of new irrigation management techniques;
- replacement of synthetic fertilizers with organic matter additions.

4. Implementation steps of the CARBONCHANGE method

The main implementation stages of the CARBONCHANGE method on enterprises are as follows:

1. Identification and calculation, for the baseline scenario, of **soil organic carbon storage** through the "Carbon Calculator", **of nitrous oxide (N_2O) emissions** from soil and from combustion, and of **carbon dioxide** (CO2) from combustion calculated according to the IPCC Guidelines and of **ammonia** (NH3) evaluated with the ALFAM 2 model. The calculations are carried out through the modeling of the entire crop rotation of the farm. The baseline scenario will be calculated using the standard cropping systems of the area as reference.

2. Identification and calculation of **climate-altering gas emissions** and **soil organic carbon storage** of the sustainable farming system using the same formulas given for the base case using data derived from sustainable farm practices.

3. Comparison between the results of the two previous points and definition of the amount of CO_2 eq stored in the soil.

The duration of the commitment is **at least 10 years**. Organizations interested in the system (Agricultural Chains, Producer Associations, Cooperatives, individual farms, etc.) will receive counts of carbon removed during the project period and will be required to report operational data to demonstrate the **persistence of soil organic carbon conservation commitments** for the years of the commitment duration. This can then be renewed at the end of the first agreement term, using the dynamic baseline scenario reported at that time.

The Organization must implement the following data in the system as input for the calculator:

- **farm location**, possibly digitized, together with management and cultivation subdivisions (orthophoto maps, cadastral maps, etc.);
- **data on soil characteristics** (analysis carried out in the past of texture, organic carbon content, reaction) as much as possible geo-referenced; if not available, they will be taken from regional maps etc. or from direct analysis;
- **climatic data** (monthly averages of T, precipitation, ETP), better if collected directly on the farm or if available from nearby weather stations;
- **the type of rotation carried out** with the crops used and the relative calendar of cultivation operations (yields, soil working, irrigation, treatments, etc.).

It is advisable to have technical staff able to support all the activities of evaluation and certification of the adoption of the regeneration system on the farm and the choice of a company contact person for the activities related to the CARBONCHANGE calculation system.

When an Organization accepts the terms and conditions of the project registration, it agrees not to register carbon removals for sale in other voluntary markets. Credits can only be converted in one market and cannot be credited or sold twice. However, registration in the market does not preclude the listing of other related ecosystem services (e.g., avoided greenhouse gas emissions, greenhouse gas emission reductions, water quality services, etc.) in other markets, provided those other markets approve the splitting of environmental services.
Document verification for carbon conservation is an attestation by an accredited verifier that the Organization has maintained project activities and kept farm operating records accessible and has not taken any actions that could have released carbon from the soil to the atmosphere.

5. The ARMOSA model at the base of the CARBONCHANGE system

The ARMOSA crop systems simulation model is software that represents, through a series of equations, the dynamic processes of the agroecosystem and how they vary in response to agricultural management, climate, and soil conditions. The model calculates soil (e.g., organic carbon content, nitrate and ammonia nitrogen, leaching, CO_2 and N_2O emissions) and crop (e.g., yield, aerial biomass, nitrogen content) variables on a daily basis.

The software code consists of three main modules: (1) crop growth and development; (2) soil water dynamics; and (3) carbon and nitrogen processes. The input data are: daily meteorological data (minimum set of variables: maximum and minimum temperature, rainfall), initial soil properties (provided layer by layer, sand, silt, clay, organic carbon content, bulk density), information on cropping systems (crop type, crop rotation, sowing and harvesting date, crop residue management, fertilization, irrigation, tillage). Regarding fertilization, soil operations, and residue management, an accurate description of the operation is possible allowing for a distinct representation of different cropping systems such as conventional, organic, or conservation agriculture.

The model has been developed since 2005 and frequent applications allow updates and integration of new modules. The model has been applied in different production contexts in Italy, Europe and outside Europe (USA, Russia, Kazakhstan), as demonstrated in several publications (Puig-Sirera et al., 2022; Valkama et al., 2020; Fronzek et al., 2018; Sándor et al., 2017; Balderacchi et al., 2016; Pirttioja et al., 2015; Groenendijk et al., 2014). The multiple applications allowed the calibration of the large set of parameters involved in the simulation of soil and crop processes. A description of the model is provided in the scientific publications Perego et al. (2013) and Valkama et al. (2020).

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