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Methods for the quantification of emissions at the landscape level for developing countries in smallholder contexts

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Front cover photo

A farmer in a maize field in Nyagatare, in Rwanda's Eastern Province. The Rwandan government is heavily promoting maize production for food security. Photo: Neil Palmer, International Center for Tropical Agriculture.

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Abbreviations and acronyms

AD	Activity data
AFOLU	Agriculture, forestry and land use
ALU	Agriculture and land use
APEX	Agricultural Policy/Environmental eXtender
A/R	Afforestation/Reforestation
ASB	Partnership for the Tropical Forest Margins
CAR	Climate Action Reserve
CBP	Carbon Benefits Project
CCAFS	Climate Change, Agriculture and Food Security
CCBA	Climate, Community and Biodiversity Alliance
CDM	Clean Development Mechanism
CFT	Cool Farm Tool
CIFOR	Center for International Forestry Research
CSU	Colorado State University
DBH	diameter at breast height
DNDC	DeNitrification-DeComposition
DPSIR	drivers, pressures, state, impact, response
EC	eddy covariance
EF	emission factors
EPIC	Erosion Productivity Impact Calculator
EX-ACT	Ex-Ante Carbon-balance Tool
FAO	Food and Agriculture Organization of the United Nations
FLUXNET	network of regional networks of micrometeorological flux tower sites
GEF	Global Environment Facility
GIS	geographical information system
GHG	greenhouse gas
GPS	global positioning system
ICRAF	World Agroforestry Centre
IPCC	Intergovernmental Panel on Climate Change
IR	infrared
IRD	Institut de recherche pour le développement
LIDAR	light detection and ranging
LU	Land Use
LULUCF	Land Use, Land-Use Change and Forestry
MRV	Monitoring Reporting and Verification
NGO	non-governmental organization
REDD	Reducing Emissions from Deforestation and Forest Degradation
RF	removal factors
RS	remote sensing
SALM	Sustainable Agricultural Land Management
SOC	soil organic carbon
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
VCS	Verified Carbon Standard

Abstract

The GHG (greenhouse gas) mitigation potential from the agricultural sector is set to increase in coming decades. Much of the agricultural mitigation potential lies in developing countries where systems are dominated by smallholder farmers. There is therefore an opportunity for smallholders not only to gain environmental benefits from carbon friendly practices, but also to receive much needed financial input, either directly from carbon financing, or from development agencies looking to support carbon friendly activities. However, the problem remains of how to quantify carbon gains from mitigation activities carried out by smallholder farmers.

Landscape-scale quantification enables farmers to pool resources and expertise, which can put participation in carbon markets and access to other funding sources, within their reach. Therefore, funding agencies, governments and NGOs are increasingly recognizing the benefits of taking a landscape approach to GHG quantification.

This paper gives an overview of approaches that have been taken to date for landscape-scale GHG quantification, covering both measurement and modelling and the reliance of one upon the other. The discussion covers ground-based measurement approaches for carbon stock changes in biomass and soils, methods for measuring GHG flux and the application of remote sensing techniques. Computational approaches for estimating carbon stock changes and GHG emissions are discussed, in addition to the use of more complex dynamic ecosystem models.

This is followed by an analysis of some of the resources that are available for those wishing to do GHG quantification at the landscape scale in areas dominated by smallholders. This analysis is intended to provide an aid to funding agencies, government agencies, NGOs, academics and others. Information for this section comes from questionnaires distributed to selected resource developers. Resources were selected through analysis of the literature including two key reviews:

Denef K, Pautian K, Archibeque S, Biggar S, Pape D. 2012. Report of Greenhouse Gas Accounting Tools for Agriculture and Forestry Sectors. Interim report to USDA under Contract No. GS-23F-8182H. Available at: http://www.usda.gov/oce/climate_change/techguide/Denef_et_al_2012_GHG_Accounting_Tools_v1.pdf (accessed November 2012).

Driver K, Haugen-Kozyra K, Janzen R. 2010. Agriculture sector greenhouse gas practices and quantification review: Phase 1 report. Market Mechanisms for Agricultural Greenhouse Gases (M-AGG). Available at: http://sustainablefood.org/images/stories/pdf/Phase-1-Draft-v13.pdf (accessed November 2012).

Resources are divided into calculators (automated software developed for calculating GHG emissions from whole systems), methodologies and protocols (documents describing quantification methods), and models and integrated resources (guidelines for quantification methods to produce inputs for specific calculators or models). Resources are compared in terms of target user groups, GHG sources and sinks and advantages and constraints (Tables 3.1-3.3). Further details for each resource are supplied in Appendix 1, including relevance to smallholders and landscape-scale application. Section 4 of the paper discusses the chosen resources in terms of research gaps and areas for improvement.

1. Introduction

In the past 40 years, great gains in agricultural production have been made in many areas of the world through the intensification of agriculture and the expansion of agricultural lands. Such measures, although associated with increased productivity, have also been associated with increased GHG emissions. From 2005 through to 2010, 12 percent of global GHG emissions were estimated to have come from agriculture (IPCC 2007). Annual GHG emissions from agriculture are expected to increase further in coming decades due to escalating demands for food and energy from a growing population. One of the biggest challenges we now face is how to increase food and nutrient security whilst simultaneously managing agricultural land for climate change mitigation.

Globally, when all GHGs are considered, the technical mitigation potential from agriculture is estimated to be ~5,500-6,000 megatonnes of carbon dioxide equivalents (megatonnes CO_2e) yr^{-1} by the year 2030 (IPCC 2007). A large amount of this mitigation potential is estimated to be in developing countries; for example, the potential for mitigation through agriculture in the African region is estimated at 17 percent of the global total, and the economic potential is estimated at 10 percent of the total global mitigation potential. Agricultural systems in many parts of the developing world are dominated by smallholder farmers (typically with holdings less than 1-2 ha depending on the country). The actions of smallholder farmers could therefore have a significant part to play in GHG mitigation. This presents a window of opportunity for smallholders to not only gain environmental benefits from carbon friendly practices, but also to receive much needed financial input, either directly from carbon financing or from development agencies looking to back carbon friendly activities.

The problem remains, however, as to how smallholder farmers, or those representing them, can quantify carbon gains resulting from agricultural activities. This paper gives a general overview of landscape approaches taken to date, before summarizing resources available for landscape-level carbon quantification today. This is followed by a discussion of resource and knowledge gaps before providing recommendations for the future development of methods.

1.1 Definition of what constitutes a landscape-based approach, or landscape-relevant method

The term landscape can mean different things in different contexts. In the context used here, in relation to smallholder farmers in developing countries, the landscape scale refers to an area that is larger than the farm scale – which could include multiple farms and other forms of land cover, in conjunction with the biophysical situation. The biophysical situation can refer to a catchment or watershed or any other geographic or ecological boundary. An assumption is also made that the area is continuous, encompassing a mosaic of land-cover and land-use types that are dynamic, as are the relationships that connect them. In addition, landscapes are usually defined by social aspects and involve a wide range of stakeholders. For many landscape-scale interventions, political and administrative boundaries may be used for practical reasons. The Sangha Group (2008) defines a landscape as:

"… the physical and biological features of an area together with the institutions and people who influence the area and their cultural and spiritual values."

For GHG accounting, landscape-based approaches can include those that treat the landscape as a single unit, making assumptions about land use and management across the whole area. They can also include more complex approaches that simulate flows of nutrients, water or energy between subunits within the landscape. Either way, ideally, a landscape analysis should be spatially integrated, recognizing that the landscape as a whole is more than the sum of its parts. Dealing with the landscape as a system allows analysis to focus on hotspots, both in temporal and geographic terms and on selected sources and sinks that are most likely to change.

In addition, there are many landscape relevant methods that were originally designed for use at other scales. For example, farm-level methods can and have been used to agglomerate results for smaller areas and some national-scale methods can be used by refining input data for the landscape scale. All these approaches are considered here.

1.2 The need for landscape-scale quantification

Individual smallholder farmers in developing countries can be marginalized from GHG mitigation activities for a variety of reasons. First, there are requirements in terms of the money, facilities and expertise needed to carry out GHG accounting that can be out of reach for individual farmers. Second, individual farmers may not have access to organizations and initiatives that provide incentives for mitigation activities. Third, the mitigation potential of individual smallholder farms is generally too low to make mitigation activities worthwhile (Berry 2011). Fourth, mitigation activities may compete with smallholder interests in achieving greater food security and avoiding climate and other risks, such as by locking them in specific agricultural practices. The FAO in its 'Climate Smart Framework' advocates a landscape-scale approach, which considers impacts in terms of watersheds and ecosystems (FAO 2010).

Landscape-scale quantification enables farmers to pool resources and expertise that can put participation in carbon markets within their reach. Transaction costs can be spread between farmers and other stakeholders involved in the landscape (local government, larger farms, cooperatives, carbon credit buyers, NGOs and so on). This can be particularly relevant when smallholdings cover a diverse range of agricultural practices requiring various expertise and resources for GHG accounting. For example Plan Vivo is a very successful pro-poor scheme set up to allow smallholder groups in developing countries to access carbon financing for carbon friendly land management activities. Total costs associated with developing, reviewing and registering a project are estimated between US$7550 and US$12550, although costs do vary widely (Plan Vivo 2012). The registration process alone can require substantial funds that are more likely to be leveraged by several groups working together.

In addition to accounting practicalities, the same advantages of landscape-scale management that apply to land management in general, also apply to management for climate change mitigation. Patterns within the landscape can be recognized and used to improve mitigation and manage resources more efficiently. For example, a landscape-scale approach allows 'transhumance' (the movement of livestock from one area to another) to be included in a way that would not be possible in a farm-level analysis. Indeed mitigation activities by smallholders working alone can sometimes have negative mitigation impacts at the landscape scale (Butterbach-Bahl, pers com). For example, an individual smallholder could decide to incorporate crop residues into the soil rather than allowing his neighbours' animals to graze them, thereby increasing soil carbon. This neighbour could then be forced to look for alternative land on which to graze his animals and clear a patch of native vegetation, releasing GHGs from the biomass and soil. However, an extreme example of this does show the benefits of taking a landscape approach that accounts for all land uses and possible interactions between them.

Recognition of such links between smallholder activities can provide opportunities to increase mitigation at the larger scale. This applies not only to management for mitigation but also to climate change adaptation. In complex landscapes (for example parkland systems in West Africa) many land-use systems are hard to define as definite units of land use, such as 'forest' or 'pasture', and hence a landscape approach is needed when dealing with the landscape as a system in its entirety. Funding agencies, governments and NGOs are increasingly recognizing the need to consider multiple ecosystem services and the trade-offs amongst them. A landscape-scale approach to GHG accounting and mitigation activities has the potential to detect conflicts of interest between stakeholders over different ecosystem services that may go undetected if activities are carried out at the farm level. In a similar way, landscape-scale activities related to watershed, economic or social management, can impact GHG mitigation activities and need to be considered if mitigation is to be sustained. Economic and social considerations can sometimes present greater challenges than technical ones in developing countries if institutions and the knowledge base are weak and there are problems enforcing agreements (Sayer and Dudley 2008).

1.3 Issues associated with current quantification methods

Among the largest constraints of GHG accounting at the landscape-scale is the paucity of suitable methodologies and models. The development of methodologies for national-scale accounting has been driven by the need to report to the UNFCCC (United Nations Framework Convention on Climate Change) (IPCC 2003; IPCC 2006). Site- and farm-scale methodologies and models have been developed because people tend to work at this scale due to financial and practical constraints. The development of landscape-scale approaches has been hindered in part by problems associated with defining a landscape boundary and accounting for GHG emissions and removals within that boundary. Methods to detect and address leakage have been developed in recent years (Gershenson et al. 2011) but they are still evolving, especially in the case of mixed landscapes with multiple land uses. This lack of methodological clarity can in part be attributed to the difficulty in defining the boundaries of the landscape. Such boundaries can be quite limited, such as where all products are used for subsistence or are traded locally. But where commodities are traded internationally, such as high value timber, the landscape boundary essentially has to be extended to all the countries where that commodity is being utilized.

The definition of 'landscape' that is used for a GHG assessment will vary, depending on a variety of factors including who the assessment is being carried out for, the rules and guidelines provided by any funding agency or accreditation agency, whether the assessment is ex-ante or ex-post and practical considerations such as access, etc. It is therefore difficult to give an ideal way of defining a landscape for a GHG assessment.

Landscape-scale assessments require a comprehensive approach that takes into account multiple land-use categories and multiple sources of GHGs. This can make sampling strategies costly, especially if a high level of precision and accuracy is required. However, there are certain economies of scale when sampling for multiple purposes. Ground-level sampling schemes can involve the collection, processing and analysis of thousands of samples requiring high inputs of labour and expertise. The use of innovative techniques, such as spectral reflectance for soil carbon, can reduce sample numbers and processing time, but measurements still have to be calibrated against libraries of previously analysed samples, which are yet to be developed for many countries.

Landscape analysis will inevitably involve large datasets, whether these data come from ground sampling, remote sensing, flux towers or a combination of these and other sources. In developing countries the cost of many technologies may be prohibitively high. In addition, social and political constraints may stand in the way of data collation. For example, smallholders may be operating in an environment where it is disadvantageous for them to reveal how much they produce and where there is a lack of trust in local governors. Gender issues can also arise if crops are cultivated by women but communication to outside parties is carried out by men. The technical capacity to process landscape-scale data can in itself be an issue, especially in countries where well-financed academic and research institutions are sparse. Understanding the data also presents unique challenges.

Approaches that use 'activity data' (information on land management activities and the areas in which they occur) can be useful (IPCC 2006). They utilize the types of land management information farmers are likely to have anyway and therefore can reduce cost. This can be useful in a developing country smallholder context where GHG accounting will work best if it is not too burdensome for those involved in reporting. This extends to the smallholders themselves who should ideally gain some benefit (either financial or practical) from any information gathering activities needed for GHG accounting. However the accuracy of methods using activity data relies on the activity data itself being accurate. At the landscape scale this can be problematic, especially in areas encompassing multiple smallholdings. Smallholders may be unwilling to provide activity data and institutions with overall responsibility for a landscape may be lacking or ineffective. Accuracy also depends on availability of appropriate emission factors (coefficients that describe GHG emissions) and these are often lacking for developing countries (Section 2.3).

In situations where landscape-scale GHG accounting is carried out for credit in a carbon market results must be accompanied by an estimate of uncertainty. Sources of uncertainty vary at the landscape scale from those found at the farm scale. This is because biogeochemical processes operate and interact at different scales (Veldkamp et al. 2001). When numerous spatial data points are aggregated to produce a landscape assessment, overall uncertainty tends to be reduced. In addition, the proportionate contribution of different sources of uncertainty changes with scale. For example, highly heterogeneous soil properties that contribute large uncertainty to analysis at the field or farm scale tend to partially cancel out at the landscape scale. Landscape-scale assessments therefore require appropriate means of estimating uncertainties and this should be kept in mind, especially if farm-scale estimates are aggregated up to give landscape-scale assessments.

Sources of uncertainty and acceptable levels of precision and accuracy differ when working at the landscape scale, as opposed to the farm or national scale. Uncertainty results from three major sources of uncertainties: (i) on activity data (inventory), (ii) due to year to year variability (climate and induced management practice variation) and (iii) on emission factors (Gibbons et al. 2006). Their different combinations imply that there is no direct and linear link between the scales and uncertainties. For instance, it is easier to get reliable data for administrative regions, whatever the scale, rather than for watersheds or ecoregions. At farm level, most activity data can be provided quite accurately by farmers, whereas at landscape level, data will be based on statistics and on regional available data or expert knowledge; thus uncertainties can be quite important. Evaluating the impact of these uncertainties is often quite difficult, and certainly the best way to reduce them is to go through an iterative process, ensuring a high accuracy for activities with most impact on the result. The accounting of uncertainty in calculators is therefore a crucial point, but extra effort is still needed in most of them for a full accounting of uncertainties.

Ideally, in addition to dealing with heterogeneous areas with multiple GHG sources and sinks, landscape-scale methods should account for multiple interactions between GHGs and take an integrated approach. However, trying to capture this level of complexity can lead to approaches that are prohibitively demanding, both in terms of expertise and financing. Most landscape-scale methods and approaches deal with individual or limited numbers of sources and sinks. Most have also been designed for specific, often very different remits. As such, there can be no 'best' landscape-scale GHG accounting approach, as suitability depends on the purpose for which the assessment is being carried out.

In this review we firstly give an overview of approaches that have been taken, before considering some of the resources that are available now for those wanting to do GHG accounting at the landscape scale, in a smallholder developing country context.

2. General overview of approaches to date

2.1 Landscape-scale measurement approaches

Measurements are an essential element of GHG assessments at any scale. In addition to providing a direct assessment of carbon stock changes and GHG emissions, they underpin assumptions made in models. Taking measurements at the landscape scale presents obvious practical problems in terms of cost and resources. Measurements are therefore most useful in landscape-scale assessments when they form part of an integrated approach involving other methods, such as remote sensing for stratification (Section 2.2), and modelling for scaling up (Section 2.3) (CBP 2011a; Goidts et al. 2009).

To implement a measurement strategy several steps are needed, including clear definition of the landscape boundary, stratification of the landscape and selection of the sampling methods and sampling size (Ravindranath and Ostwald 2008; Hairiah et al. 2011). The sampling method and strategy depend on the heterogeneity of the landscape, the pools/emissions to be considered, the level of accuracy and precision required and most importantly, the resources available. Proper consideration of all of these factors, in addition to techniques that focus on 'hot spots' of likely carbon/GHG flux should be taken to ensure efficient use of resources. The development of new mobile technologies, such as GPS applications, and the widespread use of mobile phones in developing countries, offer new ways of accurately reporting sampling sites and landscape boundaries. In addition, advances in hand-held video mapping devices linked to GIS and a GPS offer a means of reducing the number of samples needed (Stohlgren et al. 2000). Scaling up of site-scale ecological measurements has been the subject of much research and debate (Wu and Li 2006). Methods range from hierarchical patch dynamic scaling, which assumes the landscape is the sum of its parts but does not account for horizontal interactions between patches (Wu 1999) to the use of dynamic ecosystem models, which simulate biophysical processes (Section 2.3).

Landscape-scale ground-based measurements of carbon stocks in biomass and soils

Landscape-scale sampling strategies for carbon stocks in woody biomass generally employ allometric equations based on simple measurements, such as diameter at breast height and total tree height (Section 2.3). Initially these have to be derived from destructive sampling of whole trees, which is very time-consuming and expensive. The sampling strategy that should be taken varies, depending on the type of land cover in question and the activities being carried out (for example, trees in forests or trees in the landscape in settlements, orchards or agroforestry) (CBP 2011a; CBP 2011c; Hairiah et al. 2011). In situations where multiple smallholdings have single trees of different species, this can be problematic if a high level of accuracy is required and generic equations are not acceptable.

Heterogeneity in soils also presents a problem for sampling. Soils show high heterogeneity in soil organic carbon (SOC) content at the plot scale, let alone the landscape scale. Trying to capture this heterogeneity in all soil/land-use combinations in a diverse landscape can result in thousands of samples being taken. Ideally, before determining how many sampling sites are needed, preliminary measurements should be taken to estimate existing variance in each stratum. A step-by-step guide to doing this is provided by Hairiah et al. (2011). One approach is to use a nested sampling design with clusters of samples within a grid, such as the design presented in the Land Degradation Surveillance Framework (LDSF) (CBP 2011d). This can reduce the number of samples needed; however, large numbers of samples still need to be collated and processed.

Many laboratory methods to measure soil organic carbon (SOC) require a lot of sample preparation and analysis time (wet combustion, dry combustion) or involve expensive equipment (LECO), further increasing costs. Advances in the use of diffuse reflectance infrared (IR) spectroscopy provide the potential to greatly increase sampling density, with little increase in analytical cost (Shepherd and Walsh 2007). Developments of mobile IR devices that can be used in the field can also remove the need to take samples back to the lab and increase sample sizes further (Knadel et al. 2011). In terms of application in developing countries, a drawback of this technique is the need for calibration libraries, which, although being steadily developed for many regions, are still far from comprehensive.

Eddy correlation/covariance for landscape-scale assessments

Eddy covariance (EC) is a technique commonly used to quantify the vertical flux of CO_2, heat and water vapour in the atmosphere. It allows an estimation of exchange between the biosphere and the atmosphere (Baldocchi et al. 1988). In 1997 a global network of flux towers (FLUXNET) was initiated and today there are in excess of 400 EC-towers across the globe (Chen and Coops 2009) associated with FLUXNET and other national and regional initiatives (NEON, China Flux, Ameri-flux). However, less than 20 exist on the African continent, with a similar situation in Latin America and Asia. Advantages of the technique include the fact that continuous measurements can be taken without the need for people in the field; it is also non-destructive and can account for exchange over large areas simultaneously (depending on the number of towers used). Disadvantages are that in order to work effectively the terrain needs to be flat and homogeneous and stable environmental conditions are required (wind, temperature, humidity and CO_2). In addition, instrumentation is generally expensive and requires complex set-up and calibration.

In terms of landscape-scale application there are uncertainties and difficulties with scaling up eddy covariance (EC) fluxes taken at the ecosystem level (typically less than 3 km for each site) to the landscape scale. Scaling up to the landscape scale by simple extrapolation and interpolation is considered unreliable due to the heterogeneity of landscape surfaces and the non-linearity of the processes underlying biosphere/atmosphere exchanges (Levy et al. 1999). For landscapes dominated by smallholders, further uncertainties arise, as EC does not work well in landscapes with a mosaic of multiple land-use systems.

Chamber measurements – scaling to landscape scales

Micrometeorological techniques, emissions factors and process-based models are indispensable tools to quantify GHG emissions at landscape scales. However, their utility is limited when considering GHG fluxes from landscapes dominated by smallholder agricultural systems. Characteristics indicative of these environments – non-uniform topography and diverse, interspersed plant cover – mixed with logistical and contextual considerations such as security, access, a lack of activity data, and biased emissions factors, impede their application (Section 1.3). The shear number of potential confounding factors would seemingly suggest that the oft-applied methods may be misleading or unsuitable for quantifying GHG fluxes for complex landscapes in developing countries.

Scaling up chamber-based measurements present another, less frequently applied option. Chambers are typically used to quantify gas fluxes over small spatial scales. Because chambers cover a very limited fraction of the soil surface (<1m^2), there are concerns over extrapolation to larger spatial extents (100s or even 10,000s m^2). Chamber design, its positioning, and deployment can greatly influence flux estimates (Davidson et al. 2002; Rochette 2011; Rochette & Eriksen-Hamel 2008). Scaling up from uncertain flux estimates, potentially propagates common measurement errors. It is for this reason that scaling up chamber-based estimates must be done with caution, or it will tend to yield biased quantification of landscape fluxes.

Despite the challenges, scaling chamber-based measurements has provided reasonable estimates of large-scale GHG emissions for a variety of ecosystems and landscapes. Comparable results derived from chamber and micrometeorological techniques show evidence of the value of the approach at moderate spatial scales. Schrier-Uijl et al. (2010) examined CO_2 and CH_4 fluxes from a non-uniform grass ecosystem on peat soils and found that chamber-based measurement were only 16.5 percent and 13 percent different from eddy covariance measurements, respectively. Such high level of agreements was only obtained when stratifying the landscape into various source components, measuring hotspots of emissions and using all source areas in the scaling equation; simply scaling up from field measurements alone was inadequate. Stratification and intensification of sampling in this way will inevitably incur extra costs and therefore may not always be feasible. However the work of Schrier-Uijl et al. (2010) does highlight the inadequacies of scaling up without stratification.

Similar results have been shown for N_2O. Using two adjacent agricultural fields – one maize and one alfalfa – scaled static chamber estimates of N_2O were between 7 percent and 33 percent of eddy covariance estimates (Molodovskaya et al. 2011). The largest deviations between the two techniques correspond with changes in wind direction and turbulence, factors that alter the efficacy of eddy covariance methods, and contributed to differences in estimates in other comparative studies (Wang et al. 2010). Agreement between results shown in these studies and others like them (such as Laville et al. 1999; Smith et al. 1994) demonstrate that scaling up is feasible. Plenty of evidence, however, indicates poor agreement between methods (Hendriks et al. 2010; Pavelka et al. 2007), highlighting the need for careful scaling procedures to ensure robust and meaningful estimates.

Standards of practice to scale up chamber-based measurements are still very much developing. But there appear to be some common approaches that tend to improve estimates. To begin with, it is important to separate the landscape into its component parts. Stratifying the landscapes guides the development of an appropriate sampling strategy, in both space and time, and provides important information on the extent of source areas, a factor critical to scaling. Previous research in the region can be invaluable to facilitate stratification. For example, a landscape-scale study of N_2O emissions from forests in northeast USA used previous work that related nitrification potential to elevation, slope and aspect in order to locate sampling sites (Groffman et al. 2006). Often in developing countries, relevant information is unavailable. Under this circumstance, remote sensing and spatial analysis tools may substitute to some degree. Assuming spatially and temporally representative fluxes have been measured, the next critical step involves a scaling approach. Scaling methods range in sophistication from simple functions based on mean flux and source areas to the parameterization of empirical models. Mixed results have been found for both and appear to be related to inherent variation in soil processes that promote GHG evolution, environmental conditions, experimental artefacts, and difficulty in attributing source contribution. Thus, identification of the 'best' scaling method remains unresolved.

Chamber-based methods, though rarely employed, provide a relatively low-cost and potentially reliable way to verify flux estimates in non-uniform environments. Though the approach has been shown to be effective in relatively small landscapes (100 km^2), it is impossible to know the accuracy at much larger scales (Groffman et al. 2006). It is important to recognize that measurement approaches are complimentary to the other tools. At present, further refinement and standardization of scaling methods is needed to help projects and researchers understand the limitation and apply this method.

2.2 Approaches using remote sensing

Introduction to remote sensing

Remote sensing is the gathering of data about an object or area of analysis without being in direct contact with the object. There are a variety of sensors used in making earth observations that are either active or passive sensors. Active sensors include LIDAR (light detection and ranging) and RADAR (radio detection and ranging) that emit energy and measure attributes of the returned energy. Passive sensors do not emit energy, but rather measure sunlight or other sources of radiation reflected off the landscape or other object of analysis. Remote sensing has been used for the past several decades to monitor land cover and land-cover change throughout the tropics (Skole and Tucker 1993). The magnitude and rates of tropical deforestation have been well documented through standard remote sensing methods and techniques (FAO 2011). Remote sensing has also been used to document the various drivers of tropical deforestation, including logging, fire, large-scale commercial agriculture, and smallholder agriculture (Wang et al. 2005; Matricardi et al. 2010).

Uses of remote sensing

The primary uses for remote sensing in quantifying landscape GHG emissions in the agriculture, forestry and other land use (AFOLU) sector are stratification of the landscape (Hairiah et al. 2011) and quantification of land-cover change. The IPCC (Intergovernmental Panel on Climate Change) refers to this land area parameter in GHG emissions calculations as a type of activity data, or the magnitude of human activity (IPCC 2006). Remote sensing techniques are well established to classify land covers and to quantify changes in area between land covers through time series analysis of historical remote sensing data (GOFC-GOLD 2011). But remote sensing techniques are increasingly able to also estimate landscape carbon density and carbon stocks – a type of IPCC emissions factor that is also required for calculations of landscape greenhouse gas emissions (Goetz et al. 2009). Remote sensing methods are maturing for estimating above-ground biomass stocks by measuring forest greenness, and even soil organic carbon stocks, by measuring soil reflectance in a variety of land covers and at multiple landscape scales (Saatchi et al. 2011; Betemariam et al. 2011). Low (200 m per pixel) or moderate (30 m per pixel) resolution satellite data can be used to measure the fractional cover of large-scale closed canopy forests and then correlated with ground measurements of forest carbon density to map carbon stocks across large area landscapes. Analysis of multiple date satellite data can then estimate greenhouse gas emissions or sequestration from land-cover change. Fine (<1 m per pixel) resolution satellite data can be used to directly measure crown attributes of individual trees in open forests or in non-forest land covers (Palace et al. 2008). The above-ground biomass of these individual trees can be determined through allometric relationships between crown characteristics and above-ground biomass to map landscape carbon in open land covers, such as woodlands, savannahs, agroforestry systems, and human settlements. Airborne or spaceborne LIDAR sensors can directly measure tree height in closed canopy forests, which correlates to above-ground biomass of various forest types. Soil reflectance values from satellite imagery can be correlated with laboratory measured reflectance values from near infrared spectroscopy of SOC stocks to map these across large agricultural landscapes (Betemariam et al. 2011).

Remote sensing indexes

Carbon offset markets and national inventories for the UNFCCC typically require monitoring, reporting and verifying greenhouse gas emissions, strictly in units of tonnes of carbon dioxide equivalents (tCO_2e). This type of measurement

and monitoring requires the large financial expense of implementing a field-based carbon inventory for the five carbon pools (above-ground biomass, below-ground biomass, deadwood, litter and soil organic matter) in the six IPCC land-use categories (forest land, crop land, grazing land, wetlands, settlements, other land) within the project boundaries, and may become cost prohibitive. However, there are other related metrics that can provide insightful analysis into the carbon benefits resulting from smallholder investments and activities on their lands. Monitoring and evaluation efforts for development projects may seek a lower cost option to determine the impacts of their investments on smallholder landscapes. Remote sensing data are commonly used to develop indexes to assess biophysical parameters.
For example, the normalized difference vegetation index (NDVI) is a common remote sensing index to quantify seasonal greenness of forest land cover. The Carbon Benefits Project (CBP) (a project funded by the Global Environment Facility GEF) proposes several categories of project assessments and indexes that are built upon remote sensing analysis of coarse, moderate and fine resolution satellite imagery, that are cost effective for large-scale projects involving many smallholders across large landscapes (CBP 2011b). Parameters such as hectares of land-cover change, default carbon stocks, topography, fire occurrence, and social and biodiversity self-assessment, can be integrated with satellite data and analysis to develop simple but robust indexes that illustrate landscape carbon benefits in large regions. These indexes offer a low cost means of monitoring and evaluating the impacts of development efforts and changes in the agricultural and forested landscapes.

Access to remote sensing data

Although the high cost of satellite remote sensing data has historically been a barrier to access, for researchers in both developed and developing countries, there are now multiple data sources that provide free, or low-cost satellite data including both MODIS and Landsat satellite data from the US government. Although free and low-cost data are now readily available, technical capacity to store large datasets and process complex remote sensing datasets still remains as a barrier for smallholders, researchers, and government agencies in developing countries. While government agencies have been the primary early developer of satellites and sensors for remote sensing, private commercial companies are now providing fine resolution satellite data (<1m pixels) although costs around US$15/km^2 may still be a barrier for access to these commercial satellite data. Aerial LIDAR flights and data collection are also available from commercial vendors but costs are again a barrier for access to data in developing countries.

Remote sensing applications for smallholders

Smallholder agricultural systems are typically more complex than industrial agricultural systems (large-scale monocultures) and may also incorporate more above-ground woody biomass on their land through the use of agroforestry systems. The global availability of fine resolution satellite data, where single pixels (0.5m) are smaller than individual tree crowns, allows for detection and measurement of trees as objects in agricultural landscapes (even trees as small as 10 cm in diameter at 1.3 m often have crown projection areas >10 m^2). Crown attributes measured by satellites can be related directly to above-ground biomass through specialized allometric equations, or simply to diameter at breast height (DBH), for input into standard allometric equations that predict above-ground biomass from DBH. Landscape carbon in complex smallholder agricultural systems can then be mapped by integrating remote sensing analysis and basic tree inventory methods in the field. The Carbon Benefits Project is developing remote sensing methods and integrating them with online carbon management tools to enable smallholders to measure and monitor carbon in trees outside forests, agroforestry systems, and other non-forest land covers (CBP 2011a). Although smallholder farmers would not be involved with remote sensing analysis, they certainly can contribute basic tree measurement or forest inventory data from their land. These inventory data can be uploaded into an online geographic information system that calculates carbon stocks and emissions associated with current land cover and potential land-cover changes.

2.3 Modelling approaches and application to landscape-scale accounting

Landscape-scale assessment of GHGs in agriculture can present a number of practical problems. Data are needed from large heterogeneous areas, often for multiple points in time, and the collection of these data can be expensive and time consuming. Models (simplified versions of a system used to estimate outputs) can offer a means of estimating information where comprehensive large-scale measurement campaigns are not possible. They also offer the possibility of making predictions about the future carbon stock changes and GHG emissions. All models are based on a set of assumptions about a system that give an approximation of the actual situation. They therefore have an inherent level of uncertainty (which can be quantified with appropriate methods) and this should be kept in mind when deciding whether a model should be used for an assessment. The purpose for which a GHG assessment is being carried out (such as a report to a funding agency, an inventory, or a project to gain certification from a carbon market) and the associated level of accuracy and precision, should determine the type of model that is used, and indeed whether a model is used at all.

IPCC-based approaches (relying on land management activity data)

All models require input parameters that describe the system they represent. For GHG accounting models some of these input parameters relate to types of land use and management and the area on which it occurs (Activity Data – AD) and some relate to coefficients describing emissions of GHGs (Emission Factors – EF) or removals of GHGs (Removal Factors – RF). The IPCC undertook a huge international effort to develop a computational method for estimating GHG fluxes that uses both these types of data (IPCC 2003; IPCC 2006) and includes a large database of EFs and RFs plus default information on climate, soil type and land use/management (tillage and productivity). The method can be employed using this default information (a Tier 1 approach using default data provided by the IPCC) or, if available, country-, region-, landscape- or even project-specific data (a Tier 2 approach using country-specific data). The IPCC also advocate using a Tier 3 approach where possible, where advanced models with detailed country-specific data are used. Further details of the IPCC Tier system can be found in the IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (LULUCF) (IPCC 2003). There are two issues with using the IPCC method for landscape-scale assessments in developing countries. Firstly, if a Tier 1 approach is used, much of the data available for deriving the empirical factors in the IPCC default approach are from studies in North America and Europe (typically more are available for temperate versus tropical areas and mesic versus arid areas) (IPCC 2003). This situation is slowly being redressed as developing country EFs are published for various sectors; for example, CH_4 emissions from livestock in Africa, (Herrero et al. 2008), and N_2O emissions from agriculture in India (Garg et al. 2012). Nevertheless, huge gaps in developing country data remain. The IPCC manage an online database to which new EFs and RFs can be submitted (http://www.ipcc-nggip.iges.or.jp/EFDB/main.php). However, this is currently underutilized by those holding information from developing countries.

Secondly, the IPCC approach was originally designed for use at the national and subnational scale, to provide a simple method for compiling national inventories. Therefore the default method was designed to be as simple as possible and uses limited and highly aggregated data, which may not be applicable if used at a smaller scale. These problems can be addressed in part by taking a Tier 2 approach, using project-specific EFs and RFs developed for landscape-scale application. The IPCC method is a computational model considering the change in GHGs and carbon stocks in one step (such as one stock for year 1 and another for year 20) and assuming a linear rate of change over the period. This means it does not account for fluctuations throughout the period in question, or deal with dynamic interactions that occur within the system in the way that dynamic models do.

Despite the issues mentioned above, the IPCC approach provides the only standardized, globally applicable method for GHG accounting for the agricultural sector. Therefore it has been used as the basis for several GHG accounting tools that can be used at the landscape scale in developing country areas (ALU, USAID AFOLU Calculator, the CBP Simple Assessment, the CBP Detailed Assessment, EX-ACT and the Cool Farm Tool). All of these tools (with the exception of the USAID AFOLU Calculator and the CBP Simple Assessment) allow the user to input their own EFs and RFs and take a Tier 2 approach. Outputs from some of these tools (ALU and the CBP Simple Assessment, The CBP Detailed Assessment) have a spatial element allowing a more detailed analysis of spatial units within the landscape. Details of these particular tools are given in Section 3.

Regression models

In contrast to a one-step approach, regression models are generally based on equations developed from long-term studies or wide-ranging observations. Regression approaches in GHG accounting in the agricultural sector have been used in many different ways for different source categories. Some examples are given below.

Biomass carbon stocks – Landscape-scale approaches often include the need to quantify stock changes in areas of forest, or non-forest areas where trees occur in the landscape. Allometric equations used to estimate biomass or volume of above-ground woody vegetation can also be applied to estimate carbon stocks in any system with woody vegetation, including agroforestry systems and perennial cropping systems. Further equations can be used to estimate below-ground biomass from above-ground biomass. Those carrying out landscape-scale assessments have the option to draw on published databases of allometric equations that cover the relevant species. Some examples include those compiled by USDA for North America (Jenkins et al. 2004), by the CarboAfrica Project for sub-Saharan Africa (Henry et al. 2011) and by the World Agroforestry Centre for Agroforestry Species (Kuyah et al. 2012). Species-specific equations are always preferable, as tree species differ in wood density that can affect carbon stocks. However, in a landscape-scale assessment, especially those including tropical forests where hundreds of species may be present, the use of generalized equations may be necessary (Gibbs et al. 2007).

Soil carbon stocks – Falloon et al. (2002) summarized a number of approaches that have been taken to estimate SOC stock changes at a large scale. These include simple regression approaches where a model was developed from a number of long-term experiments in a region, and an assumption was made that current trends in SOC stock change will continue into the future (Smith et al. 2000). Such approaches have the disadvantage of assuming that all the site-scale studies used can be treated as representative and equally valid in an analysis. More complex regression-based approaches, based on spatially explicit soil databases were taken by Kern and Johnson (1993) and Kotto Same et al. (1997) to make spatially explicit regional analyses. These studies had the advantage of taking into account spatial heterogeneity in soil type; however they still assume a linear rate of change in SOC stocks that is unrealistic, especially following land-use change (Paustian et al. 1997).

Soil N-oxide emissions – The multivariate empirical model of Bouwman et al. (2002) – which is based on a global dataset of over 800 sites is used in the Cool Farm Tool. It is given thus:

$$N_2O = e^{const + \sum_{1}^{n=i} Factor\ class(i)}$$

where factor classes are fertilizer type x fertilizer application rate, crop type, soil texture, soil organic carbon, soil drainage, soil pH, soil cation exchange capacity (CEC), climate type and application method.

The model for ammonia (NH3) emissions is given in FAO/IFA (2001).

$$NH_3 = FA \bullet e^{\sum_{1}^{n=i} Factor\ class(i)}$$

where FA is the amount of fertilizer applied. Factors were determined by a statistical analysis.

A simple conceptual model termed the 'Hole in the Pipe' (HIP) model (Firestone and Davidson 1989) has been used in several studies to estimate spatial and temporal variation in soil N-oxide flux at the landscape scale. Verchot et al. (2006) used the model to estimate the impacts of conversion of forest to agriculture on N-oxide emissions in a watershed in Sumatra. The model is based on the underlying biogeochemical controls of N-oxide emissions, making the assumption that total N-oxide gas flux (NO + N_2O) is proportional to the rate of N cycling. Davidson and Verchot (2000) tested the applicability of the model to varying land-use categories (forest, grassland, cropland) in temperate and tropical conditions. They found good agreement between model and measured results at most sites and deemed the model to be broadly applicable, but added the caveat that in common with most models, accurate results require site-specific calibration.

Simple models such as the ones described above can be very useful tools for GHG accounting across landscapes, especially if analysis is being done for a single source/sink category. In cases where a simultaneous analysis of all sources and sinks is required, numerous regression models can prove cumbersome.

Dynamic ecosystem models

Using dynamic process-based ecosystem models offers a way of meeting the need for more comprehensive GHG analysis covering multiple GHG sources and sinks and some of the interactions between them. Ecosystem models such as Century (Parton et al. 1988) and DeNitrification-DeComposition (DNDC) (Li et al. 1992) have the advantage of describing the underlying dynamics of a system. They use complex functions to describe the movement of SOC through different pools and include submodels of plant productivity, water movement and the turnover of N, P and K. Such ecosystem models are designed for site-scale application and although there are some drawbacks to using them at the larger scale (Paustian et al. 1997), they offer potential for modelling landscape-scale processes.

Use at the landscape and larger scale involves linking the ecosystem model to a geographical information system (GIS). Falloon et al. (1998) provided an early example of this when they devised a method of linking the RothC model to spatially explicit soils, land-use and climate data via a GIS, and used it to estimate regional changes in SOC for an area of central Hungary. RothC is a relatively straightforward soil carbon model, which does not model plant productivity. Extensive work has been carried out at Colorado State University (CSU) linking the more complex Century model to a GIS to make state- and regional-scale estimates (Paustian et al. 1995, 2001, 2002). Climate, soils and land-use datasets associated with specific geographic areas are overlain in a GIS to create a unique set of polygons that define driving variables needed to run the Century model. The approach formed the basis of the development of the GEFSOC Modelling system, a scalable system which allows the user to estimate the impacts of varying land management practices on carbon stocks in soils and biomass using two models (Century and RothC) linked to a GIS (Easter et al. 2007; Milne et al. 2007). The GEFSOC system developers used data from four contrasting ecoregions to develop a system with greater applicability to developing countries. Paustian et al. (1995) point out the need to evaluate model performance in the conditions particular to the region under investigation, as most ecosystem models have been developed in North America and Europe and this can limit their applicability to developing country conditions. Therefore, a large part of the development of the GEFSOC system involved parameterization and evaluation of the Century and RothC using data from four developing country test cases (Bhattacharyya et al. 2007; Cerri et al. 2007; Kamoni et al. 2007).

Use of ecosystem models linked to GIS for landscape-scale GHG assessment involves a certain level of expertise in ecosystem modelling and GIS. This can prohibit use by farmers' groups or those representing them. With this in mind, scientists at CSU have developed a user-friendly online system, COMET VR, which involves multiple Century runs linked to a database of soils, climate and land use for the USA. The user only needs to have knowledge of current and historical land management in his/her parcel of land to be able to estimate landscape-scale changes in carbon stocks in soils. Although COMET-VR is restricted to estimates of SOC changes in the USA, this type of approach has enormous potential for estimates of net GHG balance in agricultural landscapes around the world.

A slightly different approach is taken by the APEX model (Gassman et al. 2009). Rather than using overlain layers of GIS to create unique polygons the model user has to divide a given watershed into subunits. Each subunit has homogenous soils, climate and land use. Users can then link these units to model the flow of water and nutrients between them. The APEX model is a multi-unit version of the EPIC Model. EPIC (The Erosion Productivity Impact Calculator) was developed to assess the effect of soil erosion on soil productivity. EPIC has components for hydrology, snowmelt, water table dynamics, weather, erosion, nutrients (nitrogen, phosphorus), pesticide fate, soil temperature, crop growth, tillage, plant environment control and economics (Williams 1995). As APEX is a version of EPIC, its primary focus is impacts of land-use management on water and nutrient loss. However APEX does model carbon and nitrogen cycling, providing emissions of CO_2 and N_2O in its output. There is potential to extend the linked unit approach so that other biophysical processes affecting GHG emissions are also linked. Further details of the APEX model are given in Section 3.

3. Overview of existing resources

This section of the report gives an overview of some resources that are currently available for GHG accounting at the landscape level in developing countries dominated by smallholders. It is acknowledged that the resources listed here are a selection only. Resources are discussed in four categories: 1. Calculators, 2. Models, 3. Methodologies and Protocols, and 4. Integrated Toolsets. Definitions for these categories are based in part on those used by Denef et al. (2012). 'Calculators' include automated tools, either stand-alone programs (based in Microsoft Excel or Access or similar software) or web-based programs that require specific inputs from the user to run calculations in the background. 'Models' refers to ecosystem simulation models that generally expect the user to understand the processes simulated by the model when using it and 'Methodologies and Protocols' consist of written guidelines for measuring and monitoring GHG emissions.

It is recognized that there is overlap between these categories and some of the options discussed fit into more than one category. Most examples are meant to be used in conjunction with each other (for example, calculators require data, and methodologies and protocols are needed to collect these data). The fourth category 'Integrated Toolsets' is included for two specific examples that integrate guidance on measurement and quantification methodologies with calculators and models. For each category at least one example is discussed in detail. Examples were chosen that show relevant geographical coverage that can be applied at the landscape level and cover multiple sources of GHGs (see also Table 3.2). In many cases, but not all, multiple land uses are considered; exceptions are the Cool Farm Tool and SALM, which consider only cropland. These were included as they provide examples of approaches that could be used on a purely agricultural landscape and, in the case of SALM, are designed to be used in conjunction with other tools. Consideration was also given to how accessible the resources would be to groups working in developing countries (see also Table 3.1). Information for the examples was gathered by distributing questionnaires to the resource developers. Completed questionnaires were then synthesized to produce the text in this section, plus a more detailed description of each resource that is given in Appendix 1.

3.1 Calculators

Increasingly, funding bodies and other organizations require the projects and activities they fund to report on their carbon impact. This can be difficult for projects where climate change mitigation is not the primary focus. To address this problem, many funding bodies have developed their own calculators, which simplify the GHG accounting process. These typically allow the user to run the IPCC method and/or linear or dynamic models by entering data into a user-friendly interface and provide output in a summarized format. Some are stand-alone programs that the user downloads (EX-ACT, Cool Farm Tool, ALU), whereas others can be used online (USAID AFOLU Calculator, CBP Simple Assessment).

Several calculators have been developed to look at the carbon impact of single commodities (The International Wine C Calculator, Agri-LCI models). Others have been designed to consider single source categories or subcategories (WB ARD C Calculator and the IPCC LULUCF Calculator for soil C sequestration, MANURE for emissions from manure etc.). In addition, many calculators are country- or region-specific using emission factors and underlying datasets for a specific national situation (COMET-VR USA, GHG in Agriculture Tools-Australia). Typically there are more examples of these for developed countries, where activity data are more reliable and there have been more scientific studies to develop emission factors.

In general, a landscape-scale assessment involving many smallholdings will cover a range of commodities, land-use categories and GHG source categories. Therefore if a single calculator is to be used for an assessment, it needs to reflect this. Calculators also need to be built on datasets with relevant geographical coverage if they are to be used in developing countries. Those that are not built using developing country datasets need to allow the user to input area-specific emission factors where necessary. The four examples given below fit all of these criteria to varying degrees. Calculators are described in terms of how they can be used at the landscape level, their applicability to smallholder situations in developing countries and novel features such as inclusion of uncertainty estimates and non-land-use emissions amongst others.

USAID AFOLU Carbon Calculator

The USAID AFOLU Carbon Calculator was developed by Winrock International, in collaboration with the USAID Global Climate Change team, to give USAID missions an easy way of complying with the United States Agency for International Development (USAID)'s policy of mainstreaming CO_2 as an agency-wide results indicator. The emphasis of the toolset is on agriculture, forestry and other land uses (AFOLU) – it was originally called the Forest Carbon Calculator – but tools have been added recently for specific reporting on carbon change in grazing lands and croplands. The main contacts for the tool are Felipe Casarim and Nancy Harris at carbonservices@winrock.org. The tool was first released in 2007 but has been updated multiple times since. It comprises six online and freely available calculators at http://winrock.stage.datarg.net/CarbonReporting/Welcome. The tools cover the following activities: forest protection, forest management, afforestation/reforestation, agroforestry, cropland management and grazing land management, and produce reports on above-ground forest biomass carbon, peat carbon and soil carbon. Non-land-use emissions are not covered.

The tools encompass 119 different countries mainly in tropical and subtropical areas so have high relevance to developing countries. The six tools all use different methods with a general underlying database derived from extensive literature reviews and the IPCC 2006 Guidelines for AFOLU (IPCC 2006). In terms of application at the landscape scale, the tools use an underlying default database that has information at the administrative unit (the scale therefore varies greatly depending on the country and region you are working in). These default data are used with the 'Level A' basic application of the tool. 'Level B' allows the user to enter project-specific information if known, so the scale and accuracy can be increased.

No estimate of uncertainty is given with the output and the developers are very clear in saying that the tools are not designed to produce the level of accuracy needed for carbon financing. The calculator provides a management effectiveness rating that is used as a measure of the success of project activities in terms of preventing GHG emissions or increasing removals from land-use change activities. This could be used to indirectly account for leakage. Issues of permanence are not addressed. Output gives carbon change in CO_2 equivalents for activity type, administrative unit and project. Output is not spatially explicit beyond the administrative unit. The toolset has been designed to be used by people with all levels of formal education. The tools are very easy to use at both Level A and Level B and are therefore relevant to those likely to be reporting on smallholder agriculture in developing countries (see Table 3.1 for suitability to users). The emphasis of the tool was originally on projects involving the addition or removal of trees and the tools for forests are therefore more detailed than the tools for cropland. However, the developers plan to improve these tools in the future. They also plan to improve both the spatial capabilities of the tool and default datasets.

Ex-Ante Carbon-balance Tool (EX-ACT)

EX-ACT was developed by the Food and Agriculture Organization (FAO) to provide anyone developing agriculture and forestry projects (programme officers, funding agencies and ministries) with a tool to estimate the impact of projects on GHG emissions and carbon sequestration (Bernoux et al. 2010). Although it was firstly developed for ex-ante analysis it can be used for project tracking. The tool consists of an Excel file and is free to download from the FAO website: http://www.fao.org/tc/exact/en/ The main contacts for the tool are Louis Bockel and Martial Bernoux from FAO and IRD respectively (EX-ACT@fao.org). The first version was released in December 2009 and the second version (v. 3.3) in August 2011. Version 4 was released in English in September 2012 with the inclusion of yield estimates for major crops.

EX-ACT has mostly been developed using the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006) in conjunction with other methodologies and reviews of default coefficients (Smith et al. 2007; Lal 2004). This makes it globally applicable. It assesses the impact of agriculture and forestry activities on carbon stock changes per unit of land and CH_4 and N_2O emissions in tCO_2e per hectare per year. The tool covers all GHG emissions linked with LULUCF activities covered by the 2006 IPCC Guidelines (IPCC 2006) plus some additional sources. This means it covers emissions associated with the following: carbon stock changes during land-use conversion, biomass or residue burning, flooded rice cultivation, organic soils, livestock production and inputs of lime, fertilizer and manure. In addition, the tool provides comprehensive coverage of non-land-use emissions associated with agriculture, such as those from the production, transport, storage and transfer of agricultural chemicals and emissions from energy use and infrastructure (electricity and fuel consumption associated with buildings and irrigation systems, both construction and maintenance).

The output of EX-ACT is a carbon balance resulting from project activities (for example, what would happen above a baseline scenario?). Output is not spatially explicit. This is accompanied by a rough estimate of uncertainty (a percentage rounded up to the nearest 10 percent), which is calculated using the method given in the IPCC 2006 Guidance (IPCC 2006). Issues of leakage are not addressed specifically but could be addressed by manipulating input information if the user decided to do so. Permanence is not addressed, but the uncertainty results could be used to highlight categories where problems of permanence might arise. No analysis of social or economic impacts is included, although output has been used to feed into economic analysis using Marginal Abatement Cost Curves (Bockel et al, 2012)

EX-ACT was originally designed to work at the scale of the development project (from thousands to millions of hectares) many of which are at the landscape scale. The user determines the scale so it can easily be used at the landscape scale. Advantages of use for a landscape-scale assessment include the wide range of ecosystem types and activities and emissions sources covered by the tool, including non-agricultural emissions associated with various land-use activities. A drawback is that it does not have a spatial element, so users will derive a single output for the entire geographic area they describe; however, this is broken down by land-use categories.

EX-ACT has been designed for use by anyone after a short training course (one to two days). It is an Excel file and can be used by anyone with a reasonable understanding of Excel. The fact that the tool uses standard Windows software and does not rely on an internet connection (other than to download it) makes it very accessible to users in developing countries. Tier 1 emission factors are supplied or the user can input their own data. It does however require a fair amount of detailed information. The Tool itself and the Guidelines are available in English, French, Spanish and Portuguese.

EX-ACT was not designed for carbon markets and is not certified. However when compared to the BioCarbon Fund project and Climate Community and Biodiversity Alliance standard, it gave similar results in terms of total carbon sequestered. EX-ACT has already been used in 30 projects and policy appraisals concerning 24 different countries and so is being widely used. It has recently been used on a large-scale ex-ante assessment of two rural development projects in Brazil dominated by smallholder farmers (Branca et al. 2013). It has a permanent team dedicated to its development and maintenance.

The Cool Farm Tool

The Cool Farm Tool (CFT) was developed to be a decision support tool for farmers and growers to help them gain a better understanding of the sources and sinks of agricultural GHG in their production practices. The main emphasis of the tool is on arable land, although livestock and woody perennial crops are included. The intended users of the tool are multinational or national food and beverage companies, farmers, cooperatives and development and other organizations that work with growers. The tool was developed by Unilever, the University of Aberdeen and the Sustainable Food Laboratory. The first version was released in early 2010, subsequent versions in early 2011 and a new version in May 2012. The main contact for the tool is Daniella Malin at the Sustainable Food Laboratory (Daniella.malin@gmail.com). The CFT is an Excel file, which can be downloaded free from the Cool Farm Institute, website: www.coolfarmtool.org. In addition there are some online questionnaires that help users format their data, making it more accessible to farmers.

The tool has global applicability as it uses equations, either based on modifications of the IPCC approach or on other sources in the literature (Hillier et al. 2011). It comprises a number of submodels dealing with arable crops, woody perennial crops, livestock and land-use change to or from grassland, arable land and forest. GHG emissions include CO_2, CH_4 and N_2O resulting from soil disturbance, fertilizer use, resident nitrogen, crop residue management, pesticide use, livestock production and land-use change. In addition the tool covers carbon stock changes in soil and biomass resulting from management changes. Emissions from on-site electricity use, fertilizer and pesticide production and transport (for inputs and of the final product) are also included.

Output is net GHG emissions in CO_2e in tables, graphs and charts, broken down by emissions sources and sinks. Output is not spatially explicit, as it is for individual agricultural products. The tool does not assess uncertainty and the authors state that the tool is not intended as a carbon market access mechanism, but can provide a screen for carbon market opportunities as it can be used to run 'what if' scenarios. Leakage and permanence are not addressed. The tool was originally designed to be used for individual products, but can be used at any other scale if details of all the products produced on those scales are known. For example, if a landscape includes a large number of small diverse farmers growing beans, milk, beef, corn and vegetables and large grazing and forested areas, users would use the CFT to quantify the GHG on this landscape by: 1. characterizing the farmers (larger, smaller, some that grow one type of crop some that grow another); 2. calculating the GHG emissions of each crop of each typical farmer and multiplying by the number of farmers in each category; 3. sum these crops and farmers. If the grazing areas or forested areas have undergone change in the last 20 years you would add these to the sum.

In terms of applicability to smallholders in developing countries, one of the benefits of the tool is that it is designed mainly to use information a farmer may have readily available and so can be used without a lot of extra data collection. In situations where farmers are scattered across a landscape and it is difficult to get them together, this offers an advantage. The tool is in Excel so uses standardized software available in most countries. The accompanying online questionnaire is available in English and Spanish. The tool itself is available only in English, although there are plans to make it available in more languages, starting with Spanish. The tool is currently being used by a number of companies and NGOs (some representing thousands of farmers) in at least 23 countries. Details of case studies where it has been used are available at http://www.coolfarmtool.org/CaseStudies. Many of these are for single commodities, however examples of application to numerous smallholders across a landscape in Kenya are also given. Although not designed for use in carbon markets, the CFT has been tested widely by voluntary standards systems. Rainforest Alliance, Utz Certified, Fairtrade (FLO-Cert), Solidaridad and 4C Association are considering integrating it into their auditing programmes.

Future plans are to develop a web-based version of the tool to improve the transparency, scalability, user guidance and user interface. There are also plans to enable integration of CFT into other supply chain GHG and life cycle analysis (LCA) resources used by private companies, commercial service providers and public interest organizations. The Cool Farm Tool was recently accepted by the GHG metric working group for the Stewardship Index for Specialty Crops and will be recommended to the Coordinating Council.

Agriculture and Land Use National Greenhouse Gas Inventory Software – ALU

ALU was developed by Colorado State University as a practical tool for those compiling national GHG inventories for the UNFCCC, and includes emission source categories in the agricultural, land-use, land-use change and forestry sectors (also referred to as the agriculture, forestry and other land-use sector, AFOLU). The tool is available for download free of charge from http://www.nrel.colostate.edu/projects/ALUsoftware/. The contact for the tool is Stephen Ogle (Stephen.Ogle@colostate.edu). A prototype version was released in 2007 followed by the current version in 2011. The ALU software is based on the IPCC method from the revised 1996 guidelines, and further developed in the 2000 and 2003 guidelines, along with some information from the 2006 guidelines. The software has not been fully updated to conform to the 2006 IPCC guidelines because they are not the official reporting guidelines for the UNFCCC. However, it is anticipated that ALU will be revised to fully conform to the 2006 guidelines when accepted by the convention as the official guidance for reporting GHG emissions. The software organizes into four modules the different stages involved in producing an inventory, thereby simplifying the process of producing an inventory of GHG emissions and removals related to agricultural and forestry activities. Development has focused on providing a tool for use in non-annex 1 countries, although it has global application. Users can upload their own spatial data for soils, climate and land use, or use default information. Likewise, the user can input their own emission factors or use IPCC defaults. The tool is designed for producing annual inventories, in addition to analysing potential emission reductions with a 'mitigation function' that uses the emissions inventory as the baseline.

ALU covers land uses found in the IPCC guidelines: forests, croplands, grasslands, wetlands, settlements, other lands and emissions from livestock. The associated emission source categories include enteric methane, manure methane, manure nitrous oxide, biomass burning non-CO_2 greenhouse gas emissions, soil nitrous oxide, biomass carbon stock changes and soil carbon stock changes. Non-land-use emissions (fuel use etc.) are not included. Output from the tool gives emission estimates for all source categories listed above in tonnes of the respective GHG, in the form of an Excel workbook. Uncertainty is not addressed in the current version, but a version will be released in 2012 with uncertainty based on the simple error propagation method described in the 2006 IPCC guidelines. Leakage and permanence are not addressed. Economic analysis is not included, but the tool is designed to be able to utilize information from an economic analysis to project mitigation potentials.

The tool was designed for use at the country scale and contains defaults intended for national-scale application. However, the software also incorporates user-specific factors, so could be applied at the landscape scale by entering emission factors that are specific to the landscape, addressing the influence of lateral flows on energy and matter on emissions. For this type of application, the user would have to compile activity data at a finer scale than is typical of a national inventory, which often rely on national or regional data. Landscape applications would need to map individual crop fields, pastures and forest stands and connections among the various land parcels across the landscape of interest. This type of compilation would most probably occur in a GIS software system, with data being imported into the ALU software afterwards. Emission factors could then be assigned, based on the landscape relationships and emissions estimates.

The results could then be exported into reporting tables or incorporated back into the GIS software. Field measurements to gather data for user-specific emission factors would entail resources and expertise and this would likely be needed in a landscape application, as existing factors, such as those provided by the IPCC, do not attempt to address the influence of landscape relationships on emissions. However, IPCC defaults are provided if measurements are not feasible and users can also take data from previous studies, if these exist. The software does assume a fair knowledge of the IPCC method and the terminology it employs, and this could be a barrier for non-expert users.

As a national inventory tool, ALU has not been certified for acceptability to carbon markets. However it is designed for UNFCCC reporting, so if the same standards are acceptable for carbon markets or certification schemes, then the tool could be used for this purpose. To date, national compilers in approximately 30 countries have been trained to use the ALU software and over half of these governments are actively using, or are in the process of starting to use the software for their national inventory reporting to the UNFCCC.

3.2 Models

As opposed to calculators, the use of models for the assessment of GHGs requires some understanding of the model itself and how it represents the system. For landscape-scale assessments that utilize a model linked to a GIS, some expertise in GIS is also needed. The use of models is therefore often limited to academic and research institutions. Examples of ecosystem models that have been, and can be used in this way, are Century and DNDC. Century (Parton et al. 1988) was originally designed for use in the USA, but has now been parameterized and tested in many different countries, including Kenya, Jordan, Brazil and India (Kamoni, et al. 2007; Al-Adamat et al. 2007; Cerri et al. 2007; Bhattacharyya et al. 2007). The system is available for download from http://www.nrel.colostate.edu/projects/century/. A project funded by the Global Environment Facility (GEF) produced a system which links Century, the RothC model and the IPCC method to a GIS (Milne et al.; 2007; Easter et al. 2007). The method used datasets compiled in developing countries and the system is available for download from www.nrel.colostate.edu/projects/gefsoc-uk/. DNDC (Li et al. 1992) was also originally designed for use in the USA, but has now been applied in several other places including China, India, Costa Rica and Europe (Giltrap et al. 2010). Examples of regional and landscape-scale application include work in Germany (Neufeldt 2005; Neufeldt et al. 2006) and Australia (Kiese et al. 2005). The model is available for download from http://www.dndc.sr.unh.edu/.

Models linked to a GIS in this way carry out individual model runs for each intersection of soils, climate and land-use information (polygons), but their representation of horizontal transport of nutrients, or other materials between polygons, is limited to non-existent. Ideally, landscape-scale approaches should consider horizontal interactions between units in terms of GHG emissions and carbon stock changes and the drivers behind these. However, in reality this is highly complex and is therefore not addressed by most modelling assessments. An example of a biophysical model that takes an integrated approach is the APEX model (see example below). The model has a greater focus on soil and water conservation than GHG emissions and as such, horizontal interactions are limited to the transport of water and nutrients.

Agricultural Policy/Environmental eXtender model – APEX

APEX is an ecosystem model developed by Texas Agrilife – Blackland Research and Extension Center. It is available for download from the websites http://epicapex.brc.tamus.edu/downloads/model-executables and http://winapex.brc.tamus.edu/downloads/model-executables or can be obtained from the developers on request. The main contacts for the model are Dr Jimmy Williams (jwilliams@brc.tamus.edu) or Evelyn Steglich (esteglich@brc.tamus.edu). APEX was designed to allow agricultural planners, researchers, universities, and land-use planners managing whole farms and small watersheds, to obtain sustainable production efficiency, maintain environmental quality and address environmental problems. It can be used at any geographic location if data are available. It was originally designed for use in the USA and therefore the underlying database it uses contains weather, soil and typical management information for the USA; however, the assumption is that users will input their own information.

The first version of APEX was released in 1998 and the latest in 2008. APEX is a process-based model to simulate management and land-use impacts for whole farms and small watersheds on carbon and nitrogen cycles, carbon and nitrogen storage, and nutrient loading and losses, through volatilization, leaching, erosion, and denitrification. It also assesses CO_2 sequestration via plant growth. APEX is a multi-field version of the EPIC model and can be executed for a watershed that is subdivided, based on fields, soil types, landscape positions or subwatersheds. It is based on carbon and nitrogen cycling algorithms, initially developed by Izaurralde et al. (2006) for EPIC, which, in turn, are based on concepts used in the Century model (i.e. kinetic pool approach). Leaching equations are used to move organic materials from surface litter to subsurface layers. It has a DOS version (APEX) as well as two Windows interfaces (WinAPEX and ArcAPEX). A key feature of APEX is its ability to estimate SOC losses caused by wind and water erosion.

APEX covers different types of agricultural management with an emphasis on soil and water conservation. It includes livestock grazing, pesticide, water and floodplain management and tree cropping. It simulates carbon losses including eroded carbon, CO_2 emissions (respiration from decaying residue) and N_2O from fertilizer and mineralization. The model also includes CO_2 emissions from farm machinery and there is a simple income cost analysis for farm activities. Output from the DOS version is in text format. Output from WinAPEX is in Microsoft Access tables, and output from ArcAPEX is both Microsoft Access tables and text files. APEX does not include any uncertainty analysis, but multiple runs changing individual parameters can be used for a Monte Carlo analysis and indeed, this has been done for some examples (Steglich pers. com).

APEX can be applied at the landscape scale by dividing a watershed into many homogeneous subareas based on soil type, landscape position or subwatershed. Subareas can range from a few m^2 to 1000 or more ha depending on the desired level of detail. An advantage of using APEX at the landscape scale is that it models the flow of water, sediment, nutrients, and pesticides between subareas within the landscape, taking a more integrated approach than simply summing up distinct areas. This means it could be used to consider issues of emissions displacement or leakage to geographically neighbouring non-study areas.

The inputs needed for the model are quite detailed as it works on a daily time step. For use in developing countries in landscapes with multiple smallholder farmers, data acquisition could be an issue (as with most detailed ecosystem models). For the DOS version, expertise in DOS and data analysis is needed to run the model and to process the text file results. For the Windows versions, output is given in Access, so database expertise is needed to interpret the results. Advantages of the tool are the fact that it accounts for carbon losses through erosion and that it takes an integrated approach, modelling nutrient flow between subareas. APEX has not been certified for use by any voluntary reporting standard or carbon market. It is being used widely, including by the Natural Resources Conservation Service in the USA, in its National Conservation Effects Assessment Project analysis.

3.3 Documents detailing methods and protocols

There is a wide range of methodologies and protocols that could be used for landscape-scale GHG accounting in agricultural landscapes. Many of the carbon standards and offset programmes involved in the voluntary carbon market include protocols for aspects of agriculture and land use. For example, the Verified Carbon Standard (VCS) has protocols for grassland management, Afforestation/Reforestation (A/R) and the adoption of sustainable agricultural land management (see Section 3.4 on integrated toolsets). The Climate Action Reserve (CAR) has protocols for livestock projects, forest projects and rice cultivation projects, and is developing a protocol for nitrogen management (to be released 2012). Plan Vivo provides standardized protocols specifically aimed at smallholder farmers, but the emphasis is very much on tree-based activities (A/R, agroforestry and forest restoration). The compliance carbon market has yet to fully include land management activities and therefore the Clean Development Mechanism (CDM) only provides protocols on A/R and manure management. The International Organization for Standardization (ISO) has a specification document for quantifying GHG emissions at the project level (ISO 14064-1:2006) but the sections for agriculture and forestry are not very well developed (ISO 2006).

For projects wishing to do reporting for purposes other than accreditation, the above protocols may prove too onerous. For this reason many funding agencies (GEF, FAO and the World Bank) have developed their own protocols to ensure standardized reporting from the activities they fund. A lot of work has been carried out by the World Agroforestry Centre (ICRAF), Center for International Forestry Research (CIFOR) and other CGIAR centres through the Partnership for the Tropical Forest Margins (ASB), which provides resources specifically for those living and working on forest margins. Comprehensive manuals have been developed for measuring carbon stocks across formerly forested landscapes (Palm 2005; Hairiah et al. 2011) and measuring carbon stocks in landscapes dominated by peatland soils (Augus et al. 2011). In addition, methodological planning and training materials are being produced by ASB's REALU (Reducing Emissions from All Land Uses) project, which takes a broad approach, encompassing emissions from all land uses at the landscape scale (ASB 2012).

For smallholders in developing countries, protocols that meet the following criteria are likely to be most useful: that they provide clear comprehensive advice on all stages of GHG assessment from designating boundaries to laboratory analysis; that they include examples of low-cost strategies and strategies which don't demand high technical expertise. The two examples below were chosen as they meet these criteria, but many others exist.

Integrating carbon benefits into GEF projects

This guidebook was developed by the United Nations Development Programme (UNDP) to provide methods for estimating carbon stocks and changes resulting from GEF project interventions. The contact for the guidebook is the lead author, Timothy Pearson (tpearson@winrock.org). The guidebook can be downloaded free from Winrock International's website http://www.winrock.org/Ecosystems/files/GEF_Guidebook.pdf The guidelines aim to assist project developers, managers and evaluators, and implementing and monitoring agencies. They are targeted at non-experts and a user-friendly format has been adopted. The methods can be applied anywhere geographically and cover ex-ante, project tracking and ex-post analysis. They were published in 2005 and there are no plans for further versions or updates.

Methods are drawn from IPCC guidelines, the Winrock C Methods Manual and the US Voluntary Reporting of GHGs Program (1605b). The guidelines are relatively concise (64 pages) and use accessible language to guide the user through all aspects of GHG/carbon reporting. Topics include choosing a sampling plan with an appropriate level of accuracy and precision, developing a baseline scenario, developing a measurement and monitoring plan, taking field measurements and analysing data. Methods for estimating all relevant carbon pools and emissions or avoided emissions of non-CO_2 GHGs are provided. Carbon pools covered are: trees above and below ground, dead wood, forest floor, soil organic carbon and harvested wood products. The methods focus on terrestrial systems, but can also be applied to wetlands, mangroves and any coastal or freshwater system dominated by plants.

The guidelines provide specific guidance on analysis of collected data. Details are given on how to track confidence intervals of collected field data and use a propagation of errors method to sum errors from the various sources. There is a section discussing leakage; however, assessment methods are not included. The guidelines were written in 2004 and this precedes development of most methods for leakage assessment. Similarly, 2004 was before developments occurred on buffers or most other forms of permanence management. No guidance on tracking other ecosystem services or analysing economic and social impacts is given.

GEF projects vary in size from whole landscapes, or even regions, to small-scale interventions at the farm level. The guidelines provide the necessary steps for field measurement and analysis of field measurements of carbon stocks and changes. These approaches can be applied at any scale, including landscape, or even national. The authors point out that stratification will become increasingly important the higher the scale. At present most GEF land management projects do not have climate change mitigation as a primary goal; however, this is expected to change. The guidelines therefore aim to provide guidance suited to managers of land degradation, biodiversity and other land management projects, who are perhaps new to carbon inventory methods. Most GEF projects are located in developing countries and many involve numerous smallholder farmers. The guidelines were therefore written with this in mind. Constraints to the use of these guidelines include the costs and capacity associated with measurement, monitoring and analysis. Such capacity typically exists in individuals trained in forestry, soil science or ecology.

The guidelines were designed to integrate assessment of carbon benefits into GEF projects. That said, the methods are entirely appropriate for carbon markets and certification schemes. The question will be the level of precision targeted and degree to which quality assurance and quality control processes are implemented. The level of uptake of the guidelines is not known; however they have influenced other subsequent publications (Sourcebook for Biocarbon Fund Projects and the Sourcebook for REDD).

Carbon Inventory Methods – A handbook for greenhouse gas inventory, carbon mitigation and roundwood production projects

This is a review, or a ‘cookbook’ of inventories, developed by different entities of the UNFCCC, FAO and Winrock International. The contacts are the two authors N.H. Ravindranath (ravi@ces.iisc.ernet.in) and M. Ostwald (madelene.ostwald@liu.se). The book is commercially available (Springer ISBN-3: 978-1-4020-6546-0) at US$190, so it is relatively expensive. However, it may be available through academic libraries. In addition UNDP purchased copies of the handbook and supported its use for training and capacity building programmes, so copies could be available if organizations have links with UNDP. The book was developed mainly for practitioners – professionals in forest inventories, soil chemistry and education – and for project developers and evaluators. It has a focus on developing countries, having had its origins in a UNDP-GEF manual developed earlier by one of the authors. The book is available in an English version (2008) and a Chinese version (2009).

The handbook brings together multiple methods of project development, implementation and monitoring. It provides step by step information on sampling procedures, field and laboratory measurements, application of remote sensing and GIS techniques, modelling and calculation procedures, and sources of data for carbon inventory. A unique feature is that it provides practical guidance for different types of projects. It covers forest, grassland, agroforestry systems and cropland (with a focus on perennial terrestrial systems). It does not however provide specific guidance on emissions from livestock and livestock inventory. It mainly deals with carbon in terrestrial systems (above and below ground, dead wood, litter and soil). Non-land-use emissions associated with agriculture are not covered. Guidance on how to collate and format data is given, again tailored to different types of projects, carried out at different scales.

A chapter on uncertainty analysis is included in the book. Indicators relate to lack of data and representativeness (for example, due to variations), sampling and measurement errors. The book provides descriptions of the types of leakage that can occur and refers to quantification methods. The issue of permanence is discussed but no methods are proposed.

Methods to determine the economic or social consequences of land management or impacts on other ecosystem services are not included. The book provides a range of different methods, relevant to different scales. The authors point out that heterogeneity (complexity) is a more limiting factor than the fact that an activity or project covers a landscape. Certain chapters are particularly relevant to landscape-level assessment. For example, Chapter 14 deals with carbon inventory using data from remote sensing. Techniques for estimating and monitoring project boundaries, stratifying project areas and developing sampling regimes are given for all scales, including the landscape scale.

In terms of relevance to smallholders or those representing smallholders in developing countries, knowledge of biology and mathematics is useful for all methods suggested and essential for some. For the more technically advanced methods, users need field equipment, computer programs, programming skills and remote sensing information that can sometimes be costly. An advantage of the book is that it provides a range of methods suited to different project types and resource levels, with advice on how the user can decide which one is appropriate. Many of the methods are based on the IPCC Good Practice Guidance designed for reporting to the UNFCCC Secretariat and a large number are in line with methods used for many of the voluntary market certificates. There are no plans to update the book at the moment.

3.4 Integrated toolsets

In reality, landscape-scale assessments of GHGs require a combination of ground sampling, use of data from census, remote sensing or other sources, and modelling to upscale results and make forward projections. Fitting all these aspects together needs to be done carefully to minimize uncertainties and maximize use of scarce resources. This is especially true in heterogeneous landscapes dominated by smallholders in developing countries. However, examples of integrated resources that provide guidance on all of these aspects, in particular collecting data for all of the parameters needed to run specific calculators and models, are few and far between. Two examples are given below: the first, SALM, is applicable to cropland only but provides an illustration of an accredited protocol for collecting data for, and utilizing the RothC model at the landscape scale. The second, CBP, provides a comprehensive toolset, including online calculators, protocols and models for carrying out GHG assessments in heterogeneous landscapes, with an emphasis on developing countries.

Adoption of Sustainable Agricultural Land Management (SALM)

SALM is a method developed by Joanneum Research in conjunction with Unique Forestry Consultants, funded by the World Bank. It was developed for, and is being used in the ‘Western Kenya Smallholder Agriculture Carbon Finance Project’ and has recently (December 2011) been approved by the Voluntary Carbon Standard, making it an acceptable method for reporting to voluntary carbon markets. The main contact for the method is Niel Bird (niel.bird@joanneum.at). A free PDF file of the method is available for download from www.v-c-s.org. The method is designed for use by smallholders in developing countries, but it can be applied anywhere where studies demonstrate that the use of the RothC model is appropriate for: (a) the IPCC climatic regions of 2006 IPCC AFOLU guidelines, or (b) the agroecological zone (AEZ). The method covers ex-ante, project tracking and ex-post analysis.

The method is a protocol for estimating and monitoring GHG emissions of project activities that reduce emissions in agriculture through the adoption of sustainable land management practices (SALM); for example, crop management, land-use management and residue/waste management. It does not include direct emissions from livestock and cannot be applied to wetlands. Land must be cropland or grassland at the start of a project. It consists of a set of guidelines to estimate baseline and project emissions and removals, using measurements and monitoring plus modelling for SOC. The methodology uses input parameters to accepted biogeochemical models (at the moment just RothC) for estimation of soil organic carbon. N_2O emissions from fertilizer use and carbon stocks in woody perennials follow CDM A/R methodologies. N_2O emissions from nitrogen fixers and residue and N_2O and CH_4 emissions from burning residue are covered by other equations taken from the literature. It also includes emissions from on-farm vehicle and machinery use. A monitoring survey and sample activity baseline are provided to help users format data.

Guidance on estimating uncertainty is given for soil carbon only. Guidance on assessing several forms of leakage is given relating to biomass production, use of manure and fuelwood and use of fossil fuels for cooking, heating and transport. Issues of permanence are not dealt with.

Data are monitored at the farm level but are agglomerated to the sum of all participating farms, which the developers describe as a ‘partial landscape level’. The method therefore assumes that the impacts of farm-level activities are additive. This approach requires a project participant to act as an agglomerator, collating information from individual farms.

This person needs to have skills in farm-level surveying, basic statistics and the ability to use the RothC model, and also must have access to scientific libraries. Given this, the developers indicate that the method can only be used by those with a certain level of scientific training, which could possibly exclude use by those running farmers' cooperatives. The method has been designed for use in agricultural landscapes where sustainable land management practices occur on cropland or grassland (as described above). It would therefore not be appropriate for use in landscapes where other mitigating activities such as afforestation/reforestation or wetland restoration, are also taking place and would in these circumstances have to be used in conjunction with other VCS methodologies.

To date, the methodology has been used by the project for which it was designed, plus inquiries and detailed questions about modelling and applicability have been received from two other organizations. Unique Forestry Consultants and FAO have produced a web-based tool to identify available studies and potential applicability in many developing countries. The RothC model is one of the simpler SOC models and as such has limitations. Future plans include how to modify and adapt the model to fit specific agricultural management options, rather than modifying the methodology. For example, RothC does not specifically address reduced tillage (at the moment).

The Carbon Benefits Project (CBP)

The Carbon Benefits Project (CBP) is a recent initiative funded by GEF, which has developed a suite of tools, guidelines and protocols for GEF projects to report on the carbon benefits (carbon stock changes and GHG emissions) of their land management activities. Tools can be used by any land use/management project and are freely available from http://www.unep.org/climatechange/carbon-benefits/cbp_pim. Potential users include the UN-REDD, offset projects in LULUCF and monitoring and evaluation activities for any agency. Some tools can be used online and others downloaded as stand-alone software. The tools have been developed in two components, one using a range of modelling and other tools, with more emphasis on cropland and grazing land, and the other focusing on measurement with emphasis on carbon stocks in trees (in forests, agroforestry and trees outside of forests). The two components are discussed separately here although they are designed to be used in conjunction with each other.

CBP modelling tools

The tools in the Modelling Component of the CBP were developed by Colorado State University in conjunction with partners from eight different countries. Contacts for the tool are Eleanor Milne (eleanor.milne@colostate.edu) and Mark Easter (mark.easter@colostate.edu). The tools are available free of charge and can be used online, except for the Dynamic Modelling Option, which can be downloaded from http://www.unep.org/climatechange/carbon-benefits/cbp_pim. The tools can be applied globally and can be used for ex-ante and ex-post analysis and project tracking. The system has three options:

1. The Simple Assessment which is an online tool based on the IPCC method. It requires users to input land management information and uses default IPCC factors. It was released in 2012.

2. The Detailed Assessment, also based on the IPCC method, but allows users to enter their own project-specific information and emission factors. This will be released later in 2012.

3. The Dynamic Modelling option, which is a version of the Century Ecosystem Model linked to a GIS.

All three options utilize an online map facility to define project boundaries and activity areas. The tools compare a baseline and a project scenario to determine incremental carbon benefits. Also included are a guidance section providing help on monitoring strategies, field sampling etc., a costs benefit analysis and a DPSIR (drivers, pressures, state, impact, response).

The toolkit covers all of the ecosystems classified in the IPCC GHG Inventory Methods for Agriculture, Forestry, and other Land Uses (IPCC, 2006). It covers emissions of all three major GHGs (CO_2, CH_4 and N_2O) from all sources covered by the IPCC approach and carbon stock changes associated with all carbon pools. Non-land-use emissions are not dealt with. Output is in the form of a PDF file with emissions and stock changes broken down by project areas, source and source subcategory. A detailed report (Excel file) will be added soon, which can be imported into a GIS.

GEF projects vary in scale so the tools have been designed to be used at any scale. The Simple and Detailed Assessments are designed to work on areas from a few ha to approximately ten million ha. The Dynamic Modelling option has been used at the landscape to subnational scale, but can be applied at any scale if data are available. The first step to using the system is to define the geographic boundary of the project and then identify within this where land management activities are taking place. The user either draws polygons on screen on a web-based map, defines points, or uploads a GIS file. The size of these 'Project Activity Areas' is determined by the user. In doing this the user can capture multiple areas of different land-use activity within a single landscape and carry out a landscape-scale assessment. The process is repeated for the initial land use, a baseline scenario and a project scenario. For the Simple Assessment and the Detailed Assessment, management information is then entered for each area, or group of areas, for seven different land-use categories and livestock. An advantage of the system is that several similar areas can be grouped together and land management information only has to be entered once.

In terms of relevance to smallholder farmers groups, the Simple Assessment can be used with the sort of activity data a land management project is likely to have and just requires an internet connection (as it is an online tool). For the Detailed Assessment, local datasets and measurements can be used to improve estimates, so costs and expertise associated with field sampling can apply. For the Dynamic Modelling option, expertise in GIS and ecosystem modelling are required. The Simple Assessment tool is available in English, Spanish and Chinese. The modelling tools are not certified by any carbon scheme at the moment, but would be useful in scoping the suitability of a project for certification. During development of the tools there were 10 workshops, each involving between 20 and 30 people. The Simple Assessment is currently being used in case study projects in Brazil, China (two projects), Kenya and Niger/Nigeria. Future plans are to add a database of biometry measurements from agroforestry, reforestation and afforestation projects, and to add French and Brazilian Portuguese versions of the tool.

CBP Measurement Tools

The CBP Measurement tools were developed by Michigan State University (MSU), in partnership with the World Wildlife Fund and the World Agroforestry Centre. The main contact for the tools is Mike Smalligan, (smallig2@msu.edu). The tools are free of charge and can be accessed from the web. They have global coverage and can be used for ex-ante and ex-post analysis of project activities, together with ongoing monitoring throughout the project's life cycle. The tools were released in March 2012. The measurement system provides the means to quantify carbon stocks and stock changes directly, using a combination of remote sensing observations, ground calibration and web-enabled GIS. The system also provides estimates of CH_4 and N_2O from direct field and remote sensing measurements. Non-land-use emissions are not covered.

The primary focus of the toolsets is on forests, agroforestry, woodlands, savannas and landscapes with trees outside of forests. It is also applicable in croplands, grasslands, wetlands, and settlements. Carbon stocks covered include SOC and above- and below-ground woody biomass (litter and dead wood are not covered). The approach allows for large area landscape assessments of carbon for REDD, A/R, and agroforestry systems at very high spatial resolution.

The tool output is a standard report in a PDF file. In addition there are online displays of data. Output includes tCO_2e sequestered, changes in hectares from land without trees to land with trees (criteria varies for each module), tCO_2e sequestered/$ invested. The fifth module specifically provides landscape indicators of carbon benefits, including land-cover index, tree-crown-area index, carbon-stock index, fire-risk index, watershed index, and social, economic and biodiversity index. The toolset also contains a number of project planning tools, such as an agroforestry tree database, a species selection tool, a project boundary and land-cover stratification tool and a manual for engaging communities in carbon measurement and monitoring. The user can calculate uncertainty separately using the IPCC error propagation method. The remote sensing components of the tool can be used to monitor leakage outside the project boundaries. The tools do not define leakage, but allow each project to define leakage according to selected carbon standards or project requirements. The tools address risk rather than permanence. Direct guidance on economic impacts is not given; however, a tool for assessing social co-benefits under CCBA (Climate, Community and Biodiversity Alliance) criteria is included.

The tools were specifically designed for landscape-scale application where local field inventories can be linked to remote sensing (RS) and they require field sampling to allow for statistical analysis of strata within the landscape. Minimal ground sampling is then scaled up to landscape and regional levels through RS analysis of both SOC stocks and woody biomass carbon stocks. The SOC measurement protocol requires vehicles, skilled labour, specialized soil sampling tools, GPS devices, desktop computers, specialized software, laboratories equipped with near infrared spectroscopy, or access to external soil analysis laboratories.

The non-CO_2 GHG measurement protocol also requires extensive inputs such as vehicles, skilled labour, GPS devices, specialized field sampling gas exchange chambers, gas sampling equipment, a nitric oxide monitor, desktop computers, specialized software, and labs equipped with a gas chromatograph. The woody biomass measurement protocol needs vehicles, skilled labour, standard forest inventory equipment, specialized forest inventory tools, GPS devices, access to free and commercial satellite data, high power computers with extensive storage capacity, specialized RS software, technical capacity for RS and GIS and access to a lab for plant tissue analysis. The online Monitoring Reporting and Verification (MRV) system necessitates computer servers, geospatial databases, extensive knowledge in GIS, and wide-ranging computer programming skills. Some aspects entail a workflow to be carried out in a remote sensing or GIS facility and some of the modelling uses workflows that are done 'off the web'.

The CBP measurement tools are compatible with regulatory markets and voluntary market standards, but they have not been reviewed or directly approved by any market or standard. The measurement tools have only just been released; therefore uptake is currently limited to the case study that was used during development in Kenya.

Table 3.1 Resources with their main purpose and target user groups

Resource	Primarily aimed at use with:				Could be used by*					
	Carbon market	Reports to funding agencies	Inventory	Research	Farmers cooperatives	Agricultural extension workers	Government staff without scientific training	Government staff with scientific training	Programme officers	Scientists
Calculators										
USAID AFOLU Carbon Calculator		x			yes	yes	yes	yes	yes	yes
EX-ACT		x			with training	with training	with training	with training	with training	yes
Cool farm tool		x			yes	yes	yes	yes	yes	yes
ALU			x		with training	with training	with training	yes	yes	yes
Methods/ protocols										
Integrating carbon benefits into GEF projects		x			with training	with training	with training	yes	yes	yes
Carbon Inventory Methods		x	x	x	yes for some methods	yes for some methods	yes for some methods	yes	yes	yes
Models										
APEX				x	yes	yes	limited	yes	yes	yes
Integrated toolsets										
SALM	x				maybe	yes	no	yes	yes	yes
CBP modelling		x			yes	yes	no	yes	yes	yes
CBP measurement		x			with training	with training	with training	yes	yes	yes

* Reflects the opinion of the tool/method developer

Table 3.2 GHGs, sources and sinks covered by resources (Table format after Denef et al. 2012)

	GHGs				Sources/sinks													
Resource	CO_2	N_2O	CH_4	Other	Cropland	Horticulture	Rangeland/ grazing land	Grassland	Agroforestry	Vineyards/ orchards	Livestock	Forest	Urban trees	Land-use management (afforestation/ deforestation)	Rice production	Wetlands	Energy use	Other
Calculators																		
USAID AFOLU Carbon Calculator	yes				yes		yes		yes			yes		yes				
EX-ACT	yes	yes	yes		yes		yes	yes	yes		yes	yes	yes	yes	yes	yes	yes	yes[1]
Cool farm tool	yes	yes	yes		yes	yes	yes	yes	yes	yes	yes	yes		yes	yes		yes[2]	
ALU	yes	yes	yes		yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes		
Methods/protocols																		
Integrating carbon benefits into GEF projects	yes	yes	yes		yes		yes	yes	yes			yes		yes		yes		yes[3]
Carbon Inventory Methods	yes				yes			yes	yes			yes						
Models																		
APEX	yes	yes			yes		yes			yes				yes			yes[4]	
Integrated toolsets																		
SALM	yes	yes	yes		yes									yes				
CBP modelling	yes	yes	yes		yes		yes	yes	yes		yes	yes	yes	yes	yes	yes		
CBP measurement	yes	yes	yes		yes			yes	yes			yes	yes	yes		yes		

1 Emissions (in CO_2 equivalent) from production, transportation storage and transfer of agricultural chemicals
2 On-farm energy use + fuel use in transport of inputs and product
3 Methods can be applied to mangroves and any coastal- or freshwater system dominated by plants
4 CO_2 emissions from farm machinery only

Table 3.3 Advantages and constraints of resources

Resource	Accessibility of resource				Needed for use				Analysis type		Additional attributes								
	Free	Online	Download from web	Multiple languages	Cost[1]	Specialist expertise	Specialist equipment	Labour[1]	Ex-ante	Ex-post	Spatial output	Uncertainty given	Permanence	Leakage	Social/economic analysis	Non-land-use GHGs (energy and fuel etc.)	Integrated approach[2]	Acceptable to carbon markets	Widely tested/used
Calculators																			
USAID AFOLU Carbon Calculator	x	x			L				x					x[a]					
EX-ACT	x		x	x[b]	L				x	x		x		x[c]		x			x
Cool farm tool	x		x	x[d]	L				x	x						x			x
ALU	x		x	x[e]	L	x			x	x	x[f]	x[g]							x
Methods/protocols																			
Integrating carbon benefits into GEF projects	x		x		M	x[h]		M	x	x		x						x	x
Carbon Inventory Methods				x[i]	LMH	x[j]	x[j]	LMH	x	x		x		x				x	
Models																			
APEX	x		x		L	x			x	x	x				x[k]	x	x		x
Integrated toolsets																			
SALM	x		x			x		M	x	x		x		x		x		x	
CBP modelling (overall)	x	x	x	x[l]	L	x[m]		L	x	x	x	x			x				
Simple Assessment (calculator)	x	x		x[l]	L			L	x	x	x	x			x[n]				
Detailed Assessment (calculator)	x	x			L			L	x	x	x	x			x[n]				
Dynamic Modelling (model)	x		x		L	x		L	x	x	x								
CBP measurement	x	x	x		H	x	x	MH	x	x	x	x		x	x				

1 H=High, M=Medium, L=Low
2 Resource accounts for the movement of carbon, water or nutrients between subunits within the landscape rather than simply aggregating
a Partially addressed in project effectiveness
b Guidelines available in multiple languages not tool
c Matrix can be used to assess leakage
d Online questionnaire in Spanish
e Manual only, in English, Chinese and soon Spanish
f ALU can export data that can be mapped into a GIS
g Under development
h Basic ecology, forestry expertise needed but more expertise will enhance use
i English and Chinese
j Depends on methods chosen
k Provides simple income cost analysis for farming activities
l Simple Assessment tool available in English, Chinese, Spanish (Portuguese and French being developed)
m Specialist expertise only needed for the Dynamic Modelling Option not other options
n Output feeds into CBP socio-economic tools

4. Looking forward

Section 2 of the paper described some of the key features of the different tools developed for GHG and carbon stock accounting by distinguishing between measurement-based approaches and models. Indeed all measurement-based approaches build on models that allow the observable datasets to inform target variables (in this case GHGs or carbon stocks); and all modelling approaches build on observable metrics (such as management practices and activity data) that feed into the models, whether they use simple regressions that link EFs to activity data, such as those of the IPCC Tier 1 and 2 approaches, or derive the target values from complex interrelationships in mechanistic ecosystem models, such as CENTURY or DNDC.

One clear distinction between EF-based calculators and measurement protocols and tools on the one hand and ecosystem models on the other, is that the former are stocktaking approaches, while the latter are based on flows between different compartments of the system. In essence this allows ecosystem models to simulate emission pathways and make predictions about the future for a variety of possible cases; whereas all other instruments essentially treat the time between two stocktaking exercises as black boxes and can only make predictions that are based on past emission trajectories.

These different features do not necessarily render mechanistic models superior to simple regression models or measurement approaches. Rather the different approaches are needed for different purposes and complement each other. While calculators allow for fairly quick assessments of baseline emissions and potential emission changes under an altered management system (for example, conventional versus no-tillage agriculture), mechanistic models would allow simulation of emission flux changes over time, including a variety of subsequent land-use measures and their interactions, (for example, considering the residual effects of previously accumulated litter). Furthermore, while modelling approaches, whether simple or complex, require relatively little measurement input and can derive outputs at fairly low costs, measurement approaches are ultimately needed to verify model outputs and integrate the various emission flux changes following real management decisions into a single value. This allows evaluation of the effectiveness or efficiency of different management changes over time.

While all models described in this paper can be used to address landscape approaches by connecting the units via GIS, only APEX deals with flows from one compartment to the next. By their structure, regression models or calculators cannot take lateral fluxes into account, but in principle mechanistic models could be designed to accommodate this feature. Lateral flows become important where slope induces mass transport out of one compartment into the next. For instance when nitrogen leaches into groundwater and is then transported off site it can be emitted as N_2O from an adjacent compartment. However, whether such emissions will be of a significant order of magnitude remains unclear. On the other hand, measurement tools do take account of such landscape dynamics if the measurement area is sufficiently larger than the area targeted by any given land-use change. This, though, requires a statistically representative measurement regime and the need for a significantly larger measurement area could raise the costs for quantifying lateral flow effects beyond economic feasibility.

Section 3 describes a number of different calculators, models and measurement tools currently available for GHG and carbon stock assessments at landscape scales. In this section we will look at these instruments through the lenses of the targeted user groups, view different GHGs as well as source and sink categories covered; and discuss important advantages and constraints.

User group views

Table 3.1 shows the primary user groups that the different instruments were developed for, based on the assessment of the tool developers, as well as other potential users. However, this may lead to an uneven interpretation, since the tool developers' understanding of the different user groups is likely to vary. Nonetheless, the table does allow identification of some characteristics of the different types of tools with regard to their usability for a number of user groups. All tools except ALU, APEX and SALM appear to have been primarily designed to report carbon sequestration and GHG emissions to funding agencies. ALU and carbon inventory methods were developed for the provision of inventories and APEX and carbon inventory methods were primarily for use in research. However, most developers believe that their tools could be used for all other purposes as well, if only after some training (where government staff who are not scientifically trained are considered the least capable of using the tools). This suggests that most of the tools appear to be suitable for the preparation of inventories and for research.

Carbon market applicability

With the exception of SALM, a protocol that assesses soil carbon enrichment and N_2O and CH_4 emissions following the introduction of conservation agriculture practices and crop and residue/waste management, none of the tools are ready for use by the carbon markets. The VCS recently approved SALM, and it seems that the voluntary or compliance market could approve several of the tools if they are submitted. For instance the CBP toolsets as well as the two methods/ protocols ('Integrating Carbon Benefits' and 'Carbon Inventory Methods') would lend themselves to being used by carbon projects working at landscape scales, due to the number of gases and the wide range of emission/sink sources covered, as well as their treatment of important issues like leakage and uncertainty required for use in carbon projects. The calculators could possibly also be used for this purpose, though their reliance on IPCC Tier 1, or at best Tier 2 level emission factors, and the fairly crude treatment of improved management practices, could render them unsuitable for many improved management practices – or generate mitigation values that are insufficient for project-level MRV.

GHG coverage

Table 3.2 shows that most tools deal with all three GHGs relevant for agriculture and land-use change. Only the USAID AFOLU carbon calculator and the carbon inventory methods focus exclusively on CO_2, whereas APEX estimates CO_2 and N_2O but not CH_4. However, none of the tools described, even those using Tier 3 mechanistic models to estimate carbon stock changes, use more than an emission factor approach to assess N_2O or CH_4. The table also shows that the only source/ sink category covered by all tools is cropland. Rangeland and grassland, agroforestry, forests, and land-use change are covered by most tools, whereas livestock and rice production are only covered by a small set of calculators using Tier 1 or Tier 2 emission factors, and none of the measurement protocols or Tier 3 modelling tools. Urban trees, vineyards/ orchards and horticulture are only explicitly distinguished in a few of the tools, but could possibly be covered as speciality crops or agroforestry. Wetlands appear to be a special case similar to land-use management, most tools deal with both categories. Possibly those tools that don't could easily be extended to cover wetlands as well. Energy use and other source categories, which also largely cover certain energy related emissions, are mainly included in the calculators, whereas they are not part of the mechanistic models or measurement tools.

Source/sink coverage

The only tool that seems to be covering all source/sink categories is the ALU calculator. The EX-ACT and CBP modelling calculators cover nearly all source/sink categories with the exception of horticulture and vineyards/orchards. The Cool Farm Tool covers nearly all source/sink categories with the exception of wetlands and urban trees and contains on-farm energy consumption, allowing for farm-gate GHG assessments of management systems. Having originally been developed for tree-based systems, the USAID AFOLU Carbon Calculator focuses on the assessment of carbon stock changes of forests and other tree-based management systems, but more recent inclusion of range and grassland, as well as cropland, now renders the tool more useful for other USAID projects. Nevertheless, lacking assessment of N_2O and CH_4, the tool is less well positioned to deal with agricultural management practices.

Additional attributes

Table 3.3 provides an overview of advantages and constraints of the tools with respect to their accessibility, requirements, type of analysis and additional attributes. All tools, except for the carbon inventory methods, are available free of charge. Only the AFOLU Carbon Calculator and the CBP tools have online capabilities, making them more flexible in their use. Most of the tools can however, be downloaded from the web, which can be an advantage for regions in the developing world that have low internet bandwidths or unstable connections. Several of the tools are available in a number of languages, which is a clear advantage for extension services that frequently do not speak English, although often only the user guidelines are available in another language, rather than the tool itself. Despite French being spoken widely in West and Central Africa only EX-ACT offers guidelines in that language. The CBP Simple Assessment will be available in French at the end of 2012. The language restrictions of extension services, or national government agencies, may therefore reduce the choice of tools to those that seem most accessible from the language perspective, such that provision of guidelines in common languages apart from English, may be a good way to ensure greater user friendliness and uptake.

Expertise requirements

Cost and specialist expertise and equipment can be critical constraints when considering the use of one over another. Low-cost and knowledge requirements for using the calculators is opposed by higher costs and more expertise and equipment needed for carrying out the inventory protocols and measurement tools, as well as using the Tier 3 dynamic ecosystem models. Hence, while the former can be used for ex-ante estimates of the benefits that can be expected, the latter will most likely only be used where there is a clear carbon and/or GHG benefit from land-use or management change. Given these features of the measurement tools and inventory methods and protocols, it appears advantageous to verify them for use within the voluntary and compliance markets for more widespread use.

Spatial application

In principal, all of the described calculators could be made spatially explicit; for example by developing scripts that run the calculators in a batch process, with the information required by each plot and then exporting it into a GIS, (in the way that this has been done for ALU and the CBP modelling tools). APEX is different in its approach to addressing spatial output as the model connects different landscape compartments dynamically, which makes it more accurate where considerable lateral flows can be expected, such as in watersheds or on terrain with steep hills. By virtue of their approach, measurement tools are necessarily spatially explicit, but whether the results reflect the area under consideration depends largely on an appropriate sampling design. This can be a hindrance in many developing countries with poor infrastructure where reaching randomly predefined sites for sampling can be very challenging. However, if properly designed and carried out, measurement approaches will reflect carbon stock changes more accurately than any model and should therefore be used to calibrate modelling tools that can be run at much lower costs. As for GHG flux measurements, these cannot be carried out cost-effectively within any MRV system, due to their high spatial and temporal variability. Over time measurements of land-use systems with clear distinctive features will eventually allow improvement of modelling tools, but currently far too few examples exist from developing countries, particularly from Africa and Southeast Asia, to calibrate the existing regression and mechanistic models to reflect tropical soils from low-input farming systems.

Uncertainty

Most of the tools that provide guidelines or estimates of uncertainty build on the IPCC best practice guidance (2006), which relies mainly on error propagation. In addition, the inventory methods and protocols as well as the measurement tools provide information on quantification errors, such as those related to ground-based sampling or remote sensing, where these technologies are important. It is well established that uncertainties in environmental modelling are scale dependent (Heuvelink 1998) (Section 1.3), with some source of uncertainty gaining or losing significance as one moves from the farm to the landscape scale. Therefore tools that aggregate farm-level data to produce a landscape-scale assessment may produce misleading estimates of uncertainty if the same summation approach is applied to sources of uncertainty. For example, when considering soil N_2O emissions, soil inputs contribute a larger share to total uncertainties at the point scale than they do at the landscape scale (Nol et al. 2010). Uncertainty estimates are required for use in carbon market projects; therefore the USAID AFOLU Carbon Calculator, or the Cool Farm Tool, would have to develop guidelines on assessing uncertainty if they were to be used for that purpose, though the developers currently do not have that intent.

Permanence issues

Permanence of carbon sequestration can be a serious problem for some land-use changes. For example, if trees are reforested for a carbon project and then cut down after the project comes to an end, or when minimum tillage is introduced in a conservation agriculture project that is expected to sequester soil carbon, but subsequent soil ploughing leads to loss of the labile organic matter fraction. For tree-based systems, better knowledge of the expected use of the planted trees could inform contracts in carbon benefit projects, such that the VCS now only recognizes 50 percent of the carbon sequestered in the trees in A/R projects to account for post-contract usage.

A similar treatment could be envisaged for soil carbon sequestration projects. The accuracy of the estimate depends on information of farmers' management practices following the end of the project. Regular audits could inform project managers of how project participants react and make projections of future land-use change that could then be considered in the expected total carbon sequestration at the end of the project and beyond. While the carbon calculators would account for permanence of above-ground carbon stock changes, they would not be able to capture changes in soil management practices. Process-based models would be able to account for the losses due to land management changes, but ultimately only ex-post measurements of tree cover changes or soil carbon stocks, allow verification of how much of the sequestration estimates have turned into hot air.

Leakage

Leakage is dealt with only indirectly, if at all, and only by extending the area of the landscape being assessed beyond the project boundaries. This approach captures leakage that occurs when the demand for a commodity (such as charcoal) is satisfied from an adjacent area following the start of a biocarbon project, or where protection of high carbon stock landscapes (such as forests) leads to conversion of high carbon stock landscapes in the vicinity of the project area. However, where the landscape conversion or degradation occurs from spatially dislocated areas, the tools will likely miss the leakage effects. This is a strong argument for whole landscape accounting approaches and nesting of project-based carbon and GHG accounting into national-level accounting. In addition, there are other types of leakage that are not addressed with any of the tools. For example, people-based leakage occurs where biocarbon project innovations lead to migration of people to other regions because the new management (such as afforestation) does not satisfy their livelihoods any longer. In that case the project would have to account for the additional emissions resulting from the migrants' new livelihood activities. Alternatively, if the management change leads to higher productivity the project would have to discount for the difference between conversion rate and productivity related emission increase even if the changes occur outside the project boundaries (van Noordwijk and Minang 2009). While the described forms of leakage may not be suitable for inventory tools working at the landscape level, the guidelines accompanying the tools should address the difficulties in properly dealing with emission displacement and make suggestions as to how the area of influence can best be identified, so as to find indicators of how large the assessment area would have to be to account for the leakage.

Social and economic analysis

Only three of the tools described provide any kind of social or economic analysis. By far the most advanced approach is used in the CBP modelling tools that allow analysis of the project using a DPSIR framework. While it may not be central to the task of providing a carbon stock and GHG inventory, access to socio-economic information embedded in the inventory tools is useful for project developers and funding agencies. Such tools can have particular significance for landscape-scale assessments where conflicts of interest in terms of land management for carbon benefits may arise and landscape-scale strategies need to be devised.

Of the calculators considered here, EX-ACT, the Cool Farm Tool and ALU have been tested and used widely, including examples of landscape-scale application for all three tools. This provides an advantage for smallholders in developing countries as in-country training has been carried out and some capacity to use the tools already exists. The CBP has also carried out a number of training sessions for its Simple Assessment Tool but as a new tool, capacity is still being built. The APEX tool has also been widely used and tested, although greater skills are required to use it than with the more user-friendly calculators.

Other issues specific to landscapes dominated by smallholders

Smallholders typically show high variability in crops grown, land-use and land management practices employed over very small areas. Capturing this diversity in a landscape-scale assessment is demanding. Measurement approaches that capture a single flux from multiple sources, such as eddy covariance, can overcome this, but there are limitations: fluxes are confined to CO_2 and terrain must be generally flat. The calculators reviewed here can be employed in different ways to address heterogeneity. Multiple runs of the Cool Farm Tool can be executed for different practices and then agglomerated; a similar approach can be used for EX-ACT. Only the CBP tools (Simple and Detailed Assessments) allow this high level of heterogeneity to be dealt with in a spatially explicit way over an entire landscape. If necessary, the user can define on a map, multiple (hundreds) areas (of 1 ha or more) within a landscape, each with unique land-cover, land-use and land management practices. The subsequent analysis for the entire landscape gives a single figure of GHG balance in CO_2e, which is then further broken down by source and subsource category for the entire landscape.

Landscapes dominated by smallholders may also see large temporal variations in land-use and management practices, as smallholders may try out new crops, or react to market and subsistence pressures. The EX-ACT tool deals with temporal variation by splitting the analysis into two phases: an implementation phase (the active phase of the project commonly corresponding to the investment phase), and a capitalization phase (a period where project benefits are still occurring as a consequence of the activities performed during the implementation phase). The CBP tools allow the user to build together a string of runs to give a final analysis. The minimum period for a report is one year, so a user could in theory build a string of 20 year-long analyses, with land management practices being different in each year for any or all of the multiple areas defined.

5. Conclusions

There currently exists a window of opportunity for smallholders in developing countries to gain from carbon-friendly land management practices, not just environmentally, but also financially, as funding agencies and carbon markets find ways to reward practices that mitigate climate change. Taking a landscape-scale approach to implementing and assessing carbon-friendly practices is advantageous for a variety of reasons, the most obvious being that a landscape approach can account for competing land-use pressures. Demand for landscape-scale quantification is growing from funding agencies and carbon markets. Landscape-scale tools and resources do exist, but fewer than those for farm or national-scale assessments. When geographical coverage of developing country areas is also taken into consideration this number becomes smaller still.

Measurement techniques and sampling strategies that reduce cost, but still capture heterogeneity, are key in landscape-scale assessments. Promising examples include the use of near infrared spectral reflectance to rapidly quantify soil carbon in the field. However, in common with approaches to estimate above-ground woody biomass, these need to be underpinned by libraries of data with relevance to the geographical areas and land management systems associated with smallholder farmers. At present, more work needs to go into developing these libraries. Eddy covariance to estimate CO_2 flux is another useful technique but currently it cannot satisfactorily deal with highly heterogeneous landscapes, in terms of either topography or land use. In recent years RS has made enormous advances in estimating carbon density and carbon stocks. Techniques continue to advance and costs reduce, which, in conjunction with the development of online tools and datasets such as Google Earth Engine, is increasing accessibility to RS techniques. The role of RS techniques will increase in prominence as REDD+ strategies for smallholders to operate sustainably in forested areas are realized. Financial gains for GHG emission reductions from REDD+ could reach US$30 billion a year (UN-REDD 2009). Remote sensing techniques are of less use in situations where carbon stock changes result from a change in land management rather than land cover, as may be the case in mainly agricultural landscapes with few trees. Handbooks and guides covering these and other measurement techniques should have the following features if they are aimed at assessment for smallholder areas in developing countries:

- have a user-friendly format
- be accessible to smallholder groups and those representing them (online or from funding agencies)
- give guidance for different types of projects and activities
- cover all sources of GHG emissions and carbon stock changes
- give protocols suited to a range of circumstances from low to high tech.

Measurements are used in conjunction with modelling techniques to scale up estimates and if required, to make estimates of future or potential change. Models have also advanced considerably in the past decade, with techniques of linking them to GIS to carry out spatially explicit analysis now common (Easter et al. 2007). At the landscape scale more work needs to be done on developing models which can simulate all of the complex interactions between different emission sources and sinks of GHG. In addition, where measures of uncertainty are provided, methods need to be tailored to landscape assessment. Ideally such models would then be linked to social and economic models, which could help identify the real world potential of a technically feasible GHG mitigation strategy.

Several calculators have been developed which have relevant geographical coverage for developing countries and can be used for landscape-scale assessment. Each has been developed for specific purposes and each has different attributes and weaknesses; therefore one cannot be recommended over another. None of the calculators reviewed have been certified as acceptable to a voluntary carbon market, with most being developed for reporting purposes for funding agencies. This is an obvious area for development, with the inclusion of tools for the calculation of permanence and leakage being important.

Finally, landscape-scale methods for the quantification of GHGs and estimation of change require complex datasets drawn from a variety of sources (such as remotely sensed land-cover information, census or local data on land management, ground-based measurements of carbon stocks and GHG fluxes etc.). To make the best use of these different sources, integrated methods and tools are needed that include guidance on how to take measurements to inform specific models and calculators, how to collate and format data, and how to interpret results. Such resources could open up landscape-scale GHG quantification to a wider range of stakeholders including those representing smallholder farmers. An early example of such a resource is the CBP toolset.

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Appendix 1 Summary of selected GHG resources for landscape-scale quantification in smallholder contexts

Calculators

USAID AFOLU Carbon Calculator

1.Basic Information	
Name of the tool	USAID AFOLU Carbon Calculator
Developed by	Winrock International
Contact	Felipe Casarim and Nancy Harris: carbonservices@winrock.org
Availability	Free of charge online toolset (four web-based tools)
Website	http://afolucarbon.org/
2. Tool Description	
Purpose and user group	The various calculators are meant to give USAID missions and partners an easy way to comply with USAID's policy of mainstreaming CO_2 as an agency-wide results indicator.
Geographic coverage	119 countries, all countries where USAID is present with land-based projects (tropical/subtropical regions).
Ex-ante, project tracking or ex-post	The tool is not designed to produce carbon project-specific estimates, so is neither ex-ante nor ex-post. It does not compare scenarios with each other. However, it can be used to indicate areas where carbon financing could take place and so could be said to take an ex-ante approach in that sense.
Versions and release dates	Tool first released in 2007 and updated regularly since then.
General methodology	Comprises a set of web-based calculation tools that cover the following activities: forest protection, forest management, afforestation/reforestation, agroforestry, cropland and grazing. The toolset was originally developed for projects involving forests, with the cropland and grazing options being less detailed and more recently added. The tools produce yearly estimates of the $C0_2$ impact of land management activities up to 30 years. All tools operate at two levels, Level A, which only requires information on project location and size and a rating for management effectiveness (the user chooses a % effectiveness, definitions are given in the manual) and Level B, which allows the user to change default parameters with project-specific data. Each tool uses a different approach so they are in fact different calculators, but in general they are based on equations derived from extensive literature reviews and the IPCC 2006 Guidelines for AFOLU for parameters such as biomass accumulation rates, biomass carbon stocks, and country-specific remote sensing information for deforestation rates. Some parameters in some tools currently default to 0 due to lack of information (e.g. illegal logging rate and biomass loss from fire) but the developers plan to update these as and when information becomes available. The user always has the option to replace values with their own value in Level B.
Ecosystems/ management practices covered	Forest protection, forest management, forest restoration/plantation, agroforestry, cropland management, grazing land management.
GHG emissions and carbon stock changes covered	Above and below-ground forest biomass carbon, peat carbon, and soil carbon.
Non-LU emissions covered	No
Output format	Numeric, table and graphical. Output gives CO_2 benefit by activity type, administrative unit and project. Output not spatial.
Indicators covered	CO_2 equivalent.
Uncertainty, leakage and permanence	No uncertainty. Leakage partly addressed in project effectiveness ratings but not directly estimated. Discussions to expand leakage estimations underway. No permanence.
Any analysis of economic or social impacts	No

USAID AFOLU Carbon Calculator continued

3. Application at the landscape scale						
Scale tool/method was designed for	Subnational scale, more specifically at countries' administrative unit scale.					
How the tool/method can be applied at the landscape scale	The tool can be applied broadly, at the landscape level, as well as at the project scale. That is because the default underlying database is set up with robust administrative unit scale data; however, users can modify default data with project-specific information if known. The tool is designed to allow for user determination of how specific output will be.					
4. Relevance to smallholders and developing country farmers						
Resources and constraints	The tool is designed to accommodate all levels of formal education from users. All calculators in the tool function on two levels: Level A and Level B. Under Level A, the only information required to generate a CO_2 impact result is the size, or area of the project, and the management effectiveness, which is a qualitative rating of how effective the project has been at achieving its stated goals. Level A was designed to derive a CO_2 benefit using minimal information provided by the user. Under Level B, the user is given options to change default parameters by entering project-specific data. The calculator-specific documentation links provide detailed information about each of the parameters and how the default value for each parameter was derived. This is to help users decide which data to use (e.g. to change the default data or not).					
Groups it can be used by	Farmers cooperatives	Agricultural extension workers	Government staff without scientific training	Government staff with scientific training	Programme officers	Scientists
	yes	yes	yes	yes	yes	yes
5. Application of the tool						
Acceptability to carbon markets	No The tool is not meant to provide the level of accuracy needed for carbon financing, but may provide early indication of areas that have potential for such financing. The calculators produce estimates of sequestration or avoided emissions of carbon dioxide and carbon dioxide equivalents using sound and transparent science.					
Uptake/usage of tool	No information provided.					
6. Future plans						
The USAID AFOLU Carbon Calculator will be expanded and upgraded with new funds acquired from USAID. This amendment to the tool will add new features and improve current capabilities. Amongst the changes expected to take place in upcoming years, are to: • Expand spatially explicit analysis and capabilities • Refine and improve default database such as deforestation rates, and forest biomass carbon stocks, amongst others • Improve current calculator by adding spatial capabilities to the tool • Develop a new bioenergy and land-use calculator to assess potential impact of collection of fuelwood or biogas on forests • Improve management effectiveness rating estimation • Refine benefits projection and develop a decision-making tool to allow users to plan activities before implementing • Develop a set of training materials for the tool (e.g. online training videos, in country training workshops).						

EX-Ante Carbon-balance Tool (EX-ACT)

1. Basic information	
Name of the tool	EX-Ante Carbon-balance Tool (EX-ACT)
Developed by	The Food and Agriculture Organization of the United Nations (FAO)
Contact	Louis Bockel, Agricultural Policy Support Officer at FAO, louis.bockel@fao.org Martial Bernoux, FAO Consultant, Senior Scientist at IRD, martial.bernoux@ird.fr Dedicated email: EX-ACT@fao.org
Availability	Free to download from web. Excel file.
Website	http://www.fao.org/tc/exact/en/
2. Tool description	
Purpose and user group	A simple tool to provide estimates of the impact of agriculture and forestry development projects on GHG emissions and carbon sequestration. Agriculture and forestry project (and policies) developers and programme officers from funding and implementing agencies and ministries
Geographic coverage	Global
Ex-ante, project tracking or ex-post	First designed for ex-ante analysis, but can be used for project tracking and ex-post analysis, particularly if using Tier 2 coefficients
Versions and release dates	First version (Version 1) released in December 2009; Version 2 in March 2010, Version 3 in October 2010. Present version (3.3) was released in August 2011.
General methodology	EX-ACT is a land-based accounting system, estimating carbon stocks, stock changes per unit of land, and CH_4 and N_2O emissions expressed in tCO_2e per hectare and year. It is an Excel tool that has been developed using primarily the IPCC 2006 Guidelines for National Greenhouse Gas Inventories, complemented by other existing methodologies and reviews of default coefficients where available. It requires the user to compare a project scenario against a baseline scenario and was designed as an ex-ante tool.
Ecosystems/management practices covered	Assesses the impact of agriculture (annual crops, agroforestry/perennial crops, irrigated rice, and cattle) and forestry activities (A/R, conservation/avoided deforestation, forest degradation and deforestation) on GHGs and carbon sequestration. It concerns land-use changes (from a forest to non-forest, from a non-forest to a forest, between two different non-forest land-uses) and management options for a land remaining in the same category of land-use (e.g. crop management, pasture management and flooded rice management).
GHG emissions and carbon stock changes covered	All GHG emissions (CO_2, N_2O and CH_4) linked with LULUCF activities covered by the NGGI-IPCC-2006. CO_2 emissions linked with carbon stock changes during conversion between two categories (forest land, cropland, grassland, other land) concerning 5 pools: above-ground biomass, below-ground biomass, soil, deadwood and litter. N_2O and CH_4 emissions during biomass or residues burning CH_4 emissions from flooded rice cultivation. Emissions concerning organic soils Emissions from livestock: Emissions from inputs (lime application, CO_2 emissions from urea application, N_2O emissions from nitrogen application).
Non-LU emissions covered	Emissions (in CO_2 equivalent) from production, transportation storage and transfer of agricultural chemicals (N,P,K, lime, herbicides, insecticides and fungicides). Emissions from energy use and infrastructure: GHG emissions associated with electricity consumption, fuel consumption, installation of irrigation systems and building of infrastructures (housings, buildings, offices and roads)
Output format	The main output of the tool is the carbon balance resulting from project activities (which project activities may increase GHG emissions, and which may contribute to soil carbon sequestration). Outputs are summarized in two spreadsheets, one concerning the gross GHG emissions for the baseline and the project situation, one giving the results for the difference between with and without activities, i.e. the carbon balance (net benefits of the project in comparison to the baseline). Tables and graphs provided.

EX-Ante Carbon-balance Tool (EX-ACT) continued

<table>
<tr><td>Indicators covered</td><td colspan="6">GHG emissions in CO_2 e.g. for baseline and project situations: total bulk emissions, emissions per 'category' (deforestation' plantation, annual crops, grassland) average emissions per unit of land, average emissions per year.
Net GHG emissions of the difference of the 'with project' option compare to the 'without project': total bulk emissions, emissions per 'category' (deforestation' plantation, annual crops, grassland), emissions for CO_2, for N_2O, for CH_4, average emissions per unit of land, average emissions per year.</td></tr>
<tr><td>Uncertainty, leakage and permanence</td><td colspan="6">Uncertainty calculated using IPCC method. Rough % given with output e.g. 10, 20, 33 or 50%.
The land-use conversion matrixes can in principle address leakage, thus it allows the user to capture activity shifts and tracking changes in practices.
When addressing uncertainties (see above) the tool targets the categories where a problem of permanence might arise (CO_2 emissions linked with carbon stock changes).</td></tr>
<tr><td>Any analysis of economic or social impacts</td><td colspan="6">No, but output could be used in economic analysis.</td></tr>
<tr><td colspan="7">3. Application at the landscape scale</td></tr>
<tr><td>Scale tool/method was designed for</td><td colspan="6">The tool was originally designed to work at the scale of the development project (from thousands to millions of hectares).</td></tr>
<tr><td>How the tool/method can be applied at the landscape scale</td><td colspan="6">The user determines the scale so it can be used (and has already been applied at) the farm or even country scale.</td></tr>
<tr><td colspan="7">4. Relevance to smallholders and developing country farmers</td></tr>
<tr><td>Resources and constraints</td><td colspan="6">Requires a computer with Microsoft Excel (from version 2003 onwards). Tier 1 coefficients are supplied or the user can input their own data (emission factors, carbon stocks). The guidelines are given in English, French, Spanish and Portuguese.</td></tr>
<tr><td>Groups it can be used by</td><td>Farmers cooperatives</td><td>Agricultural extension workers</td><td>Government staff without scientific training</td><td>Government staff with scientific training</td><td>Programme officers</td><td>Scientists</td></tr>
<tr><td></td><td>yes with training</td><td>yes with training</td><td>yes with training</td><td>yes with training</td><td>yes with training</td><td>yes</td></tr>
<tr><td colspan="7">5. Application of the tool</td></tr>
<tr><td>Acceptability to carbon markets</td><td colspan="6">Tool not designed for carbon markets and not certified. However when compared to BioCarbon Fund project and CCB standard it gave similar results in terms of carbon sequestered and fluxes of GHG.</td></tr>
<tr><td>Uptake/usage of tool</td><td colspan="6">EX-ACT has been used in 30 projects and policy appraisals concerning 24 countries. More details on the website, including some case studies on projects, value chains and policies (see "EX-ACT Applications" on the website). Case studies in Brazil have been published in Branca et al. (2013) http://dx.doi.org/10.1016/j.landusepol.2012.04.021</td></tr>
<tr><td colspan="7">6. Future plans</td></tr>
<tr><td></td><td colspan="6">A permanent team is dedicated to EX-ACT, thus the tool will be updated regularly. Version 4 will be released in 2012 and will include estimates of yield for main crops.</td></tr>
</table>

The Cool Farm Tool

1. Basic Information	
Name of the tool	The Cool Farm Tool
Developed by	Unilever, University of Aberdeen and the Sustainable Food Lab
Contact	Daniella Malin, Email: Daniella.malin@gmail.com
Availability	The tool is an Excel file which can be downloaded free of charge from the project website.
Website	http://www.coolfarmtool.org
2. Tool Description	
Purpose and user group	The intended user group for the tool is multinational or national food and beverage companies, farmers, cooperatives and development/other organizations that work with growers and/or source a variety of raw agricultural products globally. These types of users need to be able to tailor agronomic advice to the particularities of their suppliers' growing conditions and crops.
Geographic coverage	Global
Ex-ante, project tracking or ex-post	The tool is not intended as a carbon market access mechanism but can provide a site-specific screen for carbon market opportunities. An attractive feature of the tool is that it allows users to easily run 'what-if' scenarios to evaluate different GHG emissions mitigation possibilities so it can be used for ex-ante analysis.
Versions and release dates	The first version was released in early 2010, a subsequent version was placed up on the website for download in early 2011 and a new version was released May, 2012.
General methodology	The tool has a number of submodels that break down emissions by GHG and aspects of farm management. Each model uses equations either based on modifications of the IPCC approach or other sources in the literature. Nitrous oxide (N_2O) and nitric oxide (NO) emissions from fertilizer application are estimated using the multivariate empirical model of Bouwman et al. (2002) – which is based on a global dataset of over 800 sites. Soil CO_2 emissions use the Ogle 2005 model, N_2O, and CH_4 emissions from crop residues are modelled using IPCC (2006) and Brown et al. 2009, emissions from livestock management use the IPCC approach (Tier 1 and Tier 2). Emissions from fertilizer production are taken from Kongshaug 1998, EFMA and the Ecoinvent database; and emissions from organic amendments from Smith et al. (1997). Full details are given in Hillier et al. (2011).
Ecosystems/management practices covered	Arable crops, tree/bush crops, livestock. Land-use change to/from grassland, arable land and forest.
GHG emissions and carbon stock changes covered	GHG emissions: soil carbon, methane, N_2O from soil disturbance, fertilizers, resident nitrogen, crop residue management (and lack thereof), embodied production emission of synthetic and organic fertilizer (compost), pesticides, , methane emissions processing fermentation, livestock enteric and manure, land-use change. Stock changes: soil carbon and above-ground carbon. Cover crops, land-use change, compost and manure, tillage, mulch, trees.
Non-LU emissions covered	Fuel use in field (tillage, spraying/spreading, harvesting) Fuel and electricity use on farm and in field vehicle use, lighting heating, pumps On-farm fuel and electricity used in processing (also considers waste water containing organic compounds) Fuel use in transport (road rail, air) both for inputs and for final product.
Output format	In numerical tables, graphs and charts broken out by emission sources and sinks on a per acre/hectare, per ton/tonne/kg/lb/gal basis and in total.
Indicators covered	NET GHG emissions (sources minus sinks) in CO_2e.
Uncertainty, leakage and permanence	No
Any analysis of economic or social impacts	No

The Cool Farm Tool continued

3. Application at the landscape scale						
Scale tool/method was designed for	The tool was originally designed to be used for individual products but can be used at any other scale if all the products produced on those scales are known.					
How the tool/method can be applied at the landscape scale	If for example a landscape includes a large number of small diverse farmers growing beans, milk, beef, corn and vegetables and large grazing and forested areas, you would use the CFT to quantify the GHG on this landscape by 1. Characterizing the farmers (or categorizing if there are different types of farmers say, some larger some smaller, some that grow one type of crop some that grow another). 2. Calculating the GHG emissions of each crop of each typical farmer and multiplying by the number of farmers of each category or crop. 3. Sum these crops and farmers. 4. If the grazing areas or forested areas have undergone change in the last 20 years you would add these to the sum.					
4. Relevance to smallholders and developing country farmers						
Resources and constraints	The tool is an Excel spreadsheet calculator and is therefore very portable and accessible to developing countries. No internet access is necessary other than to download the file. It doesn't have a web interface and the developers found this can be a bit daunting for first time users, although it is developed for use by farmers themselves, so is user-friendly. It does have an online questionnaire in Spanish and English that can be easily translated to other languages and used to guide the user. There is also a user's guide. It takes about 45-60 minutes the first time round, but after that is very quick (15 minutes or so per crop). Farmers generally need assistance, at least for the first time. The tool is designed to use, almost exclusively information that farmers have off the top of their heads. But some record consultation is needed, usually just for energy calculations.					
Groups it can be used by	Farmers cooperatives	Agricultural extension workers	Government staff without scientific training	Government staff with scientific training	Programme officers	Scientists
	yes	yes	yes	yes	yes	yes
5. Application of the tool						
Acceptability to carbon markets	It has not been designed for carbon market use, but has been tested widely by voluntary standards systems. Rainforest Alliance, Utz Certified, Fairtrade (FLO-Cert), Solidaridad, 4C Association are looking to integrate the CFT into their certification and auditing programmes, as GHG accounting for climate smart agriculture is becoming increasingly important to their clients, both farmers and buyers.					
Uptake/usage of tool	A number of companies (Pepsi, Heinz, McCain, Unilever, Marks and Spencer, Tesco, Heineken, Costco,) are using the tool, as are various NGOs and consultancies. Exact uptake is not known; however it is known that at it is being used in over 25 countries, on about 20 crops, with 30 organizations, about 500 individual datasets. Some of these represent thousands of cooperative members. Details of case studies are available at http://www.coolfarmtool.org/CaseStudies Countries: Belgium, Brazil, Canada, Colombia, Dominican Republic, Egypt, El Salvador, France, Germany, Ghana, Guatemala, Honduras, India, Indonesia, Italy, Jamaica, Kenya, Mexico, Netherlands (Holland), Nicaragua, Paraguay, Poland, Rwanda, Spain, Turkey, UK, USA,					
6. Future plans						
	Develop web-based version of the tool with offline data collection ability (tablets). Also exploring 'regionalization' of the generic methods and algorithms. Improving the transparency of the tool. Improving certain features – adding a distinction between residue incorporation and mulching and improving the way the tool handles the possible relationship between residues and on-site compost production. Integration of the CFT into other existing and developing supply chain GHG calculation resources such as Earthster and The Sustainability Consortium's Sustainability Measuring and Reporting System (SMRS). The Cool Farm Tool was recently accepted by the GHG metric working group for the Stewardship Index for Specialty Crops and will be recommended to the Coordinating Council for use.					

Agriculture and Land Use National Greenhouse Gas Inventory Software – ALU

1. Basic Information	
Name of the tool	Agriculture and Land Use National Greenhouse Gas Inventory Software – ALU
Developed by	Colorado State University
Contact	Stephen Ogle Email: Stephen.Ogle@colostate.edu
Availability	Available for download free of charge from the project website. It is a stand-alone software package for the PC computing environment.
Website	http://www.nrel.colostate.edu/projects/ALUsoftware/
2. Tool Description	
Purpose and user group	The tool is aimed at national greenhouse gas inventory compilers. It is intended for reporting past greenhouse gas emissions to the UNFCCC and to project future mitigation potentials. The software is particularly useful for those who have previously been using the IPCC spreadsheets to produce national inventories and want a quicker more user-friendly tool.
Geographic coverage	ALU has global application. Users can upload their own spatial data for soils, climate and land use or use default information. Likewise the user can input their own emissions factors or use IPCC defaults.
Ex-ante, project tracking or ex-post	The tool is primarily for producing annual inventories so information is entered for a complete year for an ex-post analysis. However users can use the 'mitigation' function to project future emissions/ mitigation potential using a previous year as the baseline and explore different land-use scenarios.
Versions and release dates	A prototype version was released in 2007. Version 1 of the ALU was released in 2008. Versions 2 and 3 were released in 2010 and 2011, respectively.
General methodology	The ALU software is based on the IPCC method using the revised 1996, and 2000, 2003 guidelines with some information from the 2006 guidelines. The software organizes the different stages involved in producing an inventory into 4 modules thereby simplifying the process of producing an inventory of greenhouse gas emissions and removals related to agricultural and forestry activities.
Ecosystems/management practices covered	The ecosystems covered include the land uses found in the IPCC guidelines: forest, croplands, grassland, wetlands, settlements and other lands. Livestock systems are also addressed in the tool.
GHG emissions and carbon stock changes covered	The tool covers emission source categories associated with the agriculture and land use, land-use change forestry sectors, including enteric methane, manure methane, manure nitrous oxide, biomass burning non-CO_2 greenhouse gas emissions (crop residue, grassland/savannah and forest fires), soil nitrous oxide, biomass carbon stock changes (forest, deforestation, perennial crops/agroforestry, silvipasture/savannah, and settlements) and soil carbon stock change (all land uses).
Non-LU emissions covered	None
Output format	Microsoft Excel
Indicators covered	The tool provides emission estimates for all source categories listed above and the units are tonnes of the respective GHG.
Uncertainty, leakage and permanence	Uncertainty is not addressed in the current version. A version will be released in 2012 with uncertainty based on the simple error propagation method described in the 2006 IPCC Guidelines. Leakage and permanence are not addressed.
Any analysis of economic or social impacts	No, but the tool is designed to utilize information from an economic analysis to project mitigation potentials.
3. Application at the landscape scale	
Scale tool/method was designed for	Country/national
How the tool/method can be applied at the landscape scale	The tool could be applied at a landscape scale but would require emission factors that are specific to the landscape, because the defaults are intended for national-scale applications. However, the tool is designed to incorporate user-specific factors.

Agriculture and Land Use National Greenhouse Gas Inventory Software – ALU continued

4. Relevance to smallholders and developing country farmers						
Resources and constraints	The tool requires a compilation of activity data for a country or the scale of the application. These data may be available in national agricultural and forestry statistics, remote sensing data, and other large-scale datasets. Compiling these data can take several months. Field measurements can be used to gather emissions data for derivation of user-specific factors, but defaults are provided for most factors if measurements are not feasible and data are not available from previous studies. The tool assumes a fair knowledge of the IPCC method and the terminology it employs.					
Groups it can be used by	Farmers cooperatives	Agricultural extension workers	Government staff without scientific training	Government staff with scientific training	Programme officers	Scientists
	yes with training	yes with training	yes with training	yes with training	yes with training	yes
5 Application of the tool						
Acceptability to carbon markets	It is designed for reporting greenhouse gas emissions to the UN Framework Convention on Climate Change. If the same standards are acceptable for carbon markets or certification schemes, then the tool could be used for this purpose.					
Uptake/usage of tool	National compilers in approximately 30 countries have been trained to use the ALU software. Over half of these governments are actively using, or in the process of using the software for their national inventory.					
6 Future plans						
	The ALU software will have uncertainty routines in the coming year, and the biomass carbon stock change method is being developed for countries that have a national forest inventory.					

Models

Agricultural Policy/Environmental eXtender model APEX

1. Basic information	
Name of the tool	Agricultural Policy/Environmental eXtender model APEX
Developed by	Texas Agrilife – Blackland Research and Extension Center
Contact	Dr Jimmy Williams jwilliams@brc.tamus.edu or Evelyn Steglich esteglich@brc.tamus.edu
Availability	Available for download from the project website http://epicapex.brc.tamus.edu/downloads/model-executables and http://winapex.brc.tamus.edu/downloads/model-executables and on request from project staff.
Website	http://epicapex.brc.tamus.edu/
2. Tool Description	
Purpose and user group	APEX was designed to allow agricultural planners, researchers, universities and land-use planners managing whole farms and small watersheds to obtain sustainable production efficiency, maintain environmental quality and to address environmental problems (e.g. water supply and quality, erosion, soil quality, plant productivity and pests).
Geographic coverage	If data are available any geographic location can be covered.
Ex-ante, project tracking or ex-post	This is a diagnostic and prognostic tool.
Versions and release dates	First version 1998. Other versions 2002, 2006, 2008.
General methodology	APEX is a process-based model to simulate management and land-use impacts for whole farms and small watersheds on carbon and nitrogen cycles, carbon and nitrogen storage and nutrient loading, and losses through volatilization, leaching, erosion and denitrification. It also assesses CO_2 sequestration via plant growth. APEX is a multi-field version of the predecessor EPIC model and can be executed for single fields similar to EPIC, as well as for a whole farm or watershed that is subdivided based on fields, soil types, landscape positions, or subwatersheds. It models flow between these subareas. It is based on carbon and nitrogen cycling algorithms, initially developed by Izaurralde et al. (2006) for EPIC, based on concepts used in the Century model (i.e. kinetic pool approach). However, in contrast to Century, in APEX/EPIC, leaching equations are used to move organic materials from surface litter to subsurface layers. It has a DOS version (APEX) as well as two Windows interfaces (WinAPEX and ArcAPEX). A key feature that differentiates APEX/EPIC from other SOM and terrestrial ecosystem models is its capability to estimate SOC losses caused by wind and water erosion. APEX functions on a daily time step.
Ecosystems/management practices covered	Agricultural management (irrigation, drainage, fertilization, tillage, erosion control terraces, waterways, filter strips, residue management), pesticide management, water management (furrow dykes, ponds, reservoirs, wetlands); floodplain management (buffers, levees, channel improvement), livestock grazing, tree cropping.
GHG emissions and carbon stock changes covered	CO_2 (respiration from decaying residue), N_2O (fertilizer and mineralization) APEX simulates coupled carbon and nitrogen cycles in managed and unmanaged ecosystems. It simulates carbon losses including eroded carbon. All nitrogen losses are represented (leaching, erosion, volatilization, and denitrification).
Non-LU emissions covered	CO_2 emissions from farm machinery only.
Output format	Output from the DOS version is in text format. Output from WinAPEX is in Microsoft Access tables, and output from ArcAPEX is both Microsoft Access tables and text files.
Indicators covered	Carbon, water, nitrogen, and phosphorus balance. Also pesticide fate. Yield, biomass.
Uncertainty, leakage and permanence	No to all three.
Any analysis of economic or social impacts	Provides a simple income-cost analysis for farming activities.

Agricultural Policy/Environmental eXtender model APEX continued

3. Application at the landscape scale						
Scale tool/method was designed for	Farm/small watershed.					
How the tool/method can be applied at the landscape scale	A watershed can be divided into many homogeneous subareas . These can be based on fields, soil type, landscape position or subwatersheds. The APEX subareas can range from a few m^2 to 1000 ha or more depending on the desired level of detail. Thus, landscapes can be divided into as many segments as needed. The subarea is the basic element in APEX. Surface and subsurface flows are routed downstream from subarea to subarea along with sediment, nutrients, and pesticides. An advantage of using APEX at the landscape scale is that it models the flow of water and nutrients between subareas within the landscape.					
4. Relevance to smallholders and developing country farmers						
Resources and constraints	The APEX database contains weather, soil information and typical management for the U.S. The user would need to provide specific management data if it differs from that contained in the APEX database. Expertise is required for interpreting results.					
Groups it can be used by	Farmers cooperatives	Agricultural extension workers	Government staff without scientific training	Government staff with scientific training	Programme officers	Scientists
	yes	yes	llimited	yes	yes	yes
5. Application of the tool						
Acceptability to carbon markets	APEX has not been certified for use with any voluntary reporting standard. The changes in carbon over time are reported. Carbon dynamics depend on interactions with water, temperature, crop residues and available nitrogen.					
Uptake/usage of tool	The Natural Resources Conservation Service in the USA is using APEX in the national Conservation Effects Assessment Project analysis					
6. Future plans						
	The development team plans to continue expanding and refining APEX to meet the needs of agricultural managers worldwide.					

Documents detailing methods and protocols

Integrating carbon benefits into GEF projects

1. Basic information	
Name of the method/protocol	Integrating carbon benefits into GEF projects
Developed by	United Nations Development Programme (UNDP)
Contact	Timothy Pearson Email: tpearson@winrock.org
Availability	Available to download from Winrock's website free of charge
Website	http://www.winrock.org/Ecosystems/files/GEF_Guidebook.pdf
2. Method/protocol description	
Purpose and user group	The purpose of the guidelines is to provide methods for estimating carbon stocks and the changes in carbon stocks resulting from Global Environment Facility (GEF) project interventions. The guidelines aim to assist project developers, managers and evaluators, as well as implementing and monitoring agencies. They are targeted at non-experts and a user-friendly format has been adopted.
Geographic coverage	Global
Ex-ante, project tracking or ex-post	Suitable for ex-ante, project tracking and ex-post analysis.
Versions and release dates	First published in 2005 there have been no subsequent versions.
General methodology	The guidelines provide methods for estimating all relevant carbon pools and emissions or avoided emissions of non-CO_2 GHGs. Methods are drawn from IPCC documents, the Winrock C Methods Manual and the US Voluntary GHG emissions Reporting Program (1605b). The guidelines are relatively concise (64 pages) and use accessible language to guide the user through all aspects of GHG/ carbon reporting. Topics include choosing a sampling plan with an appropriate level of accuracy/ precision, developing a baseline scenario, developing a measurement and monitoring plan, taking field measurements and analysing data.
Ecosystems/management practices covered	Monitoring and accounting of carbon sequestration, carbon emissions and avoided carbon emissions from land-use practices. Specific guidance is given on: conservation / forest management / cropland management / grazing land management / agroforestry / forestation / mangroves-wetlands-salt marshes.
GHG emissions and carbon stock changes covered	The guidelines cover CO_2 and non-CO_2 gases (CH_4, N_2O). All pools covered (trees above and below ground, standing dead, down dead wood, forest floor, soil organic carbon and harvested wood products). "Methods are proposed for estimating all relevant carbon pools as well as emissions, or avoided emissions, of non-CO_2 greenhouse gases. The methods focus on terrestrial systems, but can also be applied to wetlands, mangroves and any coastal- or freshwater system dominated by plants."
Non-LU emissions covered	No
Assistance in formatting data provided?	The guidelines provide specific guidance on analysis of collected data.
Indicators covered	Net greenhouse gas emissions or removals relative to business as usual. Measured in tonnes of CO_2 equivalents.
Uncertainty, leakage and permanence	Uncertainty – the guidelines track confidence intervals of collected field data and use a propagation of errors method to sum errors from the various sources. There is a section discussing leakage; however, assessment methods are not included. The date the guidelines were written – 2004 – precedes most of the development of methods for leakage assessment. Similarly 2004 was before developments occurred on buffers or most other forms of permanence management.
Any analysis of economic or social impacts	No, these are covered by documents in other GEF operational programmes (OPs)

Integrating carbon benefits into GEF projects continued

3. Application at the landscape scale						
Scale tool/method was designed for	Designed for use at the project scale (likely something between a farm and landscape) but can be used at any scale.					
How the tool/method can be applied at the landscape scale	A lot of GEF projects involve both landscape-scale assessment and numbers of smallholders. The guidelines provide the necessary steps for field measurement and analysis of field measurements of carbon stocks and changes in carbon stocks. These approaches can be applied at any scale including landscape or even national. The importance of stratification will increasingly come into play the higher the scale. At higher scale it is likely there will be lower requirements for precision and since 2004/2005 the developers say they would have moved toward using simpler (default) approaches for calculation of minor pools rather than measurement.					
4. Relevance to smallholders and developing country farmers						
Resources and constraints	Financial resources to cover measurement teams and analysis. Capacity in terms of field measurement and data analysis. Such capacity typically exists in individuals trained in forestry, soil science or ecology. Basic additional training would enhance the ability of such individuals to lead and manage measurement and analysis programmes. The guidelines do not focus on changes in activity data – specifically remote sensing of forest, cropland or grassland areas. However, indirectly such abilities will be needed. Basic equipment is needed for field measurement such as measuring tapes, distance measuring equipment, sampling frames and soil probes. Where destructive samples are taken such as for dead wood, forest floor and soil carbon, access to a laboratory will be needed.					
Groups it can be used by	Farmers cooperatives	Agricultural extension workers	Government staff without scientific training	Government staff with scientific training	Programme officers	Scientists
	yes after training	yes after training	yes after training	yes	yes	yes
5. Application of the method/protocol						
Acceptability to carbon markets	The guidelines were designed to integrate assessment of carbon benefits into GEF projects. That said, the methods given are entirely appropriate for carbon markets and certification schemes. The question will be the level of precision targeted and degree to which quality assurance and quality control processes are implemented.					
Uptake/usage of method/protocol	Developers are not sure of uptake, however these guidelines, went on to influence the Sourcebook for Biocarbon Fund Projects (with the World Bank) and the Sourcebook for REDD (with GOFC-GOLD) both of which have had very heavy uptake and usage.					
6. Future plans						
	None at this time.					

Carbon Inventory Methods

1. Basic Information	
Name of the method/protocol	Carbon Inventory Methods
Developed by	A review or a 'cook book' of inventories developed by different entities of the UNFCCC, FAO and Winrock International
Contact	N.H. Ravindranath Email: ravi@ces.iisc.ernet.in Madelene Ostwald Email: madelene.ostwald@liu.se
Availability	It is a commercial book (Springer ISBN-3: 978-1-4020-6546-0) that could be available through academic libraries. If not, it is available on Amazon.com for US$190.
2. Method/protocol description	
Purpose and user group	Developed mainly for practitioners - professionals in forest inventories, soil chemistry and education and for project developers and evaluators.
Geographic coverage	Global but with focus on the developing world.
Ex-ante, project tracking or ex-post	All three.
Versions and release dates	1. Ravindranath N.H. and Ostwald M. 2008. Carbon Inventory Methods – handbook for greenhouse gas inventory, carbon mitigation and roundwood production projects. Springer Verlag, Advances in Global Change Research, pp 304, ISBN 978-1-4020-6546-0 2. Ravindranth N.H. and Ostwald M. 2009. Carbon Inventory Methods. Chinese translation of the English language edition, Carbon Inventory Methods – handbook for greenhouse gas inventory, carbon mitigation and roundwood production projects. Springer Verlag, Advances in Global Change Research. China Forestry Publishing House, pp 330, ISBN 978-7-5038-5432-3
General methodology	This is a handbook that brings together multiple methods mainly dealing with carbon inventories within land use. It provides step-by-step information on sampling procedures, field and laboratory measurements, application of remote sensing and GIS techniques, modelling and calculation procedures along with sources of data for carbon inventory. A unique feature is that it provides practical guidance for different types of projects 1) development, implementation and monitoring of carbon mitigation in forest, agriculture and grassland sectors, 2) national GHG inventory in agriculture, forest and other land-use categories, 3) forest, grassland and agroforestry development and 4) commercial and community forestry roundwood production.
Ecosystems/management practices covered	Forest, grassland, agroforestry systems and cropland with a focus on perennial terrestrial systems.
GHG emissions and carbon stock changes covered	Mainly carbon in terrestrial systems (above and below ground, dead wood, litter and soil).
Non-LU emissions covered	No
Assistance in formatting data provided?	Yes, it gives several suggestions depending on data availability, finances and time.
Indicators covered	Carbon stocks and changes over time.
Uncertainty, leakage and permanence	A chapter on uncertainty analysis is included in the book. Indicators relate to lack of data and representativeness (e.g. due to variations), sampling and measurement errors. Methods suggested are simple error propagation and Monte Carlo Simulations. The book provides descriptions of the types of leakage that can occur and refers to quantification methods. In terms of permanence the issue is discussed in the book but no real methods are proposed.
Any analysis of economic or social impacts	No

Carbon Inventory Methods continued

3. Application at the landscape scale						
Scale tool/method was designed for	For project levels (which can include landscapes)					
How the tool/method can be applied at the landscape scale	All methods suggested would fit landscape-level assessments where heterogeneity (complexity) is more the limiting factor than the fact that it covers a landscape. Certain chapters are particularly relevant to landscape-level assessment. For example Chapter 14 deals with carbon inventory using data from remote sensing. Techniques for estimating and monitoring project boundaries, stratifying project areas and developing sampling regimes are given for all scales including the landscape scale.					
4. Relevance to smallholders and developing country farmers						
Resources and constraints	Access to the book and knowledge is in English (or Chinese). For the more simple methods suggested in the book, a measuring tape can be sufficient. Knowledge in biology and mathematics is helpful for certain assessments and a requirement for others. For the more technical advanced methods, users need field equipment, computer programs and programming skills and remote sensing information that can sometimes be costly. An advantage of the book is that it provides a range of methods suited to different project types and resource levels with advice on how the user can decide which one is appropriate. Things to consider when choosing an appropriate approach are discussed e.g. the purpose of the inventory, the focus of the project/intervention, the size of the area in question, the land uses in the area and the resources available (money, people, expertise, facilities).					
Groups it can be used by	Farmers cooperatives	Agricultural extension workers	Government staff without scientific training	Government staff with scientific training	Programme officers	Scientists
	yes for some methods	yes for some methods	yes for some methods	yes	yes	yes
5. Application of the tool						
Acceptability to carbon markets	Many of the methods are based on Good Practice Guidance designed for reporting to the UNFCCC Secretariat and many are in line with methods used for voluntary markets certificates.					
Uptake/usage of tool	Usage is not known					
6. Future plans						
	No plans					

Integrated toolsets

Adoption of Sustainable Agricultural Land Management (SALM)

1. Basic Information	
Name of the method/protocol	Adoption of Sustainable Agricultural Land Management (SALM)
Developed by	JOANNEUM RESEARCH in conjunction with Unique Forestry Consultants and funded by the World Bank
Contact	Neil Bird, Email: neil.bird@joanneum.at
Availability	Freely available from the VCS web
Website	www.v-c-s.org http://www.v-c-s.org/sites/v-c-s.org/files/VM0017%20SALM%20Methodolgy%20v1.0.pdf
2. Method/protocol description	
Purpose and user group	Designed for use by smallholders looking to get gains from carbon markets, VCS approved. The methodology is being used for the project “Western Kenya Smallholder Agriculture Carbon Finance project” in Kenya. The baseline study, monitoring and project document are being prepared by the Foundation Vi Planterar trad (“We plant trees”) with assistance from Unique Forestry Consultants Ltd., the Swedish International Agency (Sida) and the International Bank for Reconstruction and Development as Trustee of the Biocarbon Fund.
Geographic coverage	Can be used anywhere where studies demonstrate that the use of the RothC model is appropriate for: (a) the IPCC climatic regions of 2006 IPCC AFOLU Guidelines, or (b) the agroecological zone (AEZ) .
Ex-ante, project tracking or ex-post	The methodology covers all three.
Versions and release dates	Final version was accepted by the V-C-S on 22 December 2011.
General methodology	The methodology is a protocol for estimating and monitoring GHG emissions of project activities that reduce emissions in agriculture through the adoption of sustainable land management practices (SALM). It consists of a set of guidelines to estimate baseline and project emissions and removals, using measurements and monitoring plus modelling for SOC. The methodology uses input parameters to existing analytical models accepted in scientific publications (at the moment just RothC) for estimation of soil organic carbon. N_2O emissions from fertilizer use and carbon stocks in woody perennials follow CDM A/R methodologies. Protocol provides tools (equation-based) for calculating N_2O emissions from N-fixers and residue and for N_2O and CH_4 emissions from burning residue.
Ecosystems/management practices covered	The method can be applied to any sustainable land management practices in the agricultural landscape (but not wetlands). For example, manure management, use of cover crops, return of residues to land or introduction of trees. It primarily refers to crop management, land-use management and residue/waste management. It does not include direct emissions from livestock.
GHG emissions and carbon stock changes covered	Above-ground biomass in woody perennials (CO_2) Below-ground biomass in woody perennials (CO_2) Soil organic carbon (CO_2) Fertilizer use (N_2O) Nitrogen fixing species (N_2O) Biomass burning (CH_4, N_2O)
Non-LU emissions covered	Vehicle and machinery use (CO_2, CH_4 and N_2O)
Assistance in formatting data provided?	The methodology provides a sample activity baseline and monitoring survey.

Adoption of Sustainable Agricultural Land Management (SALM) continued

Indicators covered	This depends on the management practices adopted, but for the soil organic carbon stocks the methodology focuses on activities and then models the changes in carbon stocks, rather than measuring the changes in carbon stocks.					
Uncertainty, leakage and permanence	Guidance on estimating uncertainty is given for soil carbon only. The methodology provides guidance for the following forms of leakage a) Displacement of biomass from outside to inside the project boundary causing the depletion of soil organic carbon outside the project boundary b) Displacement of manure from outside to inside the project boundary causing an increase in the use of inorganic fertilizers or an increase in the amount of fossil fuel for cooking outside the project boundary c) Increase in the use of fuelwood from non-renewable sources for cooking and heating purposes due to the decrease in the use of manure and/or residuals as an energy source d) Increase in the use of fossil fuel for cooking and heating purposes due to the decrease in the use of manure and/or residuals as an energy source e) Increase in the combustion of fossil fuel by vehicles due to an increase in agricultural produce shipped to market as a result of the adoption of sustainable land management practices. No guidance on issues of permanence.					
Any analysis of economic or social impacts	No					
3. Application at the landscape scale						
Scale tool/method was designed for	The data are monitored at the farm level but are agglomerated to the sum of all participating farms (partial landscape level).					
How the tool/method can be applied at the landscape scale	Agglomeration of farm-level data. The methodology assumes that the farm-level activity is additive.					
4. Relevance to smallholders and developing country farmers						
Resources and constraints	The methodology requires a project participant/agglomerator that performs the monitoring of the individual farms. This organization must have the following skills • farm-level surveying • basic statistics • ability to use the RothC model • access to scientific libraries					
Groups it can be used by	Farmers cooperatives	Agricultural extension workers	Government staff without scientific training	Government staff with scientific training	Programme officers	Scientists
	maybe	yes	no	yes	yes	yes
5. Application of the method/protocol						
Acceptability to carbon markets	The methodology has been designed and accepted for use in the voluntary market www.v-c-s.org					
Uptake/usage of method/protocol	To date the project for which the methodology was designed is using it, plus there have been inquiries and detailed questions about modelling and applicability by two other organizations.					
6. Future plans						
	Unique Forestry Consultants and FAO have produced a web-based tool to identify available studies and potential applicability in many developing countries. The RothC model is one of the simpler SOC models and as such has limitations. Future plans include how to modify and adapt the model to fit specific agricultural management options rather than modifying the methodology. For example, RothC does not specifically address reduced tillage (at the moment).					

Carbon Benefits Project – Modelling Tools

1. Basic Information	
Name of the tool	Carbon Benefits Project – Modelling Tools
Developed by	Colorado State University in conjunction with partners from eight different countries
Contact	Eleanor Milne Email: Eleanor.Milne@colostate.edu Mark Easter Email: Mark.Easter@colostate.edu
Availability	Free of charge web-based tools.
Website	http://www.unep.org/climatechange/carbon-benefits/cbp_pim
2. Tool Description	
Purpose and user group	The tool was designed for GEF project managers to report to the GEF on impacts of land management projects on carbon stock changes and GHG emissions. It can however be used by anyone after registration.
Geographic coverage	The geographic coverage is worldwide, excluding a limited number of regions for which data needed to drive emissions equations are not available. These include areas covered with permanent snow and ice, bare rock, and tundra regions at the poles and at extreme elevations of mountainous regions.
Ex-ante, project tracking or ex-post	It includes tools that can be used for ex-ante analysis, project tracking or ex-post analysis. Ex-ante analysis can be best accomplished with the Simple Assessment. Project tracking and ex-post analysis may be accomplished with any of the tools.
Versions and release dates	A soft release of a development version of the Simple Assessment occurred in February,2012. A hard release is predicted for June, 2012. The Detailed Assessment will be released later in 2012. The Dynamic Modelling option is a modified version of the GEFSOC System, which was released in 2005. Updates are scheduled periodically through 2012.
General methodology	The CBP provides a suite of tools for measuring and modelling carbon balance in land-use management projects. The modelling tools comprise three options; 1. Simple Assessment 2. Detailed Assessment (based on the IPCC method) and 3. Dynamic Modelling Option (based on Century linked to a GIS). Options 1 & 2 are online tools, Option 3 is stand-alone software downloaded from the website. All three options utilize an online map facility to define project boundaries and activity areas. The tools compare a baseline and a project scenario to determine incremental carbon benefits. Option 1 uses IPCC defaults (analogous to a Tier 1 approach), Option 2 incorporates user defined emission factors (analogous to a Tier 2 approach). Also included are a guidance section providing help on monitoring strategies, field sampling etc., a costs benefit analysis and a DPSIR (social analysis).
Ecosystems/management practices covered	The toolkit covers all of the ecosystems classified in the IPCC GHG Inventory Methods for Agriculture, Forestry, and other Land Uses.
GHG emissions and carbon stock changes covered	GHG emissions: enteric methane, manure methane, manure nitrous oxide, rice methane, soil nitrous oxide, biomass burning, non-CO_2 emissions. Carbon stocks: forest land, grassland/savanna, annual cropland, perennial, cropland, agroforestry, settlements, deforestation, shifting cultivation, organic soil carbon in mineral soils, organic soil carbon in organic soils.
Non-LU emissions covered	No
Output format	All users create a PDF file summary report that provides information on project management followed by a summary of GHG emissions in two tables. A detailed report in an Excel file will be added soon. This will give spatially explicit output that can be input to a GIS and mapped.
Indicators covered	The tool provides an estimate of the total GHG balance of the project, presented in CO_2 equivalents.
Uncertainty, leakage and permanence	Uncertainty is calculated using the error propagation method recommended by the IPCC. Default or user-specific emission factors can be used. When addressing uncertainties it could be said that the tool highlights categories where a problem of permanence might arise, but no specific tools for permanence are included.
Any analysis of economic or social impacts	The toolkit includes a cost benefit analysis that allows the user to assess the greenhouse gas benefits of their projects on the basis of price per tonne of CO_2 equivalents. It also includes a DPSIR framework for assessing socio-economic issues.

Carbon Benefits Project – Modelling Tools continued

<table>
<tr><th colspan="7">3. Application at the landscape scale</th></tr>
<tr><td>Scale tool/method was designed for</td><td colspan="6">GEF projects vary in scale, so the tools have been designed for use at any scale. The Simple and Detailed Assessments are designed to work on areas from a few ha to approximately ten million ha. The Dynamic Modelling option has been used at the landscape to subnational scale, but again can be applied at any scale if data are available.</td></tr>
<tr><td>How the tool/method can be applied at the landscape scale</td><td colspan="6">The first step to using the system is to define the geographic boundary of the project and then identify within this where land management activities are taking place. The user either draws polygons on screen on a web-based map, defines points, or uploads a GIS file. The size of these ‘Project Activity Areas’ is determined by the user. In doing this the user can capture multiple areas of different land-use activity within a single landscape and carry out a landscape-scale assessment. The process is repeated for the initial land use, a baseline scenario and a project scenario. For the Simple Assessment and the Detailed Assessment, management information is then entered for each area or group of areas for seven different land-use categories and livestock.</td></tr>
<tr><th colspan="7">4. Relevance to smallholders and developing country farmers</th></tr>
<tr><td>Resources and constraints</td><td colspan="6">The Simple Assessments can be used with the sorts of activity data a land management project is likely to have anyway. The tool is online and no specific expertise is needed beyond understanding of land management issues. For the Detailed Assessment, local datasets and measurements can be used to improve estimates so costs and expertise associated with field sampling can apply. For the Dynamic Modelling option, expertise in GIS and ecosystem modelling are required. The tool is available in English, Spanish and Chinese.</td></tr>
<tr><td>Groups it can be used by</td><td>Farmers cooperatives</td><td>Agricultural extension workers</td><td>Government staff without scientific training</td><td>Government staff with scientific training</td><td>Programme officers</td><td>Scientists</td></tr>
<tr><td></td><td>yes</td><td>yes</td><td>no</td><td>yes</td><td>yes</td><td>yes</td></tr>
<tr><th colspan="7">5. Application of the tool</th></tr>
<tr><td>Acceptability to carbon markets</td><td colspan="6">The toolkit is not certified at the moment. The tools would be useful in scoping the suitability of a project for certification.</td></tr>
<tr><td>Uptake/usage of tool</td><td colspan="6">During development ten workshops were held, which involved between 20 and 30 people each. The Simple Assessment is currently being used in case study projects in Brazil, China (two projects), Kenya and Niger/Nigeria.</td></tr>
<tr><th colspan="7">6. Future plans</th></tr>
<tr><td></td><td colspan="6">A database of biometry measurements from agroforestry, reforestation, and afforestation projects will be available in late 2012. French and Brazilian Portuguese versions of the tool will be added.</td></tr>
</table>

Carbon Benefits Measurement Tools

1. Basic Information	
Name of the tool	Carbon Benefits Measurement Tools
Developed by	Michigan State University, in partnership with the World Wildlife Fund and the World Agroforestry Centre.
Contact	Mike Smalligan, Email: smallig2@msu.edu
Availability	The CBP Measurement Tool is free and can be accessed from the projects website. Some aspects require a workflow to be carried out in a remote sensing or GIS facility and some of the modelling uses workflows that are done 'off the web'. The basic tool contains the protocols, but the workflows are only semi-automated.
Website	http://www.unep.org/climatechange/carbon-benefits/ or http://www.goes.msu.edu/cbp/
2. Tool Description	
Purpose and user group	The tool was designed for GEF project managers to report to the GEF on impacts of land management projects, on carbon stock changes and GHG emissions. Potential users include the UN-REDD, offset projects in LULUCF and monitoring and evaluation activities for any agency.
Geographic coverage	Intended for global coverage applicable in all countries of the world. Where there exist data limitations, the tools provide guidelines for collecting new data.
Ex-ante, project tracking or ex-post	Ex-ante analysis, ongoing monitoring throughout the lifecycle of a project, and also ex-post analysis of project activities.
Versions and release dates	The CBP Measurement Tools will be released in 2012. Subsequent versions are intended but do not have anticipated release dates.
General methodology	The measurement system provides the means to measure carbon stocks and stock changes directly, using a combination of remote sensing observations, ground calibration, and web-enabled GIS. The system also provides estimates of CH_4 and N_2O from direct field and remote sensing measurements. This approach allows for large area landscape assessments of carbon for REDD, A/R, and agroforestry systems at very high spatial resolution.
Ecosystems/management practices covered	Primarily focused on forests, agroforestry, woodlands, savannas and landscapes with trees outside of forests. It is also applicable in croplands, grasslands, wetlands, and settlements.
GHG emissions and carbon stock changes covered	Soil organic carbon and above- and below-ground woody biomass, the three primary terrestrial carbon pools (litter and dead wood are typically smaller pools and not covered explicitly). The tools also include guidelines for measuring non-CO_2 greenhouse gases like nitrous oxide and methane.
Non-LU emissions covered	No
Output format	Standard report (PDF file). Also online displays of data.
Indicators covered	tCO_2e sequestered, changes in hectares from land without trees to land with trees (criteria vary for each module), tCO_2e sequestered/$ invested. Module 5 is specifically to provide landscape indicators of carbon benefits including land cover index, tree crown area index, carbon stock index, fire risk index, watershed index, social, economic and biodiversity index.
Uncertainty, leakage and permanence	The user can calculate uncertainty using the IPCC error propagation method. The remote sensing components of the tool are applicable to monitoring leakage outside the project boundaries. The tools do not define leakage but allow each project to define leakage according to selected carbon standards or project requirements. The tools address risk rather than permanence.
Any analysis of economic or social impacts	The tools are compatible with ecosystem services and economic analysis. They do not have direct guidance for other ecosystem services or economic analysis; however, they provide broad core indicators that can be calculated for project monitoring and a tool for assessing social co-benefits under the CCBA criteria.
3. Application at the landscape scale	
Scale tool/method was designed for	Landscape scale (large GEF projects covering thousands of ha); can be applied at any scale where local field inventories are related to RS.
How the tool/method can be applied at the landscape scale	The CBP Measurement Tools require field sampling throughout the landscape to allow for statistical analysis of strata within the landscape. Minimal ground sampling is then scaled up to landscape and regional levels through remote sensing analysis of both soil organic carbon stocks and woody biomass carbon stocks.

Carbon Benefits Measurement Tools continued

4. Relevance to smallholders and developing country farmers						
Resources and constraints	The SOC measurement protocol requires vehicles, skilled labour, specialized soil sampling tools, GPS devices, desktop computers, specialized software, laboratories equipped with near infrared spectroscopy, or access to external soil analysis laboratories. The non-CO_2 GHG measurement protocol requires vehicles, skilled labour, GPS devices, specialized field sampling gas exchange chambers, gas sampling equipment, a nitric oxide monitor, desktop computers, specialized software, and labs equipped with a gas chromatograph. The woody biomass measurement protocol requires vehicles, skilled labour, standard forest inventory equipment, specialized forest inventory tools, GPS devices, access to free and commercial satellite data, high power computers with extensive storage capacity, specialized RS software, technical capacity for RS and GIS, and access to a lab for plant tissue analysis. The online MRV system requires computer servers, geospatial databases, extensive knowledge in GIS, and extensive computer programming skills.					
Groups it can be used by	Farmers cooperatives	Agricultural extension workers	Government staff without scientific training	Government staff with scientific training	Programme officers	Scientists
	yes with training	yes with training	yes with training	yes	yes	yes
5. Application of the tool						
Acceptability to carbon markets	The CBP Measurement Tools are compatible with regulatory markets and voluntary market standards but they have not been reviewed or directly approved by any market or standard.					
Uptake/usage of tool	Tools not yet released					
6. Future plans						
	The developers of the Carbon Benefits Project intend to support and revise the tool as ongoing GEF support allows.					

The GHG (greenhouse gas) mitigation potential from the agricultural sector is set to increase in coming decades. Much of the agricultural mitigation potential lies in developing countries where systems are dominated by smallholder farmers. There is therefore an opportunity for smallholders not only to gain environmental benefits from carbon friendly practices, but also to receive much needed financial input, either directly from carbon financing, or from development agencies looking to support carbon friendly activities. However, the problem remains of how to quantify carbon gains from mitigation activities carried out by smallholder farmers.

This paper gives an overview of approaches that have been taken to date for landscape-scale GHG quantification, covering both measurement and modelling and the reliance of one upon the other. This is followed by an analysis of some of the resources that are available for those wishing to do GHG quantification at the landscape scale in areas dominated by smallholders.

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