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REVIEW OF GHG CALCULATORS IN AGRICULTURE AND FORESTRY SECTORS

A Guideline for Appropriate Choice and Use of Landscape Based Tools

Version 2.0

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REVIEW OF GHG CALCULATORS IN AGRICULTURE AND FORESTRY SECTORS: *A Guideline for Appropriate Choice and Use of Landscape Based Tools*

1 Executive Summary

Climate change and its consequences are now recognized amongst the major environmental challenges for this century. Land based activities, mainly agriculture and forestry, can be both sources and sinks of greenhouse gases (GHG). In most countries, they represent significant share of total GHG emissions, around 30 % at global level. In order to reach global or national reduction target, as well as meeting food security challenges, agriculture and forestry sectors need to evolve. In parallel to IPCC work and progress on methodological issues, many GHG tools have been developed recently to assess agriculture and forestry practices. Denef et al. (2012) classify these tools as: calculators, protocols, guidelines and models. This review focus on calculators, i.e, automated web-, excel-, or other software-based calculation tools, developed for quantifying GHG emissions or emission reductions from agricultural and forest activities. These calculators have a limited complexity and must be considered as decision supporting tools for policy makers and project managers, whereas models are more complex and oriented for research, according to Denef et al. definition. Review considers calculators working at landscape/farm scale, including several productions: crop, livestock and forest. Eighteen major calculators were identified, amongst them EX-ACT, ClimAgri®, Cool Farm Tool, Holos, USAID FCC and ALU. For the review, calculators identified have been tested and analysed according to several criteria. Then questionnaires have been sent to calculator developers for them to validate and complete the methodological analysis of their tool.

GHG calculators have been developed following different approaches, with different target and objectives. They are also suitable for a defined geographic coverage. A broad typology is proposed for classifying these calculators and help user to choose the most suitable for its need.

- Raising awareness: simple calculators, no training required, limited scope, reveal main hotspots, not solution oriented.

- Reporting: The aim is to describe and analyse in detail the current situation. These calculators were created to provide values for reporting, to allow comparisons between countries or farms based on a common basis and to help decision makers to elaborate adapted policies. These calculators take into account the full diversity of management practices in each area or farm.

- Project evaluation: Calculators for project evaluation compare a baseline to a "with project" situation. They can be split in between two sub categories, depending if they are carbon market oriented

- Market and product oriented calculators. These calculators provide GHG results per product. The aim is to compare different products rather than assessing a territory. This allows to compare emissions for a similar level of production (avoid leakage). The results are expressed as quantity of GHG per kg of product.

Table 1: Calculators classified according their main objective and geographical zone.

OBJECTIVE OF THE USER		CALCULATORS AND GEOGRAPHICAL ZONE OF APPLICATION
Raising awareness		Carbon Calculator for New Zealand Agriculture and Horticulture (NZ), Cplan v0 (UK); Farming Enterprise GHG Calculator(AUS); US cropland GHG calculator (USA).
Reporting	Landscape tools	ALU (World); Climagri (FR), FullCam (AUS)
	Farm tools	Diaterre(FR); CALM (UK); CFF Carbon Calculator (UK);IFSC (USA)
Project evaluation	Focus on carbon credit schemes	Farmgas (AUS), Carbon Farming tool (NZ);Forest tools : TARAM (world), CO_2 fix (world)
	Not focus on carbon credit schemes:	EX-ACT (World);US AID FCC (Developing countries), CBP (World), Holos(CAN), CAR livestock tools(USA)
Market and product oriented tools		Cool farm tool (World); Diaterre (FR), LCA tools and associated database (SimaPro, ecoinvent, LCA food etc: mainly data for developed countries.)

AUS: Australia; CAN: Canada; FR: France, NZ: New Zealand; UK: United Kingdom; USA: United States of America; FullCam: calculator used by Australia for its national accounting. Only evaluates carbon fluxes, not N_2O or CH_4. High accuracy level obtained coupling extensive dataset and bio-physical process models.

All tested calculators are accounting for main GHG sources and emissions and should be able to identify hotspots (except emissions from land use change that are often ignored). All these calculators provide results in tonne of CO_2 equivalent (teqCO_2)[1] but **they have some important differences concerning methodologies and scope, impacting significantly on results.** Therefore it is impossible to do a straight comparison between studies done using different calculators. While interpreting results, it is necessary to check for the scope and parameters accounted (ex: embedded emissions) and while comparing projects keep in mind **uncertainties**.

Main challenges with landscape assessment is how to consider the **heterogeneity of production systems and biological processes involved in GHG emissions**. Up scaling from farm scale to landscape assessment implies a change in data availability. At plot scale and farm scale, technical data are easily available and can be provided directly by farmers. At regional scale, data inventory often needs to be obtained from statistical data base or expert knowledge, increasing uncertainties. For accounting of biological processes, calculators either use biophysical models (e.g: Roth-C and Century) possibly linked with spatial databases, or average emission factors provided by IPCC or national studies. Accounting for time dynamic is especially important for considering soil and biomass carbon pool, with large quantities of CO_2 at stake. These pools are impacted by management and land use changes. In the future, proxy (e.g. Near Infra-Red Spectroscopy) or remote sensing (satellite image analyses) technologies might enable for cheap direct measurement of the carbon stock changes. Further development of process based models and cheap direct measurement methods for GHG fluxes, linked with GHG calculators are required to improve assessments accuracy.

Major hotspots which deserve special focus in GHG assessments and calculators are:

- Arable land: N fertilisation practices, crop residue decomposition, rice production, peat land conversion, land use change and management change (impact on carbon stock).
- Livestock: Feeding practices and accounting method for imported food (share of pastures), management of dejections and accounting for organic manure use.
- Horticulture: accounting of energy and infrastructure
- Forest: soil carbon, plantation vs natural forest, land use change

[1] CO_2 equivalent: Carbon dioxide equivalent is a quantity to express the relative impact on the radiative forcing, i.e. on the global warming, of a substance (mostly greenhouse gases) compared to that of CO_2, and is calculated using the Global Warming Potentials. GWPs are measurements of the relative radiative effect of a given substance compare to that of CO_2, over a specific time period. For instance the official values for Clean Development Mechanism of methane (CH_4) are set to 21 (meaning that 1 kg of CH_4 is as effective, in terms of radiative forcing, as 21 kg of CO_2) and to 310 for nitrous oxide (N_2O), based on a secular time scale.

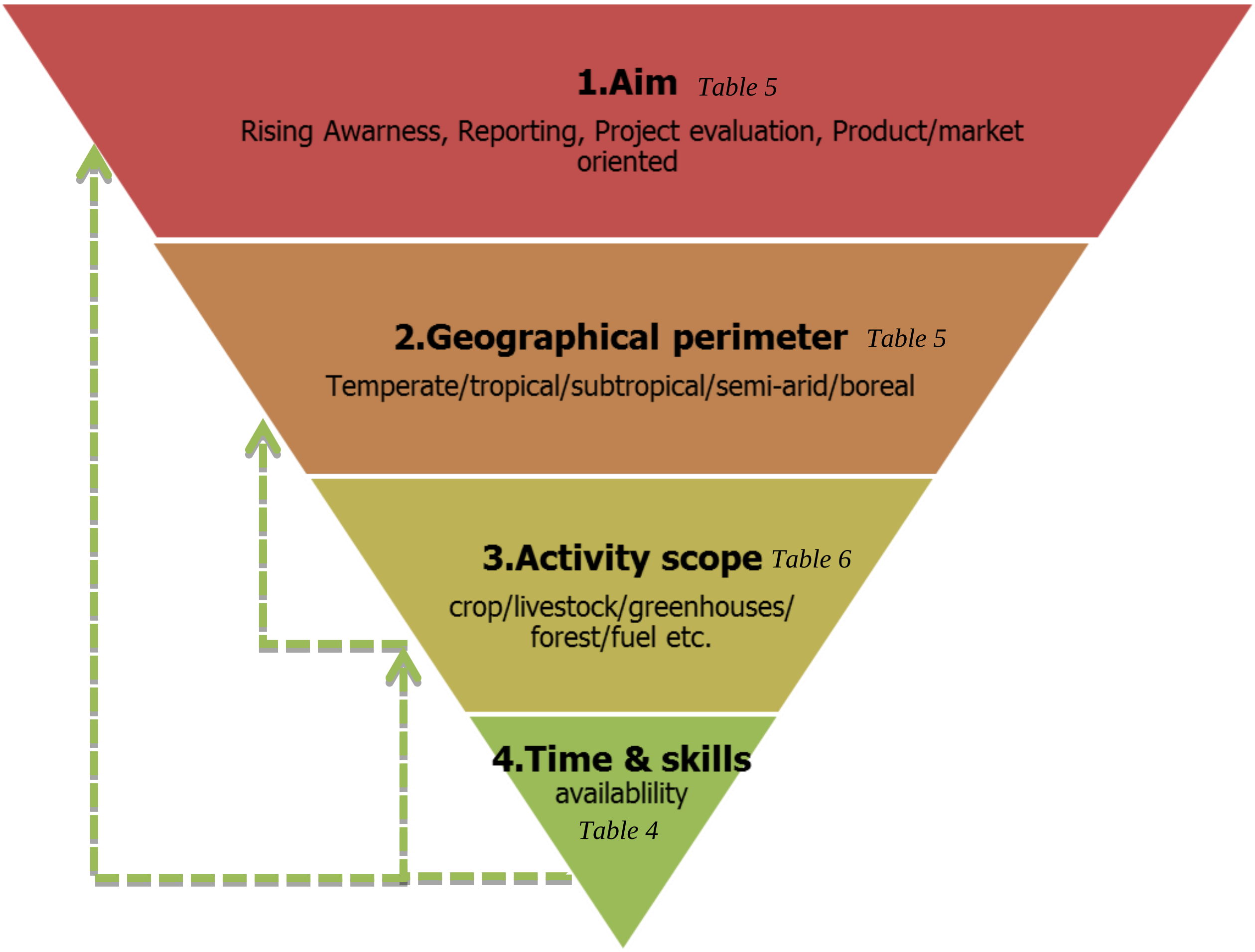
Calculators provide results in CO_2-eq.year^{-1}, CO_2-eq.hectare^{-1}, CO_2-eq.project^{-1} or CO_2-eq.quantity of product^{-1} (e.g kg of milk, cereals etc.). Best indicators must be considered depending on the aim of the assessment. However, the link between emissions per area (ha) and production level of the area needs to be kept in mind in order to avoid leakage, i.e. an increase of emissions outside of the studied perimeter induced by changes of production in the studied area. Permanency issues also need to be kept in mind: some reductions/increases of emissions are temporary, while others are continuous due to change in production systems. A very important point is that environmental/sustainability assessment cannot be restricted to GHG assessment and improvement of GHG balance must not be done ignoring possible drawbacks on other criteria (e.g. increase of pesticide use, water scarcity, reduced biodiversity etc.). The final aim of environmental assessment must always be to increase overall sustainability of the system.

In highly productive systems, GHG assessment should focus on improving input efficiency per production. For low production area, focus should be stressed on agriculture resilience and food security, through improvement of agronomic practices. There are clear synergies between agronomic efficiency and agro-ecology practices/climate smart agriculture.
An important finding of this review is that adapted calculators for each situation are already available, however in many regions calculators only provide results with very high uncertainty and links with socio-economic parameters are still missing. Further development of the calculators would help policy makers and project managers to better account for climate change issues. Calculator developers must always keep in mind what kind of indicators and results are best suited for assessing any situation. Further methodological standardisation, as for LCA methodology which follows international standards (e.g. ISO 14040) could bring clarity and help building clear and transparent references.

Finally; depending on the aim of the user, each calculator tries to find the best compromise between user-friendliness, time consumption and result accuracy. As long as GHG assessment is mostly voluntary and limited economic return is expected (no CO_2 tax, no labelling etc.), cost and skill requirements for using GHG calculators should remain limited. If more restrictive policies would be implemented, then method standardization and improved accuracy would become essential.

Suggested process for choosing GHG assessment calculator

Users should select tools according to more and more specific criteria, helped by the tables provided in the full report. However, if no tool is available for the specific target and area, the choice must go on more general tools, with a feedback process.



Keywords: greenhouse gases emissions, calculators, landscape assessment

2 Introduction

Climate change and its consequences are now recognized amongst the major environmental challenges for this century. These issues impact agriculture and forestry in several ways:

1) Productive systems are affected by climate change and need to develop adaptation strategies.
2) In many parts of the world agriculture heavily relies on chemical inputs, likely to be more and more expensive in the future. On the other hand growing demand for food and bio-energy imply increasing production in the future.
3) Farming, livestock production and deforestation are major GHG producers.
4) Forest and agricultural lands can be major carbon sinks under appropriate management practices.

Considering above mentioned aspects, many tools for agriculture and forestry have been developed for assessing GHG emissions. Denef et al. (2012) classify these tools as : calculators, protocols, guidelines and models. This review focus on calculators, i.e, automated web-, excel-, or other software-based calculation tools, developed for quantifying GHG emissions or emission reductions from agricultural and forest activities. These calculators have a limited complexity and must be considered as decision supporting tools for policy makers and project managers, whereas models are more complex and oriented for research, according to Denef et al. definition.

The « Agence de l'Environnement et de la Maîtrise de l'Energie » (ADEME, French Agency for Environment and Energy Management), the Food and Agriculture Organisation of the United Nations (FAO) and the « Institut de Recherche pour le Développement » (IRD, French Research Institute for Development) have decided to make a review on these calculators. The aim is to provide users with helpful information for choosing the most appropriate calculator in each case, and to highlight major methodological differences between the calculators. At the end, the idea is to promote transparency in carbon analysis, appropriate analysis of results by final users, and provide development ideas for carbon calculator designers.

3 Methodology

This review has been carried out in several steps. Through internet research and cross referencing a large range of calculators has been identified (Full list in Annex 1). The research was carried out in English, Spanish and French. Many calculators identified are product specific (milk, meat, cereals, wood etc.), while only few ones are covering different sub sector (cropland, forestry, deforestation, livestock etc.) and adapted for landscape approach. From this extended list, only multi-activity assessment calculators were selected, corresponding to 18 calculators (Table 2). These farm/landscape calculators have been tested and compared on several criteria regarding practical and methodological aspects. Based on this work, a pre-filled questionnaire has been sent to each calculator developer of the restricted list for completing and validating the analysis. The results presented here summarize this work.

Table 2 List of farm and landscape calculators identified

Calculator list	Questionnaire validated	Developing institute	Person in charge	email adresse
ALU	x	Colorado State University, (USA)	Stephen M. Ogle	ogle@nrel.colostate.edu
Calculateur AFD	no	Agence Francaise de Developpement (FR)		
CALM	x	Country land and Business Association (UK)	Derek Holliday	Derek.Holliday@cla.org.uk
Carbon Calculator for NZ Agriculture and Horticulture	x	AERU, Lincoln university (NZ)	Caroline Saunders	Caroline.Saunders@lincoln.ac.nz
Carbon Farming Calculator	x	Carbon Farming Group (NZ)	Clayton Wallwork	clayton@carbonfarming.org.nz
CBP; carbon benefit project	x	GEF, Colorado State University (USA)	Eleanor Milne Mark Easter	eleanor.milne@colostate.edu; mark.easter@colostate.edu
CFF Carbon Calculator	x	Farm Carbon Cutting Tookit (UK)	Jonathan Smith	jonathan@cffcarboncalculator.org.uk
Climagri®	x	ADEME, calculator developped by Solagro (FR)	Sarah Martin, Sylvain Doublet,	sarah.martin@ademe.fr sylvain.doublet@solagro.asso.fr
CoolFarmTool	x	Unilever Sustainable Agriculture, Sustainable Food Lab; University of Aberdeen (UK)	Jon Hillier (Aberdeen University)	j.hillier@abdn.ac.uk
CPLAN v2	x	SEE360 (UK)	Drew Coulter, Ron Smith & Jan Dick	drew@cplan.org.uk
Dia'terre®	x	ADEME (FR)	Audrey Trévisiol	audrey.trevisiol@ademe.fr
EX-ACT	x	FAO	Martial Bernoux, Louis Bockel	EX-ACT@fao.org, martial.bernoux@ird.fr, louis.bockel@fao.org
FarmGAS	yes	Australian Farm Institute (AUS)	Renelle Jeffrey	jeffreyr@farminstitute.org.au
Farming Enterprise Calculator	x	Queensland university, Institute for Sustainable Resources (AUS)	Peter Grace	isr@qut.edu.au;
Full CAM	no	Australian Government (AUS)	-	nationalgreenhouseaccounts@climatechange.gov.au
Holos	x	Agriculture and Agri-food Canada (CAN)	José M. Barbieri	Holos@agr.gc.ca
IFSC	yes	Peter University of Illinois (USA)	David Kovaicic,Peter McAvoy, Tim Marten, and Aaron Petri	pete@octagonal.org
USAID FCC	x	Winrock International (USA)	Felipe Casarim and Nancy Harris	carbonservices@winrock.org

Comment: Overseer calculator could not be tested in available time due to access difficulties.

4 Geographical coverage

All calculators identified have been developed by Annex 1 countries of the United nation Framework Convention on Climate Change (industrialised countries), and thus mostly focus on industrial agricultural systems (Table 3). The most active countries in developing GHG calculators are the USA (although not in the Kyoto Protocol), Australia, New Zealand, United Kingdom, Canada, France. Other European countries focus more on product specific calculators (Ex: biofuel). Calculators developed for "low income countries" focus on development projects and CDM possibilities. It is worth noticing that some "emergent" countries with strong export activities, such as Chile and South Africa, are developing their own calculators for their main production, possibly to anticipate a risk of tax barrier in western markets based on "green" criteria. Some regional calculators are likely to have been ignored if they were not developed in English, French or Spanish language. Many case studies have been done for Brazil, China, India or Russia, major food producers. However the calculators used were always developed by international agencies or developed countries and no specific calculator developed by local teams was identified for these countries. Nothing dedicated to North Africa and Middle East countries (calculator in Arabic) have been identified either, while their agriculture sector is very vulnerable to climate change.

Table 3 Calculators assessed and their country of use

Country of use (primary target)	Main calculators identified*	Total number of calculators
Australia	FullCam; Farmgas; Farming Enterprise GHG Calculator; many product oriented calculators	>10
Canada	Holos	1
Chile	All product specific calculators	3
France	Climagri®, Dia'terre	3
New Zealand	Carbon Calculator for New Zealand Agriculture and Horticulture; Carbon Farming calculator	2
South Africa	wine specific	1
UK	CALM; Cplan; CFF Carbon Calculator	4
USA	IFSC, mostly activity specific calculators (cropland, livestock, forest etc.)	>10
World	EX-ACT; Cool Farm tool; calculateur AFD; CBP simple assessment; ALU	5
Developing countries	USAID FCC	1

*only main calculators available for landscape assessment are mentioned here. Total number of calculators also includes product specific calculators.

5 Calculators developers

Several stakeholders are developing carbon calculators. Most of them are public research institutes providing free calculators for farmers and policy makers to better take into account climate change issues. These teams usually carry out in parallel research on biological processes involved in GHG emissions. Private sector is also developing GHG calculators. These calculators are product oriented, and developed as part of sustainable development strategies of the companies. Calculators can be developed by brands (Cool Farm Tool) or activity pools (ex: the wine industry) and they are usually available for free or after registration. They favor life cycle approach. Private consultancies also developed their own calculators (Cplan) or use official calculators with paying licence or mandatory training fees (e.g.: Dia'terre®, France). Finally, NGOs have developed some calculators to raise awareness on climate change and promote some environmentally friendly practices.

6 Time and skill requirements

Some tools are really easy to implement and data collection require limited amount of time whereas other require much more investment. It is difficult to estimate precisely the amount of time necessary for each tools or assessment, as it will strongly depends on the level of accuracy, reliability, and data availability in each study. However, we try to provide an indicator to help users to have a rough idea, and to compare tools between one another (Table 4). Skill refers to the agronomic/forestry; and software skills to use the tools.

Table 4. time requirements for assessment

Calculators	Time necessary to conduct one study	Skill required to use the tool
AFD calculator	++	+
ALU	++++	++++
CALM	++	++
Carbon benefit project CPB	+++	+++
Carbon Calculator for NZ Agriculture and Horticulture	+	+
Carbon Farming Group Calculator	+	+
CFF Carbon Calculator	++	+++
Climagri®	++++	++++
CoolFarmTool	++	++
CPLAN v2	++	++
Dia'terre®	++	++++
EX-ACT	+	++
FarmGAS	+++	+++
Farming Enterprise Calculator	+	+
FullCAM	++++	++++
Holos	+++	++
IFSC	+	+++
USAID FCC	+	++

Legend: + to ++++; from less time (<1 day)/skill requirements to more time (>1 months) /skill requirements (formal training obligatory)

7 Intergovernmental Panel on Climate Change (IPCC) methods

IPCC is an international group of scientist in charge of reviewing and compiling all studies on climate change. They provide information for the public and policy makers concerning climate change issues and publish guidelines and good practices references for GHG accounting (IPCC, 2006). These guidelines are mentioned by all GHG calculators. IPCC is classifying GHG accounting using three approaches called Tiers 1, Tiers 2 and Tiers 3. Tiers 1 corresponds to very large scale approach, with average emission factors provided for large eco-regions of the world. Tiers 2 is similar but use state or region specific data, with more accurate emission factors when available. At last, Tiers 3 is very detailed approach usually including biophysical modelling of GHG processes. However these models are only available for few emissions sources and few areas in the world.

For emissions of CO_2 from energy consumption and all N_2O and CH_4 emissions, the generic approach considers multiplying an activity data (it can be area, animal numbers, mass unit or fuel quantity) by its specific emission factor for each source. For non-energy related CO_2 emissions or sinks, most calculations, except if specified, use an approach with a stock-difference method: the emissions or sinks are calculated as the change over time of carbon stocks for the different pools. IPCC methods are based on 5 compartments: Above ground biomass, below ground biomass, litter, dead-wood and soil carbon.

8 Different calculators for different aims

GHG calculation can be implemented for different reasons, depending on stakeholders and local context. This attempt to classify each calculator is not strict and some calculators can correspond to several categories. The idea is to provide a general matrix, with key criteria for classifying calculators and helping the user in his choice.

This typology is completing the broader tool typology suggested by the Coalition on Agricultural Greenhouse Gases (C-AGG, 2010; Driver et al., 2010a), the typology for soil carbon emissions done by Post et al. (2001) and the study of Milne et al. (2012) which focus on small holders.

- Raising awareness:

Set of calculators usually for farmers and farming consultants. The aim is to inform them about climate change issue and the role of agriculture. The calculator must be very simple (no training required); user friendly and identify hotspots. Usually there are free online calculators. Calculators follow typical Tiers 1 approach and have a large uncertainty. Most of them exclude soil carbon and land use change. Example: *Carbon Calculator for New Zealand Agriculture and Horticulture (NZ), Cplan v0 (UK); Farming Enterprise GHG Calculator(AUS); US cropland GHG calculator (USA).*

- Reporting:

These calculators are based on a landscape or farm approach, and must be able to take into account the diversity of management practices in each area. They are using Tiers 1 or Tiers 2 approach. The aim is to analyse specifically the current situation, to make comparisons between countries or farms based on a common basis and elaborate adapted policy in the future.

  - Landscape calculators: Assessment of GHG emissions demanded by official institutes. Calculators must avoid double counting and correspond to official standards. They have large uncertainty on results due to uncertainty on both activity data and emission factors. These calculators have to use average data, they can be quite time consuming, especially for data collection. Example: *ALU (World); Climagri® (FR)*

  - Farm calculators: For farmers, knowing in detail the current situation is a first step to implement reduction strategy, even if these calculators are not really built to assess changes. Example *: Dia'terre® (FR); CALM (UK); CFF Carbon Calculator (UK)*

- Project evaluation

Calculators for project evaluation compare a baseline to a "with project" situation. They can be split in between two sub categories, depending if they are carbon market oriented. Tools are tailored for different types of projects, for example the tools for the C market assume a project is being run primarily for C mitigation or with a heavy mitigation focus, whereas the tools for project evaluation are often aimed at projects which have a primary focus on something else (improving productivity or livelihoods, restoring degraded lands and even socio-political projects aimed at resource sharing). This also determines the level of expertise expected to be able to use the tool. These calculators should account for all possible mitigation options, including carbon storage.

  - Focus on carbon crediting schemes: Mostly in countries where agriculture is subjected to carbon credits or with potential CDM projects. Example: *Farmgas (AUS), Carbon Farming Calculator (NZ);Forest tool : TARAM (world),* CO_2*fix (world)*

  - Not focus on carbon crediting schemes: usually account for all possible mitigation options, and especially carbon storage. However the calculators must be cost efficient and user friendly. They aim at providing information for project managers, stakeholders and donors. Example: *EX-ACT (World);US AID FCC (Developing countries), CBP (World), Holos (CAN), CAR livestock tools(US)*

- Market and product oriented calculators. These calculators provide GHG results per product. The aim is to compare different product rather than assessing a territory. This avoids omissions of GHG emissions during leakage and indirect land use change. Usually these calculators will include process and transport. Example: *Cool farm tool (World); Dia'terre® (FR), LCA tools and associated database (SimaPro, ecoinvent, LCA food etc.; data available mainly for developed countries.)*

Table 5 Calculator typology based on final aim

OBJECTIVE OF THE USER		CALCULATORS AND GEOGRAPHICAL ZONE OF APPLICATION
Raising awareness		Carbon Calculator for New Zealand Agriculture and Horticulture (NZ), Cplan v0 (UK); Farming Enterprise GHG Calculator(AUS); US cropland GHG calculator (USA).
Reporting	Landscape tools	ALU (World); Climagri (FR), FullCam (AUS)
	Farm tools	Diaterre(FR); CALM (UK); CFF Carbon Calculator (UK);IFSC (USA)
Project evaluation	Focus on carbon credits schemes	Farmgas (AUS), Carbon Farming tool (NZ);Forest tools : TARAM (world), CO2 fix (world)
	Not focus on carbon credits schemes:	EX-ACT (World);US AID FCC (Developing countries), CBP (World), Holos(CAN), CAR livestock tools(USA)
Market and product oriented tools		Cool farm tool (World); Diaterre (FR), LCA tools and associated database (SimaPro, ecoinvent, LCA food etc: mainly data for developed countries.)

AUS: Australia; CAN: Canada; FR: France, NZ: New Zealand; UK: United Kingdom; USA: United States of America; FullCam: calculator used by Australia for its national accounting. Only evaluates carbon fluxes, not N_2O or CH_4. High accuracy level obtained coupling extensive dataset and bio-physical process models.

8.1 From field to country

In this study we focus on calculators with a territorial approach, considering different activities such as cropping, livestock and forestry. This territorial approach ranges from farm to region and country scale. At farm level, very detailed data can be available, with reduced diversity of management practices at one time. On the other hand, on larger scales statistical data are needed, and detailed data can be very hard to obtain. At landscape scale expert knowledge for estimating management practices is often required, increasing uncertainties. Thus different calculators have been developed depending on the scale of the evaluation needed. Uncertainty is not correlated in a linear way with scale. Indeed, it is easier to get reliable data for administrative regions such as state or counties, rather than for watershed. Increasing scale can also reduce uncertainty with some local heterogeneity (ex: soil, management practices) getting balanced by working on medium rather than small scale (Post et al., 2001).

For GHG landscape assessment, specific calculators designed for landscape approaches should be used (Table 5). However, if these calculators are not available for the study area, farm calculators can be used, simulating a "regional/national farm". In these cases, average management practices must be estimated, and several management systems might be necessary (ex: simulating a farm with both intensive and extensive dairy cow production). Not all calculators allow simulating both in one farm. Most detailed farm calculators will also not be appropriate for landscape assessment as they require management data which are not available at landscape scale, or very specific data which are too heterogeneous too allow meaningful average values for one territory (detailed data on machineries etc.).

8.2 From regional to global calculator

The geographical suitability of calculators goes from regional (e.g. Queensland Australia) to world (e.g. EX-ACT). Some emissions are specific to local situations such as the burning of savannas or crop residues, rice production or peat land. Global calculators need to account for all these options whereas regional calculators can focus only on local relevant emissions. Data availability also differs between world regions. Global calculators stick to basic indicators, and struggle to include economic approach, whereas regional calculator can more easily be built based on locally available data and include relevant economic indicators. Mitigation options depend on local situation and socio-economical parameters, i.e. improved practices are very different in different part of the world. Therefore it is easier for regional calculators than global ones to suggest and assess detailed action plans. However, as mentioned in the first paragraph, research investment on GHG calculators highly depends on countries and some global calculators are very useful to compensate lack of local investigation.

9 Taking into account climate and soil

In agriculture, many emissions depends on the local environment, especially soil and climate conditions. These parameters have an especially strong impact on N_2O emissions (nitrification-denitrification processes) and C storage potential.

Good accounting of soil emission is crucial for agriculture calculators. Indeed, soil N_2O account for 40 % of agriculture emission on global scale, and soil carbon storage/destocking is the highest carbon sink potential, with the ability to store or release the equivalent of several years of global emissions (Baumert et al., 2005). Soil carbon turnover varies from few weeks to several thousand years depending on the carbon pool.

At regional and local scale climate is usually quite homogenous. Special care is needed working on islands or mountainous territories where sub-regional climates can differ significantly on rather small scale. On the other hand, management practices can have a strong impact on microclimates (ex: hedges, residue cover or bare soils), which will impact bio-physical processes involved in GHG emissions, such as volatilization. Emissions factors and actual calculators do not have sufficient accuracy to take into account the impact of micro-climate on soils emissions.

Soil heterogeneity can also be very high, especially concerning carbon content which is strongly affected by cropping management practices. Thus, for limiting uncertainties from soil emissions, field scale approach seems more appropriate than farm scale or regional scale.

To take into account soil/climate parameters on emissions, three options are possible:

-User-define data

-Using national/regional averages

-Using GIS approach

The most accurate data are obtained when asking users to describe soil and climate with key parameters such as temperature, rainfalls, C content, bulk density, texture etc. These data should be obtained from multiple samplings to reduce uncertainty, with minimum sample size provided by literature depending on parameter required (Post et al., 2001). Several issues with regards to time and space scales must be addressed and considered when the objective is to obtain sequestration rates of a determined practice at farm scale (Bernoux et al., 2006). Also, direct laboratory measurement of soil carbon is usually complicated or too time-consuming and expensive. On the opposite, parameters cited previously can be measured on-field easily and enable to run biophysical model (if calibrated for the conditions) in order to provide reliable measure of soil emissions and carbon storage. The main process based models identified for estimating soil GHG are Century-Daycent (Del Grosso et al., 2001; Parton and Rasmussen, 1994), CERES-EGC (Gabrielle and Lehuger, 2009), RothC (Coleman and Jenkinson, 1999), DNDC (Giltrap et al., 2010), EPIC 5125 (Williams et al., 1984) and Socrates (Grace et al., 2006). These models work considering the dynamic of several pools of organic matter with different stability. The models work at plot scale and can be used for landscape approach if they are linked with spatial dataset. The Verify Carbon Standard (VCS) which validate projects for carbon credits, has recently approved its first methodology for sustainable land management practices (SALM), proposing the use of Roth-C model for soil carbon accounting (VCS, 2012).

Average data is often used at national scale, corresponding to IPCC Tiers 1 approach. However these average data can hide strong heterogeneity. For instance, in France soils and climate can greatly differ between the Mediterranean region, the Alpine region and the Parisian basin. Therefore using national average data at farm scale induce strong uncertainty on results.

The GIS approach is developing with detailed climatic maps, soil maps and other spatial data set being created in many places in the world. It allows users to select an area, defining at the same time climate and soil parameters through an underlying database. The accuracy of data depends on the resolution of the database. This approach is the most simple for users; however the scale does not allow accounting for impact of past cropping practices. Few soil maps now provide direct values for carbon soil and can be used for estimating extra-carbon stock potential. However most maps will rather provide soil parameters that can be used by models for calculating emissions N_2O or CO_2 emissions. Remote sensing and proxy-sensing technology (e.g. NIRS-MIRS) could provide large scale and cheap estimate of soil and biomass carbon in the future (Post et al., 2001; Gomez et al., 2008). By comparing carbon stock over time, direct estimation of emissions with reduced uncertainty could be done. For remote sensing with digital picture processing, the main problem remains for soil with constant plant cover. Cheap direct measurement of N_2O and CH_4 fluxes at landscape scale seems to be more complex to obtain on the short term, compare to carbon stock changes measures.

A conceptual design for regional planning, verification and monitoring of carbon soil is proposed by Post et al. (2001). Saby et al. (2008) evaluate requirements for carbon accounting in each European country related to the minimum detectable change for C sequestration. These studies describe step by step, methods from soil-sampling, analysing and regional up-scaling stressing the critical points for reducing uncertainties. Still considerable effort is required for most states to settle monitoring system allowing acceptable accuracy for annual soil carbon accounting, current accuracy generally allowing detectable change on a 10 year time interval (Saby et al., 2008).

One important aspect concerning C storage is the depth of soil considered. At the moment, IPCC impose for national inventories to consider a minimum of 30cm depth but mention that significant changes may occur at 30-50 cm depth in certain conditions, such as in deep tropical soils (IPCC, 2006). This 30 cm limit is mostly based on practical reason (sampling process) and ploughing depth. Considering that cereals roots can reach more than 1m depth, and tree roots several meters depth, it is clear that in some areas soil nutrient dynamics and carbon storage can happen much deeper than 30 cm, even for temperate conditions (Guo and Gifford, 2002). Some authors describe significant amounts of carbon in soil up to 3m depth and suggest that up to 50% of carbon soil could lie under 30 cm depth (Jobbágy and Jackson, 2000; Salomé et al., 2010). It is especially the case in agroforestry systems where tree roots are forced to develop under crop roots, and for grasslands with high deep root turnover (Ramachandran Nair et al., 2009). In the future, better accounting for carbon in deeper soil layers seems necessary, especially considering that this carbon is likely to be stored on longer period that superficial carbon (less biological activity). It is expected that top soils and sub soils mechanisms implying carbon might be different. Some recent studies observe a decrease of stable soil carbon following a supply of fresh carbon in deep soils. The main hypothesis is that supplying fresh carbon in deep layers increases biological activity which degrades fresh and old carbon stocks (Fontaine et al., 2007). The phenomenon is called priming-effect and is not accounted in any model yet. Thus special care using SOM models is also required, as they can work either deeper or shallower to 30 cm depth (Post et al., 2001). The accuracy gains when integrating such detailed approaches (e.g. deep carbon storage or priming effetc) in future calculators should be balanced with the "costs" for obtaining the data, and should depend on the aim of the calculator.

Waterlogged soils (mostly peatlands), also called organic soils deserve special attention. They contain large quantities of carbon but are also major source of CH_4 emissions due to anaerobic conditions. Emissions from waterlogged soils result from complex equilibrium between methanogens and oxidising processes, depending on soil bacteria communities, vegetation cover and soil physical properties. In case of drainage of soils for farming, decrease of CH_4 emissions is expected; meanwhile increase of N_2O and CO_2 emissions occurs. On the opposite, rewetting of peat land is expected to produce opposite results (Le Mer and Roger, 2001; Couwenberg, 2009; Couwenberg and Fritz, 2012). In areas concerned with organic soils, it is necessary to use calculators including these emissions (Table 6). However the values provided by IPCC have a very large uncertainty and have been criticized (Couwenberg, 2009). In order to improve accuracy of estimations, bio-physical models adapted to these conditions and integrated to GHG calculators would be necessary; no such calculator has been identified. The other major source of soil CH_4 emission is due to rice cultivation. Due to its economic importance, rice production has been extensively studied and many calculators developed dedicated modules (Table 6).

Urbanization and loss of agricultural land is concerning most of the world regions. However little information is available on carbon soil dynamic under urbanization(Pouyat et al., 2002). Calculators are not specifically accounting for urbanization at the moment, although urbanized land might be assimilated to degraded land in some calculators.

Main causes of soil carbon emissions are still under debate in scientific community. Evidences of the impact of management practices on carbon stock exist and are assessed by some calculators (e.g. EX-ACT). However recent studies tend to indicate that potential for carbon storage have probably been over-evaluated, especially in Europe and concerning no till- practices (Powlson et al., 2011). Change in management practices can induce increase of soil carbon stock, but might be partially or fully offset by increase of N_2O or CH_4 emissions, depending on site specific conditions (especially pH and oxygen availability) (Rochette, 2008; Labreuche et al., 2011). These aspects are not taken into account by any calculators identified. Lands with the greatest potential for soil carbon storage would be degraded land, mostly present in southern hemisphere. Smith et al. (2008) estimate that 75% of the global potential for carbon land sequestration occurs in developing countries.

An important point concerning soil carbon is that increasing organic matter in soils enables better water and nutrients retention, and improves overall fertility (Hunt et al., 1996; Rawls et al., 2003; Lal, 2006). These positive feedbacks are not included in any calculator so far. EX-ACT developers are currently working on a water and soil module with this aim but there is a lack of quantitative references to link increase in soil carbon and increase in yields in each ecosystem (Bernoux 2012, personal communication).

At last, some studies also indicate that at the global level, the main driver for carbon soil loss could be climate change (Bellamy et al., 2005). Thus it might be worth for calculators not only to consider current climate for estimating soil emissions and storage potential but also to consider future climate and its impact on biological activity. Global climate models could be used in this aim (Cubasch et al., 2001; Ruosteenoja et al., 2003; Marti et al., 2005; Wang, 2005).

10 Calculators' scope

One major point raised by this study is the lack of homogeneity concerning accounting scope. Indeed every GHG calculator account for different sources. Some include energy, some infrastructures and transport, some N-fixing plant emissions, some soil carbon dynamics etc. This impedes any direct comparison of results between studies done by different calculators. For a better interpretation of results, users need to have references and standard in mind (ex : average emission per ha for cereal crops in Europe), seldom provided by user guides. As long as there is no unique standardization these references will not be available.

These differences in scope can strongly affect the final results; especially if some calculators account for carbon soil sequestration and other do not (Soil Association Producer Support). However in most situations, calculators account for hot spot of GHG emissions and variation in scope have a rather limited impact on the final result as indicated by studies comparing several GHG calculators on a similar situation. (Soil Association Producer Support; FAO, 2010). LCA studies indicate that agricultural stage represents the major stage for GHG emissions in most food product life (Weber and Matthews, 2008; Roy et al., 2009; Virtanen et al., 2010), thus transport (if not by air), processing, and packaging (except for glass and tins) are not hot spot for GHG emissions in food production.

The most important spot excluded in many calculators is soil and biomass CO_2 emissions/storage following land use change. This can have a very significant impact on results, especially for land use change between forest/grassland and crops or urbanisation. On the global scale, deforestation alone account for 11% of human GHG emissions (Van der Werf et al., 2009). For instance, in European conditions, during a 20 year period, soil and biomass emissions following change from old grassland to cropland are about as high as emissions for wheat productions (fertilisers, fuel, etc.) (Figure 1). Indeed after 20 years, soil has reached a new equilibrium and only emissions from "standard" management remain (Arrouays et al., 2002; Guo and Gifford, 2002). Despite this importance in results, some calculators do not account for it, either for practical reason, methodological complexity or because of permanence issues (land use change is reversible). Direct land use change (dLUC) can be accounted quite objectively: if a project includes incentives for land use change on one territory, then change in carbon stocks can be evaluated on that territory. However it can be argued that this change will impact on other territories, considering that food demand is not flexible. Still, land use change depends not only on offer-demand balance, but also on many socio-economic parameters. Production increase can be obtained either by increase of yields (no land use change induced, but management changes induced) or by extension of cultivated land. On the ground, the drivers for land use change can be more land tenure issues, production capacities and state regulations rather than global or even local food demand. Therefore it is really difficult to establish clear consequential relationship between changes in one territory and changes in other ones, sometimes thousands of km away (e.g. bioenergy, soy for European cattles). Such land use change is called indirect (iLUC) and is calculated either by economical modelling or consequential assessment (e.g. hypothesis are made based on experts knowledge). Although it is clear there are some interactions, quantifications is really difficult and one major challenge for environmental assessment (Lambin et al., 2001; Veldkamp and Lambin, 2001; Lapola et al., 2010; Plevin et al., 2010; De Cara et al., 2012). So far only direct land use change is sometime accounted in the calculators.

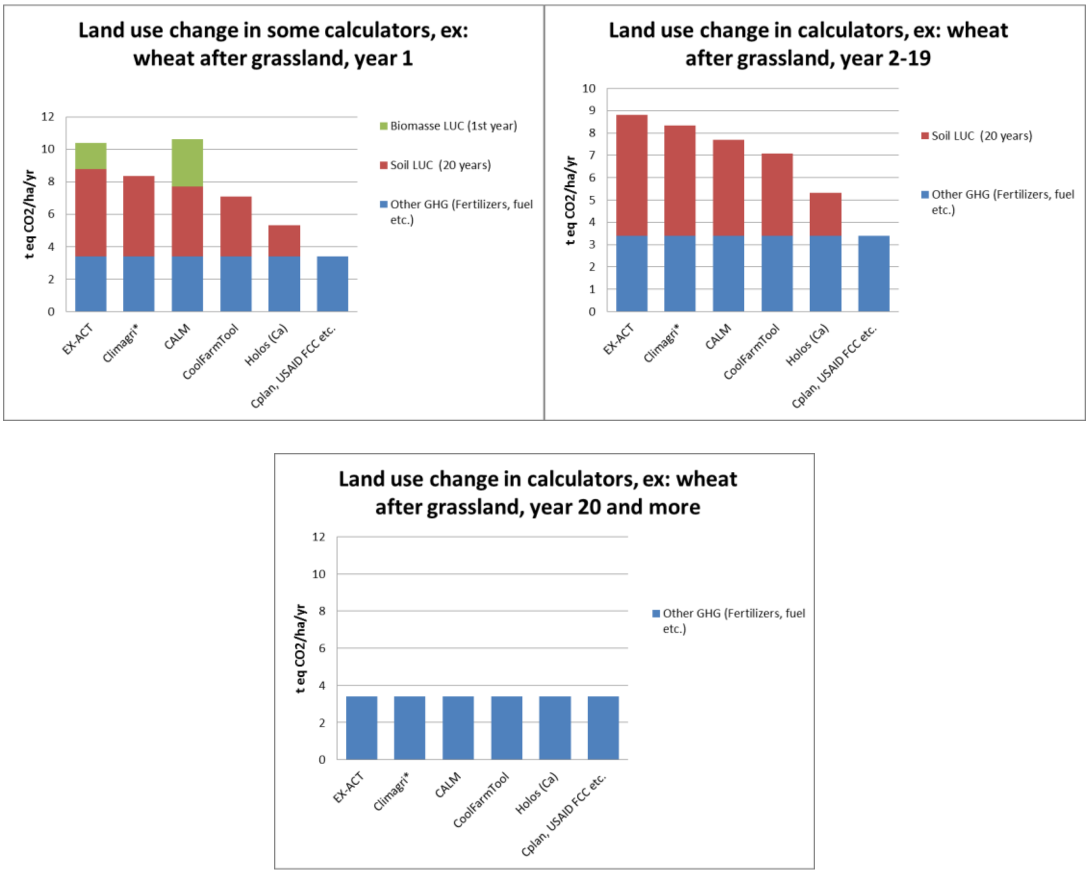


Figure 1 Direct land use change accounting in several calculators

Accounting method for soil N_2O emissions can also differ between calculators, potentially impacting significantly the results. IPCC recommends that all N_2O emissions resulting from anthropogenic nitrogen (N) inputs should be accounted. Anthropogenic N inputs are synthetic fertilizers, animal wastes and other organic fertilizers, biological nitrogen fixation by crops, nitrogen deposition, and mineralization of crop residues returned to the field. The quantity of N_2O emitted depends on local pedo-climatic conditions influencing nitrification/denitrification processes (IPCC, 2006). For N biological fixation, IPCC consider that evidence for N_2O emissions are missing thus this source could be neglected. Regarding calculators, some consider all the above mentioned N input sources while other only mineral and/or organic fertilizers. Thus, a checking of N sources accounted for should be done when using calculators and the methodology used should be clearly indicated with the results.

The other major difference in soil N_2O accounting is the split between direct and indirect emissions. Direct emissions correspond to on-field emissions due to N-input, while indirect emissions result from transport of a share of the total N from agricultural systems into ground and surface water. Processes inducing indirect emissions are drainage, surface runoff, volatilisation of ammonia or nitrogen oxides and deposition elsewhere. These emissions can be just as high as direct emissions in high N input systems (Hénault et al., 1998; Mosier et al., 1998). Special care need to be taken to avoid double counting of N sources when using direct and indirect accounting. Some calculators split between direct and indirect emissions while other do not. At the moment it is possible to identify each process in the N cycle but the specific emission factors for each process are missing, so it does not impact results significantly. Considering direct and indirect emissions improves accuracy; however it is mainly the completeness accounting for all N sources that influence the final results rather than the split between direct and indirect emissions. Once again, process models for better understanding of N cycle are probably the best way to improve accuracy of N_2O emissions assessment in the future. These models could provide more accurate emissions factors or be linked directly to calculators to estimate N_2O fluxes.

Agroforestry systems are especially difficult to analyse with most calculators. The IPCC does not provide emission factors and methodologies to account for agroforestry systems as a whole. Therefore, most calculators consider one crop system next to a perennial or forestry system. This does not take into account interactions between trees and crops, impacting notably on carbon storage. In this report, the calculators considered as "including agroforestry systems" are the ones where user can clearly define, as a whole, the agroforestry system.

On farm processing is often partially addressed but poorly identified in carbon calculators. The main processing activities on farm are drying, cooling or heating and cooking. They can be accounted through the module of energy consumption, with gas and electricity. The emissions for the materials and machineries are not accounted. These aspects concerning processing would deserve to be improved as they can bear significant reduction potential, like improving milk tanker cooling system or switching to renewable energy for hay drying. The potential of GHG reduction in processing activities will often depend on the local GHG intensity of the electricity mixt (very GHG emissive if electricity comes from coal).

Table 6a Activities accounted in calculator

Tools	Temperate crops	Tropical/Equatorial crops	Rice cultivation	Grassland	DairyCattles	Other livestock	Field trees, hedges, agroforestry	Perennial production (orchards, vineyards)	Horticultural products; Greenhouses productions	Forest
AFD calculator	x	x	no	x	x	x	no	no	no	no
ALU	x	x	x	x	x	x	x	x	no	x
CALM	x	no	no	x	x	x	no	x	no	x
Carbon benefit project CPB	x	x	x	x	x	x	x	x	no	x
Carbon Calculator for NZ	x	no	no	x	x	x	no	x	no	no
Carbon Fming Group Calc.	x	no	no	x	x	x	no	no	no	x
CFF Carbon Calculator	x	no	no	x	x	x	x	x	x	x
Climagri®	x	no	no	x	x	x	x	x	x	x
CoolFarmTool	x	x	x	x	x	x	no	x	x	x
CPLAN v2	x	no	no	x	x	x	no	x	no	x
Dia'terre®	x	no	no	x	x	x	x	x	no	no
EX-ACT	x	x	x	x	x	x	not really	x	x	x
FarmGAS	x	no	no	x	no	x	x	x	partialy	no
Farming Enterprise Calculator	x	x	no	x	x	cattle+sheep	no	no	no	no
FullCAM	x	x	no	x	no	no	no	no	no	x
Holos	x	no	no	x	x	x	x	x	no	no
IFSC	x	no	no	x	x	x	no	no	partialy	no
USAID FCC	x	x	no	x	x	X except poultry.	x	x	no	x

Table 6b Sources accounted

Calculators	Infrastructure CO_2	Fossil fuel and Electricity CO_2	Soil N_2O emissions from fertilzers and manure application	Enteric CH_4	Manure CH_4	N_2O from N input due to N-Fixing plant	N_20 from N input from residues	Off farm emissions (fertilizers, imported food)
AFD calculator	x	x	x	x	x	no	no	x
ALU	no	no	x	x	x	no	x	no
CALM	no	x	x	x	x	x	x	only fertilizers
Carbon benefit project CPB	no	no	x	x	x	no	x	no
Carbon Calculator for NZ Agriculture and Horticulture	no	x	x	x	x	no	no	x
Carbon Farming Group Calculator	no	x ("joint calculator")	x (no organic fertilizer)	x	x	no	no	no
CFF Carbon Calculator	x most detailed calculator	x	x	x	x	x	x	x
Climagri®	only machineries, not buldings	x	x	x	x	no	x	x
CoolFarmTool	no	x	x	x	x	x	x	x
CPLAN v2	no	x	x	x	x	x	x	no
Dia'terre®	x	x	x	x	x	no	x	x
EX-ACT	x	x	x	x	x	no	no	yes: fertilizer no: imported feed
FarmGAS	no	no	x	x	x	x	x	no
Farming Enterprise Calculator	no	x (only fuel, not electricity)	x	x	x	no	no	no
FullCAM	no	no	no	no	no	no	no	no
Holos	no	x	x	x	x	no	x	x
IFSC	no	x	x	x	x	no	no	yes: fertilizer no: imported feed
USAID FCC	no	no	no	no	no	no	no	no

Calculators	Biomass Burning Non CO_2 GHG	Rice CH_4	Change in soil C stock in case of direct LUC Soil	Change in biomass C stock (above and below ground) in case of direct LUC	Soil C change due to change in management practices (tillage, residues)	Peat land CH_4	Off farm processing (mainly CO_2, but also HFC, PFC etc.)	Transport CO_2	Renewable energy production (solar panel, windmill, biofuels etc.)
AFD calculator	no	no	no	only deforestation	no	no	no	x	no
ALU	x	x	x	x	x	x	no	no	no
CALM	no	no	x	yes for forest	no	x	no	no	x
Carbon benefit project CPB	x	x	x	x	x	x	no	no	no
Carbon Calculator for NZ Agriculture and Horticulture	no	no	no	no	no	no	no	no	no
Carbon Farming Group Calculator	no	no	no	x (forest)	no	no	no	no	no
CFF Carbon Calculator	no	no	x	x	x	x	x	x	x (no detail)
Climagri®	no	no	no, possibility for indirect calculation	x	no	no	no	no	no (only biodiesel+biogaz)
CoolFarmTool	x	x	x	x	x	no	x	x	x
CPLAN v2	no	no	x	x	no	no	no	no	no
Dia'terre®	no	no	x	no	no	no	no	no	x
EX-ACT	x	x	x	x	x	x	no	no	no
FarmGAS	x	no	no	x (ony above groung)	no	no	no	no	no
Farming Enterprise Calculator	no	no	no	no	x only residues ("socrate" model)	x	no	no	no
FullCAM	no	no	x	x	x	no	no	no	no
Holos	no	no	only :crop/grassland/ fallows; no deforestation	x only above ground biomass	x (century model)	x	no	no	no
IFSC	no	no	x (only pasture to annual crop;COMET VR model)	partially	x (cf COMET-VR model)	x	no	x	x
USAID FCC	x	x	no	x	x	x	no	no	no

11 Results

Results are expressed in different units. They can be expressed in ton CO_2 equivalent ($t\text{-}CO_2eq).yr^{-1}$; $t\text{-}CO_2eq.project^{-1}$ (several years) ; $t\text{-}CO_2eq.ha^{-1}.an^{-1}$; $t\text{-}CO_2eq.kg$ of products $^{-1}$ etc. (Table 7). Results might also be expressed in net value (Emission – Storage); or provide both values. User must be careful not being mixed up between tons of carbon and tons of CO_2 (factor 44/12). Some calculators provide results only for one situation, whether others provide value for baseline and with/without project situation (also known as "business as usual"). The result unit influence on the interpretation of the GHG assessment.

Considering the global context with increasing demand and the possibility of leakage (transfer of emission to other territories), it is worth distinguishing "industrial agriculture" from "small scale" agriculture.

Industrial agriculture is clearly market oriented, has high productivity level and provides a considerable share of total food for humans. Its main challenge is to develop better efficiency and reduce the carbon footprint per kg of product. Thus, for assessing these agricultural systems, results should always be related somehow to productivity level, meaning $t\text{-}CO_2eq.$ kg of products^{-1}; $t\text{-}CO_2eq.$ Kg DM^{-1} (dry matter) ; $t\text{-}CO_2eq.calory^{-1}$; $t\text{-}CO_2eq.$ proteins $^{-1}$ etc. Several calculators are developing this approach: LCA tools; calculators with quantity of GHG per kg of product, Climagri® with a "Territory Feeding potential indicator" etc. These methodologies require either allocation rules or very general productivity indicators (ex: dry matter) for farms with more than one output: ex milk + meat or bioenergy production with the co-products (Hospido et al., 2003; Schau and Fet, 2008; Cherubini et al., 2009). They somehow reflect efficiency of the production. Not considering productivity levels induce a strong risk of leakage. Indeed projects that would decrease GHG emission proportionally to productivity will induce a rise of production and emissions in other places, and possibly worsen global situation if inducing indirect land use change.

One important option for decreasing agricultural footprint is reducing losses. In developing countries post-harvest and post market losses are still very high. Reducing losses through improved storage capacities, logistic chains and reduced wasting is one of the most efficient and environmentally friendly ways to reduce agricultural footprint. No calculator is including this aspect so far although it can somehow be done considering yields at the consumer end rather than the field or farm door.

On the opposite, in project oriented towards rural development, agriculture productivity is not an issue at global scale but rather a local socio-economical issue. The aim is to maximize population welfare and improve population life conditions. The $t\text{-}CO_2eq.kg$ product^{-1} is less suitable. Indicators should be more oriented towards socio-economy criteria, such as t-CO_2eq. eqCO2.$\$^{-1}$; t-$CO_2$eq. .$job^{-1}$ created; t-CO_2eq..HDI^{-1} (Human development index) etc. Links with methodologies developed in social LCA would probably be interesting (Feschet et al., 2010). These indicators would be a good way to promote low carbon development path for "low income countries". No such approach has been identified so far for GHG calculators. At the moment for small holders and developing countries, calculators are more oriented towards carbon credits and possibility to get monetary benefits from reduction emissions compare to baseline.

GHG calculators can also be used together with economic tools. EX-ACT has been used with Margin Abatement Cost Curves (MACC), providing information on the cost of carbon sequestration depending on chosen options. Such studies can show that which actions are profitable for the economy, which have a reasonable cost and which are unsuitable. Economic studies also indicate that carbon storage and reduction of deforestation are amongst the most efficient way to fight against climate change (Smith et al., 2008). Studies indicate the potential of GHG mitigation for different carbon prices, showing the possible effect of a carbon tax or carbon market, thus Smith et al. (2008) found a potential reduction of 0,64 ; 2,240 and 16 Gt CO_2-eq.yr-1 for a price of 20, 50 or 100 US\$.tCO_2^{-1}. Considering that in 2004 total emission reached 49 Gt CO_2-eq, this indicates a theoretical 30% reduction of total emission for a price of 100$ per ton of C.

At last, carbon calculators are environmental assessment tools focused only on one criterion. For the analyses and solution proposed, special care for trade off must be considered (C-AGG, 2010). Some solutions that reduce carbon footprint might worsen biodiversity (ex: large biofuel plantations), increase water consumption or induce health risk (ex: growth hormone). Developing sustainable agriculture and forestry activities implies management practices that improve overall environmental footprint of products. More global methods that can be combined with carbon accounting are currently developed, such as LCA or impact assessment analyses.

Table 7: Results types provided by the calculators

Calculators	GHG/ha	GHG/product ex: GHG/ kg grain, GHG/1000 l milk)	GHG/project with comparison between several scenarios	Other results (only GHG for full farm/territory)
ALU				X
Calculateur AFD			x	X
CALM				X
Carbon Calculator for NZ Agriculture and Horticulture	X	x		
Carbon Farming Calculator				X
CBP; carbon benefit project	X		x	
CFF Carbon Calculator				X
Climagri®	X			
CoolFarmTool	X	x		
CPLAN v2				X
Dia'terre®	X	x		
EX-ACT	X		x	
FarmGAS	X	x	x	
Farming Enterprise Calculator				X
Full CAM				x
Holos	X		x	
IFSC				x
USAID FCC			x	

*Calculators are classified according to displayed results. Indeed most calculators have some flexibility and manually it is sometime possible to compare projects, farms, or calculate per kg/product although the calculator is not providing this value. Some calculators such as Climagri® do not display a value in "GHG. kg product^{-1}" but provide other indicators on the land productivity (feeding potential).

12 Uncertainties

Uncertainty is a vast research field, and many work based on statistic approach and advanced classification is being developed for better estimating them (Rypdal and Winiwarter, 2001; Winiwarter and Rypdal, 2001; Gibbons et al., 2006; Ramírez et al., 2008; C-AGG, 2010). The idea here is not to provide detailed information on uncertainty but to consider how they are accounted for in calculators and mentioned for final users.

Global uncertainty results from three sources of uncertainties: uncertainties on activity data (inventory), uncertainty due to year to year variability (climate and induced management practice variation) and uncertainty on emission factors (characterization) (Gibbons et al., 2006). Uncertainties can be very high for agricultural sector, over 100% depending on the emission process considered. Some calculators mention these uncertainties, whereas others do not.

At farm scale, there is little uncertainty caused by inventory as data are directly provided by farmers. At landscape or regional scale, data are based on statistic average or expert knowledge thus uncertainties can be quite high. GHG calculators never assess inventory uncertainties; it is the user to be aware of them. However, evaluating the impact of these uncertainties is often quite difficult. One way to reduce them is to go through iterative process, insuring a high accuracy for activities with strong impact on the result, such as number of cattle, or quantity of N fertilizers.

Year to year uncertainty can be reduced using average climatic data and management practices on a several years period. The intra-annual climate variability, interfering with management practice also induces uncertainties but as calculator work on an annual basis there is no way to take them into account. For example due to different climatic condition, for the same amount of nitrogen, nitrification-denitrification rates will be higher some years than others. Only bio-physical models with daily or monthly pace could account for that.

At last, uncertainties from emission factors are often mentioned by calculators. Values are provided by IPCC with each emission factor provided and can be very high, such as concerning N_2O induced by fertilizers (IPCC, 2006) (Figure 2). Moving from tiers 1 to tiers 3 approach reduces these uncertainties.

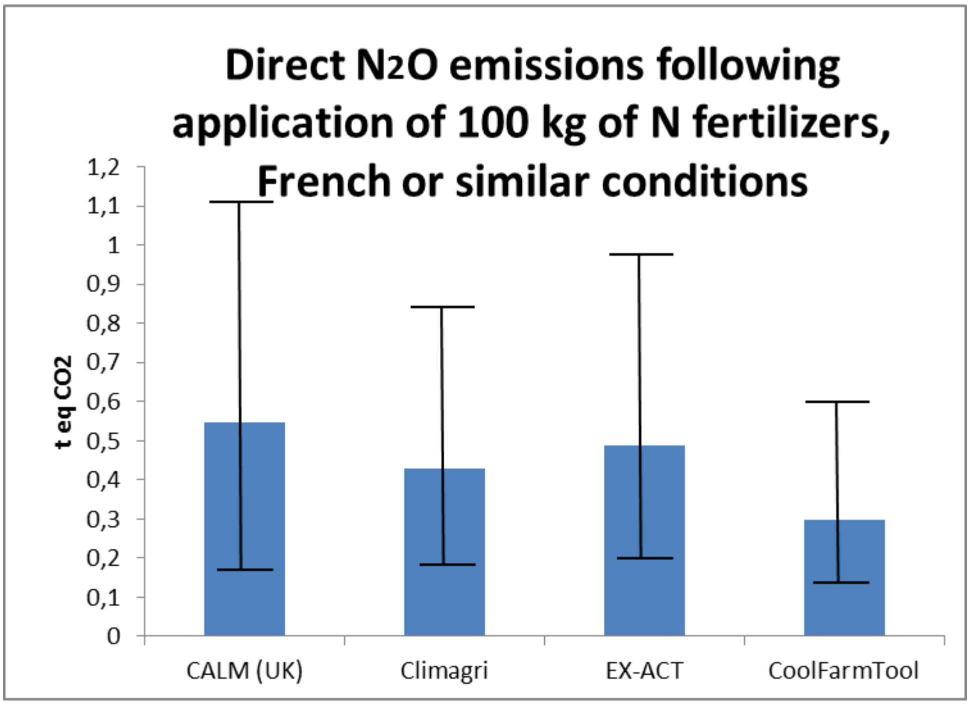


Figure 2 Uncertainties on N20 emissions following N fertilization

Due to the high level of uncertainty occurring in agriculture and forestry activities, they ought to be mentioned, especially when comparing two projects or two areas (Table 8). However, for good interpretation, users should have information on the cause of the uncertainties and how to understand them. The acceptable level of uncertainty depends of the question being asked, at landscape scale questions are generally more generic than those asked at the farm level, thus higher uncertainty level is acceptable.

Table 8 Uncertainty accounting in calculators

Calculator list*	no value for uncertainty	Quantitative estimation of uncertainty provided
ALU	x	
Calculateur AFD	x	
CALM	x	
Carbon Calculator for NZ Agriculture and Horticulture	x	
Carbon Farming Calculator	x	
CBP; carbon benefit project		x
CFF Carbon Calculator	x	
Climagri®	x	
CoolFarmTool	x	
CPLAN v2		x
Dia'terre®	x	
EX-ACT		x
FarmGAS		x
Farming Enterprise Calculator		x
Full CAM	x	
Holos	x	
IFSC	x	
USAID FCC	x	

*Many tool developers are working on including uncertainties estimation in their calculators in a near future (e.g. ALU by mid 2012).

13 Economic and political context surrounding GHG calculators

This review shows the large uncertainties associated with results and significant methodology differences between calculators. However all calculators provide good orders of magnitude and enable to identify hot spot for GHG emissions, with the remarkable exception of land use change. This level of detail is somehow sufficient at the moment considering that reduction of carbon emissions and carbon sequestration is mostly based on voluntary actions, even for carbon credit schemes. Thus, all calculators are somehow to raise awareness, and relatively little is at stake concerning the accuracy of results and methodologies, especially considering that mitigation options are quite well known.

This could change if:

-Most donors would start including a strong GHG criterion in their choice for financing development projects.

-GHG market would start including agriculture and forestry, with significant cost/benefit for emissions and storage.

-Environmental labelling would spread, become compulsory in major markets and provide comparative advantage.

-Eco-tax and trade barrier would be implemented in large markets.

If one or several of these policy choices would be implemented, carbon calculators' methodologies and especially uncertainties and leakage would become major issues.

Clean Development Mecanism (CDM) projects have been criticized for their complexity and their high transaction costs. At the same time, voluntary carbon credit system developed with simplified methodologies. It shows the importance of finding a good balance between accuracy and complexity. Standardized methodology with high uncertainties can temporarily be acceptable but impede good cross-sector comparison and penalized agriculture sector mitigation efforts compare to energy savings with very low uncertainties (in construction or transport sectors for instance) (Driver et al., 2010b). For checking mitigation options, real changes in carbon stocks can be verified, or checking can stick to implementation of good practices which is much easier. Thus, in the USA, Chicago Climate Exchange chose to pay for "GHG friendly" agronomic practices rather than measured GHG savings.

Implementations of significant actions or rules to limit climate change is a two way process. As long as political will is not strong, there is no interest for complex and detailed tools, but as long as accurate methodologies and tools are not available policy makers cannot oblige economic actors to strongly base their decision on carbon footprint. Thus, stronger legislation and tool development are complementary; one cannot proceed without the other.

There is also a high complementarity between climate change policies and food security. On the long run, limiting climate change will protect most vulnerable agricultural zone, especially in semi-arid agro-systems. However this is a global challenge, not only in the hand of most affected countries which are not always major GHG emitters. On the other hand, carbon storage in soils is a local and very efficient action to increase resilience of vulnerable agro-systems and fully justify investment on low emission agriculture for developing countries.

14 Availability of the calculators and their technical guidelines

Most calculators are available and can be obtained either on a web site (Table 9), either asking the developer (see Table 1 and Annexe 2 for contacts). Descriptions of the calculators are generally provided on their website, as well as some case studies occasionally. The description and case studies of some calculators have been also published in peer reviewed scientific papers, vouching for methodological quality: Hillier et al. (2011) for the Cool Farm Tool, Bernoux et al. (2010)and Branca et al. (2012) for EX-ACT.

Table 9: List of calculators and websites:

Tools	Web sites
AFD calculator	http://www.afd.fr/home/projets_afd/AFD-et-environnement/changement_climatique/Mesures_Impacts_Climat
ALU	http://www.nrel.colostate.edu/projects/ALUsoftware/software_description.html
CALM	http://www.cla.org.uk/Policy_Work/CALM_Calculator/
Carbon benefit project CPB	http://www.unep.org/ClimateChange/carbon-benefits/cbp_pim/
Carbon Calculator for NZ Agr. and Horti.	http://www2.lincoln.ac.nz/carboncalculator/
Carbon Farming Group Calculator	http://www.carbonfarming.org.nz/calculators/
CFF Carbon Calculator	http://www.cffcarboncalculator.org.uk/carboncalc
Climagri®	http://www2.ademe.fr/servlet/KBaseShow?sort=-1&cid=96&m=3&catid=24979
CoolFarmTool	http://www.unilever.com/aboutus/supplier/sustainablesourcing/tools/
CPLAN v2	http://www2.cplan.org.uk/index.php?_load=page&_pageid=3
Dia'terre®	http://www2.ademe.fr/servlet/KBaseShow?sort=-1&cid=96&m=3&catid=24390
EX-ACT	http://www.fao.org/tc/exact/ex-act-home/fr/
FarmGAS	http://www.farminstitute.org.au/calculators/farm-gas-calculator
Farming Enterprise Calculator	http://www.isr.qut.edu.au/greenhouse/index.jsp
FullCAM	http://www.climatechange.gov.au/government/initiatives/ncat.aspx
Holos	http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1226606460726&lang=eng
IFSC	http://web.extension.illinois.edu/dsi/projectdetail.cfm?NodeID=4035&type=Research
USAID FCC	http://winrock.stage.datarg.net/CarbonReporting/Project/Index/

15 Overall comments and conclusion

After this large review of carbon calculators, it appears that all tested calculators are accounting for main GHG sources and emissions and should be able to identify hotspots (with special care for area subjected to land use change). However there is a lack of homogeneity in methodologies, therefore it is impossible to do a straight comparison between studies done using different calculators. Indeed all calculators refer to IPCC but this does not ensure homogenous approach as IPCC provide a general framework including many methodologies with different levels of details. Only detailed comparative study would enable to evaluate precisely the variability of results depending on the calculator. Such studies are sometime available and confirm the ability of tested calculator to provide coherent order of magnitudes (Soil Association Producer Support; FAO, 2010). While interpreting results, it is a necessity to check for the scope accounted and while comparing project keep in mind uncertainties.

It appears from this review that now calculators are available for most activities to be assessed in every part of the world. The accuracy level is still restricted but active research is on-going and most calculator developers are frequently updating their calculators. The trend is for calculators to enlarge their scope (including more management options, more land types, agronomic practices, land use change etc.) and their geographical suitability. Improving accuracy implies more detailed input data, and more time demanding studies. Thus a balance must be found between efficiency and accuracy. The recent proliferation of calculators testifies of this research for appropriate balance. It is not expected that one calculator becomes dominant as each calculator is dedicated to different situation. However there is some "competition" between calculators with similar aim and geographical coverage. It might bring some confusion for non-specialist and we hope that this study will bring some clarity. For more details on carbon tools and methodologies, the reader can also refer to the work of the "Coalition on Agricultural Greenhouse Gases"(C-AGG) that is actively working on carbon issues and GHG market mechanisms applied to agriculture (C-AGG, 2010; Driver et al., 2010a) and other recent reviews (Denef et al., 2012; Milne et al., 2012). A webpage updated with the list of carbon calculators and their main characteristic would probably be most useful for project managers and farming consultants.

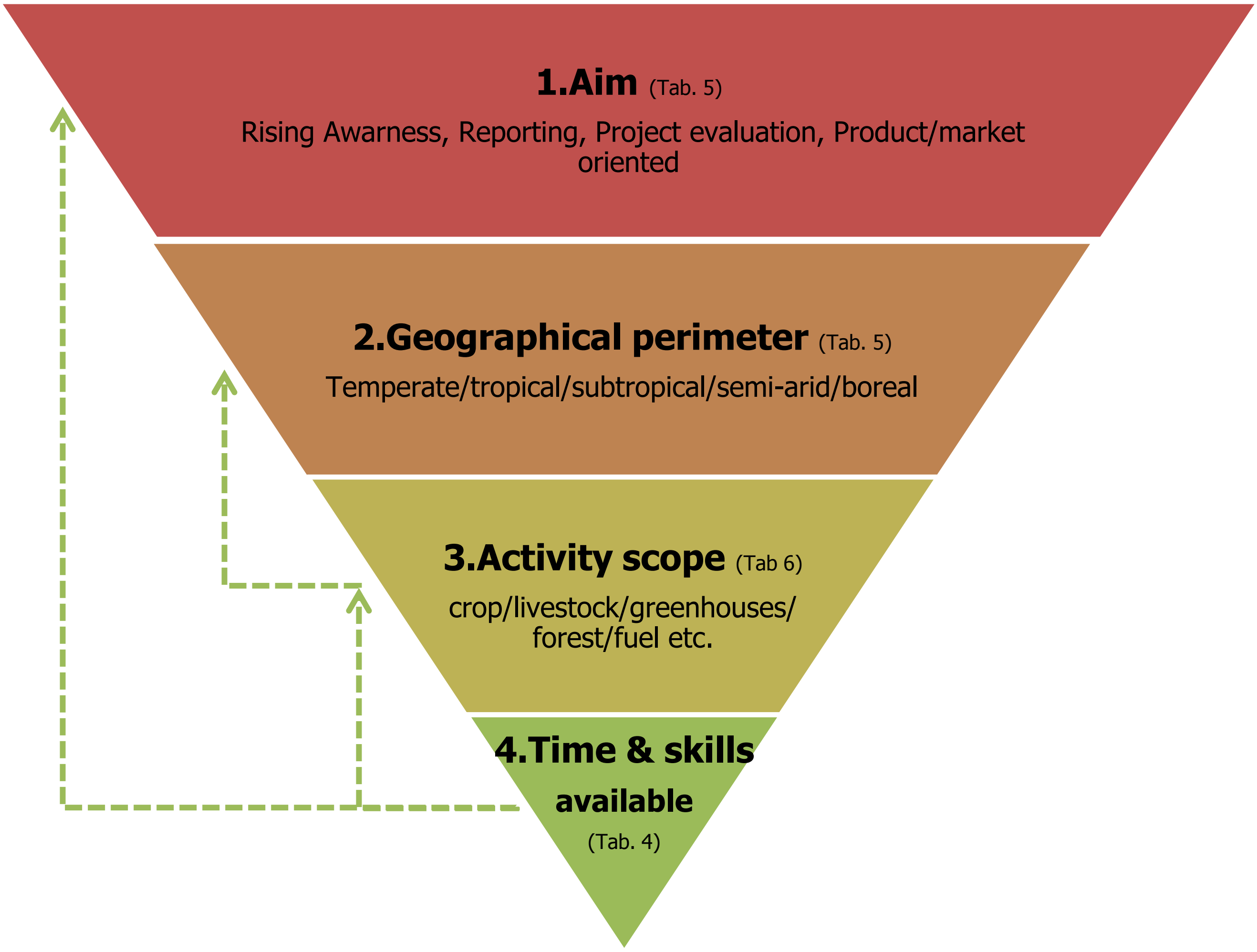
Choosing one carbon calculator: a 4 steps process

1.Define your aim for doing carbon evaluation and identify appropriate set of calculators (Table 5)

2.Define geographical area and look if one or several specific calculators are available (Table 5)

3.Check that the scope (forest, soil, LUC etc.) of your calculator is adapted to your aim (Table 6), if the local calculator is not adapted, you will have to choose more global calculators.

4.Check your time and skills availability (Table 4 and Annex 2)



16 List of Acronyms

ADEME: French Environment and Energy Management Agency
C-AAG: Coalition on Agricultural Greenhouse Gases
CDM: Clean Development Mechanism
FAO: Food and Agriculture Organisation
GHG: Greenhouse Gases
GIS: Geographical Information System
GWP: Global Warming Potential
HDI: Human development index
IPCC: Intergovernmental Panel on Climate Change
IRD: Institut de Recherche pour le Développement
LCA: Life Cycle Assessment
LUC: Land use change
MIRS: Medium Infra-Red Spectroscopy
N: nitrogen
NIRS: Near Infra-Red Spectroscopy
SALM: Sustainable land management practices
SOM: Soil Organic Mater
tC: Tonne of Carbon
tCO_2 eq : Tonne of CO_2 equivalent
VCS: Verified Carbon Standard

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