Chapter 1
Introduction

Authors:

Marlen Eve, U.S. Department of Agriculture, Office of the Chief Economist

Mark Flugge, ICF International

Diana Pape, ICF International

Contents:

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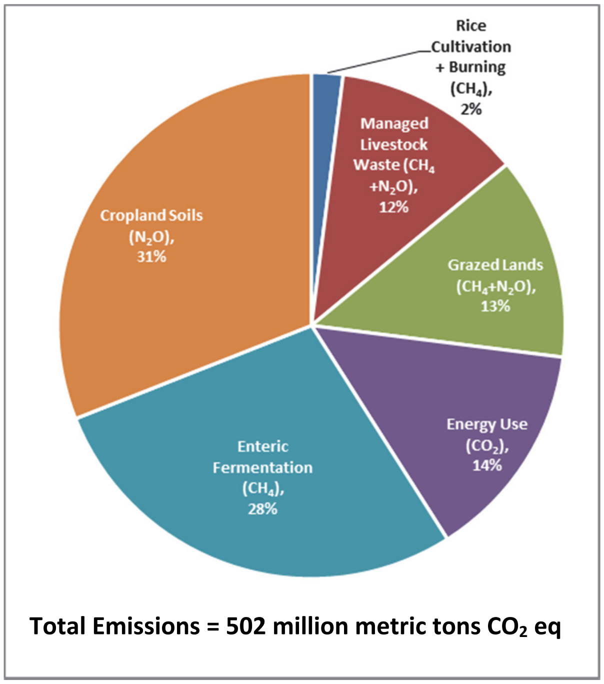
Acronyms, Chemical Formulae, and Units

C	Carbon
CH_4	Methane
CO_2	Carbon dioxide
CO_2-eq	Carbon dioxide equivalents
EO	Executive Order
EPA	U.S. Environmental Protection Agency
GHG	Greenhouse gas
ISO	International Organization for Standardization
LCA	Life cycle assessment
LCI	Life cycle inventory
N_2O	Nitrous Oxide
USDA	U.S. Department of Agriculture

1 Introduction

In 2008, agriculture contributed 6.1 percent of the total greenhouse gas (GHG) emissions in the United States (USDA, 2011).[1] The distribution of emissions across the agriculture sector is illustrated in Figure 1-1. In addition, forestry sequestered enough carbon to offset about 13 percent of total U.S. GHG emissions (USDA, 2011). Since the late 1990s, the U.S. Department of Agriculture (USDA) has analyzed and reported GHG emissions and removals via national-scale inventories, and field-scale measurement of these fluxes has been done for decades by USDA researchers. USDA also has done significant work in the development of GHG estimation models and tools within the agriculture and forestry sectors.

Figure 1-1: Agriculture Sources of Greenhouse Gas Emissions in 2008[a]



[a] Cropland soils emissions include emissions from major crops; non-major crops; histosol cultivation; and managed manure that accounts for the loss of manure nitrogen during transport, treatment, and storage, including volatilization and leaching/runoff.
Source: USDA (2011).

This report provides methods and a scientific basis for estimating GHG emissions and sequestration at the landowner, land-manager scale—entity scale. The report was authored by recognized experts from across USDA, other U.S. Government agencies, and academia and reflects estimation methods that balance scientific rigor, scale, practicality, and availability of data.

This chapter provides an overview of the report as well as the objectives set out for the project and the process used in developing the report. The remainder of the chapter is organized as follows:

- Overview of the Report
- Report Objectives
- Process for the Development of the Methods
- Contents of the Report
- Uses and Limitations of the Report
- Chapter 1 References

[1] Here the agriculture sector includes GHG emissions and removals from livestock, grasslands, croplands, and energy use on farms; it does not include GHG emissions and removals from industrial processes (e.g., fertilizer production) or from off-farm energy use (e.g., transportation fuels used in exporting commodity crops).

1.1 Overview of the Report

Under provision of Section 2709 of the Food, Conservation, and Energy Act of 2008, USDA has been directed to "establish technical guidelines that outline science-based methods to measure the environmental service benefits from conservation and land management activities in order to facilitate the participation of farmers, ranchers, and forest landowners in emerging environmental services markets." The legislation further states that the initial emphasis of the methods development should focus on GHG emissions. Agreement on that set of methods is the primary scope and purpose for this report. The findings in this report provide the foundation for entity-level tools to measure the GHG benefits from conservation and land management activities.

This report and the estimation methods are not intended as an addition to or replacement of any current Federal or State GHG reporting systems or requirements. This report has been prepared to outline methods to calculate direct GHG emissions and carbon sequestration from agriculture and forestry processes and builds upon existing inventory efforts such as U.S. Environmental Protection Agency (EPA) and USDA's national inventories and the U.S. Department of Energy's Voluntary Greenhouse Gas Reporting Program Section 1605(b) Guidelines, with an aim of providing simple, transparent, and robust inventory and reporting methods.

The report provides technical methods for estimating and reporting GHGs from significant agriculture and forestry sources and sinks. These methods are designed to quantify significant emissions and sinks associated with specific source categories as well as annual reductions in those emissions or fluxes in carbon storage resulting from land-use change and land management practices and technologies. Therefore, the report will support the development of entity-, farm-, or forest-scale GHG estimates and inventories.

Because the report is intended as a means of evaluating management practices across the full scope of the farm, ranch, and forest management system, the methods in the report need to be as comprehensive as possible. Research and data gaps exist that result in some management practices not being accounted for or are reflected in higher levels of estimate uncertainty. Completeness is important, though, and the report attempts to identify the most significant research gaps and data needs.

The methods were developed according to several criteria in order to maximize their usefulness. In particular, the methods must:

1. Stand on their own, independent of any other accounting system, yet maintain consistency with other accounting systems to the maximum extent possible;
2. Be scalable for use at entity-scale sites across the United States, with applicability at county and/or State levels as well;
3. Facilitate use by USDA in assessing the performance of conservation programs;
4. Provide a broad framework to assess management practices to evaluate the GHG aspect of production sustainability;
5. Maintain maximum applicability for use in environmental markets, including possible future Federal, State, or local GHG offsets initiatives;
6. Be scientifically vetted through USDA, U.S. government, and academic expert review and public comment;
7. Provide reliable, real, and verifiable estimates of on-site GHG emissions, carbon storage, and carbon sequestration (methods will be designed so that over time they can be applied to

quantify on-site GHG reductions and increases in carbon storage due to conservation and land management activities); and

8. Provide a basis for consistency in estimation and transparency in reporting.

1.2 Report Objectives

The objectives for this report are to create a standard set of GHG estimation methods for use by USDA, landowners, and other stakeholders and to serve as input into the development of USDA estimation tools. The methods presented in the report address GHG emissions and carbon removal for the entire entity or operation and provide the opportunity to assess individual practices or management decisions.

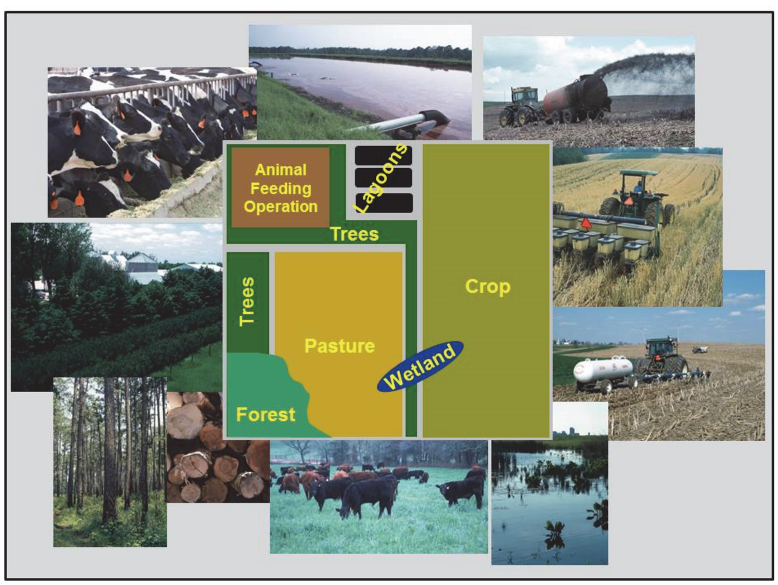
> *Greenhouse Gas Mitigation Options and Costs for Agricultural Land and Animal Production within the United States* covers mitigation practices in crop production, animal production, and land retirement systems in the United States. This report reviews available scientific methods for estimating GHG sources and sinks at an entity level and recommends particular estimation methods for each livestock type and agriculture/forestry practice. To estimate the costs, USDA has developed another report that estimates the implementation costs, GHG mitigation potential at the farm level, and break-even prices (i.e., GHG incentive) for different mitigation practices on a farm level.
>
> The report is available for download on the project website at: http://www.usda.gov/oce/climate_change/mitigation_technologies/GHGMitigationProduction Cost.htm.

A co-objective is to establish consensus on a standardized set of methods for the Department, which become the scientific basis for entity-scale estimation of the GHG impacts of landowner management decisions. Therefore, scientific rigor and transparency are also critical.

While USDA has long been involved in development of GHG inventories and estimation tools, this report brings together estimation approaches from all agriculture and land management sectors into one place. These methods are combined in such a way that an integrated estimate can be derived for all activities within the boundary of the farm and forest management operation. Figure 1-2 shows the diversity of activities and the complexity of estimating GHG emissions and carbon sequestration across the entire management entity.

Figure 1-2: Conceptual Diagram of Activities Covered in This Report

Combining a landowners' crop, livestock and forest management activities into a seamless greenhouse gas estimate for the entity.



Source: Eve (2012).

1.3 Process for the Development of the Methods

This report was developed by three author teams (i.e., working groups) under the direction of one lead author for each team (plus one co-lead author for the forestry chapter). The lead authors were chosen based on their experiences with GHG inventories and accounting methodologies and their professional research experiences. With input from each lead author, USDA chose 10 to 13 working group members per team to write the report. These working group members each had different backgrounds that fit with the anticipated content of the document. Members also had experience with GHG accounting and/or field research that was unique and addressed one or more of the niche methods that were essential for ensuring the comprehensiveness of the methods for each sector. The author teams were provided with a preliminary outline of a chapter and two background reports developed as part of the project. One background report was an analysis of the scientific literature related to rates of carbon sequestration or emissions reduction resulting from various management practices and technologies (Denef et al., 2011); the other was a compilation of all of the available tools, protocols, and models and basic information on each one (Denef et al., 2012). Both reports are available for download on the project website at: http://usda.gov/oce/climate_change/estimation.htm.

There are several general ways to estimate GHG emissions and sequestration at an entity scale, and each approach gives varying accuracy and precision. Typically, the most accurate way to estimate GHG fluxes is through direct measurement, which often requires expensive equipment or techniques that are not feasible for a single landowner or manager.[2]

Lookup tables and estimation equations can be much simpler to implement and use, but when used alone may not adequately represent local variability or local conditions. This report attempts to delineate methods that balance user friendliness, data requirements, and scientific rigor in a way that is transparent and justified.

Figure 1-3 illustrates the scope of the GHG emission sources and removals and processes in managed ecosystems that these methods estimate.

The author teams considered the following general approaches in deriving the methods for this report:

- Basic estimation equations – Involve combinations of activity data[3] with parameters and default emission factors.[4] Any default parameters or default emission factors (e.g., lookup tables) are provided in the text, or if substantial in length, in an accompanying (or referenced) compendium of data.

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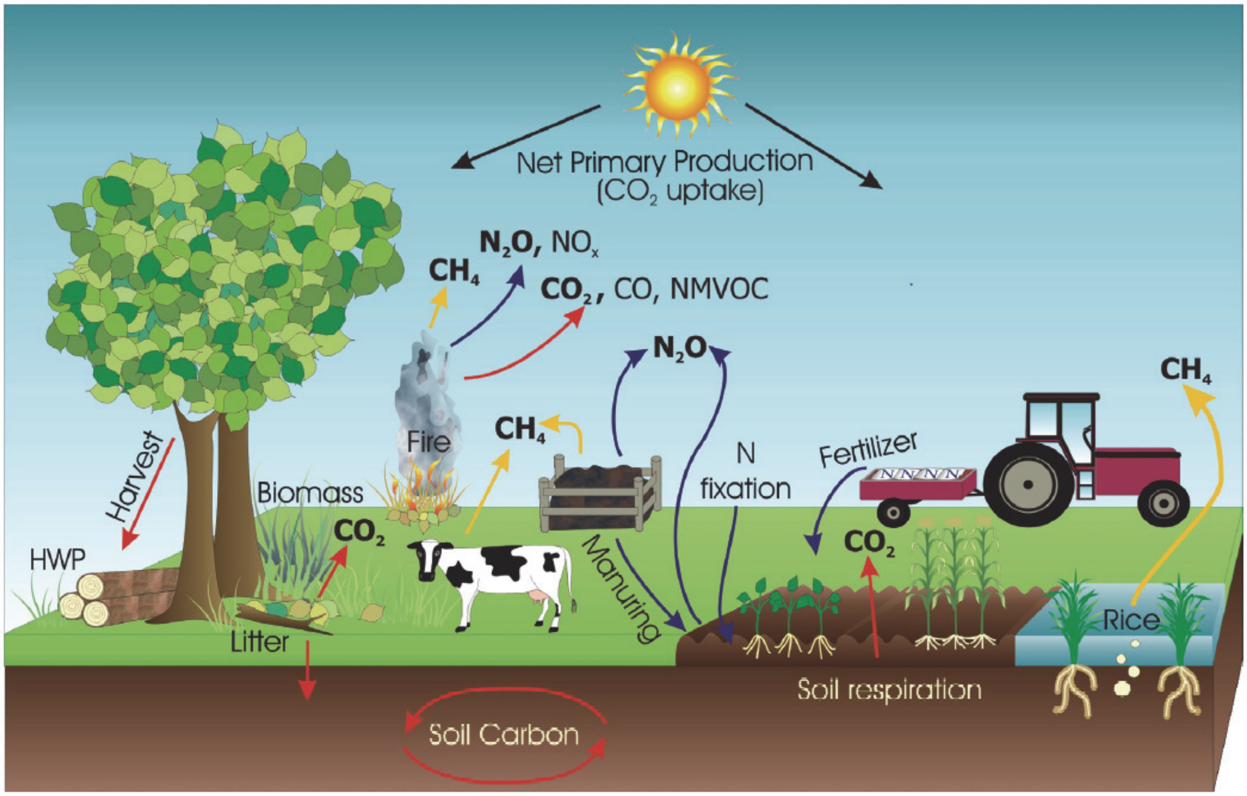
[2] Examples include intermittent measurement of soil organic carbon and biomass reserves. Estimates of flux for dynamic process measures like N_2O emissions need to be based on multiple measures taken at reasonable frequency. Direct measurement may work for comparative analysis but must be extended to estimate total emissions using assumptions or modeling method.

[3] Activity data is defined as data on the magnitude of human activity resulting in emissions or removals taking place during a given period of time (IPCC, 1997).

[4] Emission factor is defined as a coefficient that quantifies the emissions or removals of a gas per unit of activity. Emission factors are often based on a sample of measurement data, averaged to develop a representative rate of emission for a given activity level under a given set of operating conditions (IPCC, 2006).

Figure 1-3: Greenhouse Gases Emission Sources/Removals and Processes in Managed Ecosystems



Source: Paustian et al. (2006).
NMVOC= non-methane volatile organic compounds

- Models – Use combinations of activity data with parameters and default emission factors. The inputs for these models can be ancillary data[5] (e.g., temperature, precipitation, elevation, and soil nutrient levels that may be pulled from an underlying source), biological variables (e.g., plant diversity), or site-specific data (e.g., number of acres, number of animals). The accuracy of the process model is dependent on the robustness of the model and the accuracy of the inputs.
- Field measurements – Actual measurements that a farmer or landowner would need to take to more accurately estimate the properties of the soil, forest, or farm or to estimate actual emissions. Measuring actual emissions on the land requires special equipment that monitors the flow of gases from the source into the atmosphere. This equipment is not readily available to most entities, so more often, field measurements are incorporated into other methods described in this section to create a hybrid approach. A field measurement such as a sample mean tree diameter could be incorporated into other models or equations to give a more accurate input.
- Inference – Uses State, regional, or national emissions/sequestration factors that approximate emissions/sequestration per unit of the input. The input data is then

[5] Ancillary data is defined as additional data necessary to support the selection of *activity data* and *emission factors* for the estimation and characterization of emissions. Data on soil, crop or animal types, tree species, operating conditions, and geographical location are examples of ancillary data.

multiplied by this factor to determine the total onsite emissions. This factor can have varying degrees of accuracy and may not capture the mitigation practices on the farm or the unique soil conditions, climate, livestock diet, livestock genetics, or any farm-specific characteristics, unless they are developed for specific soil types, livestock categories, or climactic regions, etc.

- Hybrid estimation approach – An approach that uses a combination of the approaches described above. The approach often uses field measurements or models to generate inputs used for an inference-based approach to improve the accuracy of the estimate.

With this background, and evaluating these and other data and resources, each author team developed the text for its chapter. Development of the text has been iterative as various drafts of the document have been put through several review stages. The review process for the report of methods consists of:

- *USDA Technical Review*. USDA performed an intra-agency review. The result of this review was a series of comments and questions for the lead authors and their working groups. These comments were received by, discussed within, and responded to by the working groups and lead authors. For example, one specific outcome of this review process was a nitrous oxide (N_2O) Cropping Practices Workshop consisting of 20 experts in the field of N_2O emissions from croplands and grazing lands. The workshop was convened to review the methods that were originally proposed by the working group and to determine if there was a more scientifically rigorous method to quantifying N_2O emissions from agricultural soils.
- *Inter-agency Technical Review*. The May 2012 version of the report was circulated for review by an inter-agency group of GHG emissions and inventory experts. The reviewers included over 50 members from nine agencies including USDA, U.S. Department of Energy, U.S. Department of the Interior, EPA, U.S. Department of State, and several of the White House Offices. The result of this review was a series of comments and questions for the lead authors and their working groups. These comments were received by, discussed within, and responded to by the working groups and lead authors.
- *Scientific Expert Review*. Following the inter-agency review, the next version of the report was reviewed by a team of scientific experts. The reviewers were chosen based on recognized expertise, experience in expert reviews, availability, and willingness to participate. Each reviewer was asked to review those chapters and/or sections of the report relating to his or her expertise. A subset of the group of expert reviewers was asked to review the report in its entirety and provide comments specifically regarding issues of consistency, completeness, and accuracy. Again, the lead authors and author teams responded to each of the comments posed by the expert panel and edited the document as appropriate.
- *Public Comment Period*. Once all of the expert comments were addressed and appropriate edits were made, the report was made available for public comment. This coincided with a final review by USDA and other Federal agency GHG experts. Comments from this review were assessed, and the report was edited as necessary prior to final publication of the report.

How to Use the Report

In order to accomplish the objectives noted above, the report is laid out by broad land-use sector (i.e., croplands and grazing lands, wetlands, animal production, and forestry). Each sector chapter is further delineated into two main parts: first the current scientific understanding and available data for estimating GHG fluxes within the sector; second, the methods that demonstrate the current best approach to estimating GHG fluxes, balancing the available science and data with the criteria and considerations mentioned previously. The report is intended to be considered in its entirety with contextual information provided in the first and second chapters as background to the content presented in the following chapters. The authors realize that many users may find specific chapters or sections especially valuable or useful; therefore, summarized contextual information is also included at the beginning of each chapter. The beginning to the croplands and grazing lands, wetlands, animal production, and forestry chapters include tables that summarize the methods for each source or removal of GHG emissions. The subsequent sections in the report are organized according to the sources mentioned in the summary table.

1.4 Contents of the Report

The remainder of the report is organized by sector. For each sector, background and information on management practices are presented first, followed by the detailed methods proposed for estimating emissions and sequestration for those practices. Each of the chapters is summarized as follows:

- **Chapter 2: Considerations When Estimating Agriculture and Forestry GHG Emissions and Removals.** Chapter 2 sets the context for the methods, including linkages and cross-cutting issues that span the sectors. This includes, for example, definition of entity, definition of system boundaries, etc.
- **Chapter 3: Quantifying Greenhouse Gas Sources and Sinks in Cropland and Grazing Land Systems.** Chapter 3 describes the GHG emissions from crop and grazing land systems. The chapter presents methods for estimating the influence of land use and management practices on GHG emissions (and sinks) in crop and grazing land systems. Methods are described for estimating biomass and soil carbon stocks changes, direct and indirect soil N_2O emissions, methane (CH_4) and N_2O emissions from wetland rice, CH_4 uptake in soils, carbon dioxide (CO_2) emissions or sinks from liming, non-CO_2 GHG emissions from biomass burning, and CO_2 emissions from urea fertilizer application.
- **Chapter 4: Quantifying Greenhouse Gas Sources and Sinks in Managed Wetland Systems.** Chapter 4 provides guidance for estimation of carbon stock changes, CH_4, and N_2O emissions from actively managed wetlands.
- **Chapter 5: Quantifying Greenhouse Gas Sources and Sinks in Animal Production Systems.** Chapter 5 describes on-farm GHG emissions from the production of livestock and manure management. The chapter presents GHG estimation methods appropriate to the production of each common livestock sector (i.e., beef, dairy, sheep, swine, and poultry), with methods related to manure management combined for all livestock types.
- **Chapter 6: Quantifying Greenhouse Gas Sources and Sinks in Managed Forest Systems.** Chapter 6 provides guidance on estimating carbon sequestration and GHG emissions for the forestry sector. The chapter is organized to provide an overview of the elements of forest carbon accounting, including definitions of the key carbon pools and basic methods for their estimation.

- **Chapter 7: Quantifying Greenhouse Gas Sources and Sinks from Land-Use Change.** Chapter 7 provides guidance on estimating the net GHG flux resulting from changes between land types—i.e., conversions into and out of cropland, wetland, grazing land, or forestland—at the entity scale.
- **Chapter 8: Uncertainty Assessment for Quantifying Greenhouse Gas Sources and Sinks**. Chapter 8 provides a framework for a Monte Carlo assessment of estimation uncertainty.

The report also describes methods for uncertainty assessment for each source as well as for the estimate in total. The authors recognize that for some sources, current data are not complete enough to allow for a reliable statistical estimate of uncertainty. In some cases, expert judgment was used to delineate estimated uncertainty bounds. In other cases, the report simply notes that more data are required to reliably estimate uncertainty. Each sector chapter of the report contains a section on uncertainty and limitations.

The authors acknowledge that for many practices and technologies, adequate data do not currently exist to accurately estimate GHG emissions and/or carbon sequestration. For each sector, the authors have included a discussion of research gaps or priority areas for future data collection that are important in order to improve the completeness or accuracy of the estimation methods put forth in this report.

1.5 Uses and Limitations of the Report

Specific potential uses of the methods include aiding:

1. Landowners and other stakeholders in quantifying increases and decreases in GHG emissions and carbon sequestration associated with changes in land management;
2. USDA in understanding GHG and carbon sequestration increases and decreases resulting from current and future conservation programs and practices; and
3. USDA and others in evaluating and improving national and regional GHG inventory efforts.

The report will provide additional cobenefits. For example, the report may provide improved methods for voluntary GHG registries, help to facilitate regional GHG markets, or inform existing and/or future GHG reporting programs (e.g., sequestration/emissions from land use and agriculture under Executive Order [EO] 13514).[6]

These methods are designed to provide the most appropriate, single, accounting method for quantifying GHG emissions/sequestration for each particular source category (e.g., CH_4 from rice cultivation) determined from the activity data, published emission factors, and accounting methods and tools typically available for the entity scale. These methods are **not** designed to provide a range of emission/sequestration accounting options, or a range of similar options, at varying levels of complexity (i.e., tiers) for each particular source category. That said, there may be specific instances (e.g., forest carbon stocks) where different individual options might be specified for entities within

[6] It should be noted that under EO13514, agency-level reporting of emissions and sequestration as a result of land management practices is not required at this time. In addition, reporting of emissions from wildfire management, prescribed burning, land use, and land-use changes is not required. Agencies choosing to report activities undertaken to date in calculating such emissions would address them in the qualitative portion of their GHG inventory. Emissions resulting from manure management and enteric fermentation when the animals are owned by the Federal agency would be reported voluntarily in scope 1 at this time. If the activities take place on Federal land, but are operated by others, these emissions may be voluntarily reported as scope 3.

source categories where there are significantly different operational scales (e.g., commercial forest plantations versus small woodlots).

This report is designed to provide GHG accounting methods to determine actual GHG emissions at the entity scale (i.e., an emissions inventory) and/or to quantify the emission (or emission reductions) associated with an existing or future mitigation practice/technology. At the time of this writing, the United States does not have a national policy guiding GHG emissions reduction, monitoring, or crediting in the agriculture and forestry sectors. Presented are the recommended methods for quantifying GHG emissions and emission reductions. The report is **not** intended as an accounting framework for emission reduction crediting or trading—i.e., the methods do not constitute an offset protocol. As a result, this report does **not** provide specific guidance on critical policy features of such offset protocols including additionality, permanence, and leakage. Any national policy would provide precise definitions of these terms, and then the methods described in this report would be adapted to conform to policy standards and requirements.

As stated above, this report does not address policy issues related to crediting reductions such as permanence, additionality, or leakage. The intended purpose is simply to provide a quantitative estimate of what is occurring under a given set of practices and activities, or what could be expected to occur given a change in management. While the report is not addressing policy issues, it may address practical concerns around GHG estimation, such as the risk of reversal if management practices revert back in the foreseeable future. For example, a land manager must understand that a change in management that results in soil carbon sequestration, if reversed, will lead to the extra stored carbon likely being rereleased to the atmosphere. For the context of this report, we are most concerned with “what the atmosphere sees” or what the long-term net effect is to GHG levels in the atmosphere.

The source categories covered in the report are specific to the agriculture and forestry sectors (e.g., croplands, grazing lands, managed wetlands, animal agriculture, and forestry). The report does not approach emissions from these sources from a life-cycle perspective. In other words, the report does **not** include source categories that are associated with management activities related to certain agriculture and forestry activities (e.g., transportation, fuel use, heating fuel use), upstream production (e.g., animal feed production, fertilizer manufacture), or downstream (e.g., wastewater treatment, pulp and paper manufacture, or landfills). As a result, the report does **not** provide GHG accounting methods for sectors including: energy and industrial processes (e.g., fertilizer production).

The report also does **not** include emissions from stationary source combustion (e.g., burning heating oil or natural gas to heat animal housing) or mobile source combustion (e.g., fuel use in vehicles) at this time. However, where there are obvious changes in the level of combustion due to a change in practices, that change is qualitatively discussed. For example, a shift from conventional tillage to no till can result in a large reduction in fuel consumption because of fewer trips across the field. These relationships are noted qualitatively in the report, but quantitative methods are not proposed. Methods for quantifying emissions from stationary or mobile combustions are available from other Federal agencies.

The scope of this report is assessing the impact of specific decisions made by the farm or forest manager within the confines of the farm or forest gate. A life-cycle perspective, while valuable, is outside the scope of this report. A life-cycle assessment (LCA) is a useful tool for quantification of environmental impacts and benefits on a basis that allows for analysis of environmental burden shifting and trade-offs between different options. LCAs include the environmental impact of management decisions during product manufacturing and processing of raw inputs to, as well as products output from, the farm or forest system, continuing through its use by the end consumer.

The methodologies presented in this report do not constitute an LCA, but support several components of LCAs. For example, this report covers emissions (e.g., from croplands) that could be used as part of an attribution LCA for a commodity crop product, or used as part of a consequential LCA studying the impacts of agricultural policy decisions on GHG mitigation potential.

The text box below provides further information on LCAs as they relate to quantifying GHG sources and sinks in agriculture and forestry systems, including background information on the purpose of LCAs, the LCA process, the interpretation of LCA results, and current LCA efforts by USDA and other organizations related to agriculture and forestry.

Life Cycle Assessment

An LCA is a tool for addressing the environmental aspects (e.g., use of resources) and potential environmental impacts (e.g., global warming potential) throughout the life-cycle of a product or material. When applied to agriculture and forestry products, the scope of an LCA would likely include upstream impacts from extraction and production of material inputs (e.g., fuels, fertilizers); the environmental impacts of management decisions during crop, livestock, or tree growth on site; and the outputs from the farm or forest system, including the downstream impacts from use and disposal by the end consumer. The accounting boundary of GHG emission sources and sinks quantified in an LCA for an agricultural or forest consumer product would extend beyond the accounting boundary of the methodologies presented in this report. For example, an LCA for a grain product would not only include N_2O emissions from fertilizer application, but also other upstream inputs such as emissions from synthetic fertilizer production, and downstream impacts such as emissions from grain transportation and storage, processing, use, and disposal.

The International Organization for Standardization (ISO) has established several international standards addressing LCA, including ISO 14040 (ISO, 2006a) describing the principles and framework for LCAs, ISO 14044 (ISO, 2006b) addressing LCA requirements and guidelines, and ISO 14048 (ISO, 2002) presenting a standardized LCA data documentation format.[a] As defined in ISO 14040 (ISO, 2006a), the LCA development process includes the following primary steps: defining the goal and scope; conducting a life-cycle inventory (LCI) analysis by gathering data and quantifying all relevant inputs and outputs of the product system, as defined in the scope of the study; conducting a life-cycle impact assessment through evaluation of the significance of the environmental impacts defined in the scope of the study and determined during the LCI process; and interpreting the results (ISO, 2002; 2006a; 2006b). USDA has several initiatives applying LCAs to agriculture and forestry.

- USDA's National Agricultural Library has developed the LCA Digital Commons Project, a database and tool intended to provide LCI data for use in LCAs of food, biofuels, and other bio-products. The database currently includes data on inputs (e.g., fertilizers) and outputs (e.g., air emissions, residues) per unit of field crop production from 1996–2009 for corn, cotton, oats, peanuts, rice, soybeans, and wheat (durum, spring, and winter) in States covered by the USDA Economic Research Service annual Agricultural Resource Management Survey. Future phases of this work will include the addition of data representing irrigation, manure management, farm equipment operation, crop storage, transport, and production of mineral and organic fertilizers, herbicides, insecticides, and fungicides.

(continued)

Life Cycle Assessment (continued)

- USDA also recently worked with the National Cattlemen's Beef Association and the chemical company BASF in the development of an eco-efficiency assessment for the U.S. beef industry by quantifying life-cycle inputs and outputs for beef production over time. The process involved measuring the life-cycle environmental impacts and life-cycle costs for different beef production processes at a defined level of output. The USDA Agriculture Research Service's Integrated Farm System Model was used to estimate environmental impacts (e.g., air emissions, water use, abiotic depletion potential, toxicity, etc.) based on data from the USDA's Roma L. Hruska Meat Animal Research Center (Battagliese et al., 2013).

Beyond USDA, other LCAs and studies related to quantifying environmental impacts from agriculture and forestry products have been published. Below is a list of recent studies, projects, or resources that use LCAs or could be used in the development of LCAs to evaluate climate impacts from agriculture and forestry.

- The Innovation Center for U.S. Dairy analyzed fluid milk, cheese, and dairy processing and packaging. These data have recently been made publicly available through the USDA's LCA Digital Commons database.[b]
- The Innovation Center for U.S. Dairy developed the FarmSmart tool that compares energy use, GHG emissions, and water use against regional and national averages. The tool takes approximately 20 minutes to complete and will have enhanced decision support features added in 2014.[c]
- The National Pork Board funded a study of pork products conducted by researchers at the University of Arkansas.[d]
- The United Kingdom's Carbon Trust developed a "carbon footprinting" methodology that has been used by the grocery chain Tesco to determine the life-cycle GHG impacts of many of their products.[e]
- The United Kingdom Food Climate Research Network maintains a compendium of food LCAs.[f]
- Kumar Venkat of CleanMetrics Corp. compared 12 organic and conventional farming systems from a life-cycle GHG emissions perspective using agricultural production data from the University of California-Davis.[g]
- Field to Market prepared a report presenting environmental and socioeconomic indicators for measuring outcomes from on-farm agricultural production in the United States.[h]
- A coalition of food industry companies, academic organizations, and non-governmental organizations created The Cool Farm Tool, a GHG calculator designed to help farmers reduce emissions.[i]

(continued)

[a] See http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_tc_browse.htm?commid=54854.
[b] See http://www.usdairy.com/sustainability/Greenhouse%20Gas%20Projects/Pages/ProcessingandPackagingLCA.aspx and http://www.lcacommons.gov/?q=node/16.
[c] See http://www.usdairy.com/FarmSmart/Pages/Home.aspx.
[d] See http://www.pork.org/filelibrary/NPB%20Scan%20Final%20-%20May%202011.pdf.
[e] See http://www.carbontrust.com/our-clients/t/tesco/.
[f] See http://www.fcrn.org.uk/research-library/lca.
[g] Venkat, K. 2012. Comparison of Twelve Organic and Conventional Farming Systems: A Life Cycle Greenhouse Gas Emissions Perspective. *Journal of Sustainable Agriculture* 36 (6): 620-649.
[h] See http://www.fieldtomarket.org/report/national-2/PNT_SummaryReport_A11.pdf.
[i] See http://www.coolfarmtool.org/Home.

Life Cycle Assessment (continued)

- The National Pork Board developed a predictive model that provides estimates on the GHG emissions, water consumption, and associated costs involved in sow and grow-finish production. The Pig Production Environmental Footprint Calculator requires fundamental inputs only (herd size, feed composition, manure handling system, farm location, barn size, characteristics of heating, ventilation, and air conditioning system) and generates an annual "cradle to gate" estimate.[j]
- The Technical Working Group on Agricultural Greenhouse Gases has published three editions of a synthesis of literature related to the GHG mitigation potential of agricultural land management in the United States.[k]
- The EPA developed and maintains the Waste Reduction Model, an interactive tool that calculates and totals GHG emissions of baseline and alternative waste management practices for 46 common material types, including food waste, yard waste, dimensional lumber, and other organic materials. EPA is currently in the process of developing detailed food waste energy and emission factors to quantify the life-cycle impacts of production and disposal of five common food types—grains, fruits and vegetables, beef, chicken, and dairy.[l]

There are many potential applications for LCA results. When conducted for several comparable agricultural or forest products, LCAs can allow for analysis of the tradeoffs between yield and environmental impacts between different production processes or inputs. For example, comparing LCA results for grain products using different production inputs could show fewer life-cycle GHG emissions and similar yields by switching to a different fertilizer. However, there are limitations to how LCA results can be applied, including use of GHG emissions results in annual reporting or emission inventories. Since LCAs are intended to quantify the environmental impacts across the entire product life cycle, the GHG emissions and sinks frequently occur across several years (and several source categories) and are therefore not appropriate for use in applications that require annual emissions data.

[j] See http://www.pork.org/Resources/1220/CarbonFootprintCalculatorHomepage.aspx#.Us7mGbSwWSo.
[k] See http://nicholasinstitute.duke.edu/ecosystem/land/TAGGDLitRev#.Usbx9tJDuSp.
[l] See http://www.epa.gov/warm.

Finally, the methods in this report are not intended as a sustainability assessment. Other environmental services and cobenefits are not addressed by these methods. Nor are potential tradeoffs or detriments to other environmental concerns addressed here. The methods are specific to GHG emissions only, and sustainable farm, ranch, or forest management should consider the GHG implications of management in tandem with other environmental concerns such as water quality, soil health, and ecosystem health.

Chapter 1 References

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