A methodology for greenhouse gas emission and carbon sequestration assessments in agriculture

Supplemental materials for info note series analysing low emissions agricultural practices in USAID development projects

Working Paper No. 187

CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)

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Abstract

As many countries are increasing commitments to address climate change, national governments are exploring how they could best reduce the impact of their greenhouse gas (GHG) emissions. Agriculture is a major contributor to GHG emissions, especially in developing countries, where this sector accounts for an average of 35% of all GHG emissions. Yet many agricultural interventions can also help to reduce GHG impacts. This paper presents the methodology to estimate impacts of agricultural interventions on GHG emissions and carbon sequestration. This methodology is used in an analysis of several development projects supported by the United States Agency for International Development (USAID) and presented as a series of case studies. The methodology allows users to estimate (1) GHG impacts at project scale, (2) GHG emissions by agricultural practice, and (3) GHG emissions per unit of output (i.e., GHG emission intensity). The presented approach is a rapid assessment technique that is well suited to provide an indication of the magnitude of GHG impacts and to compare GHG impact strength of different field activities or cropping systems. It is well adapted to a context of data scarcity, as is common in agricultural investment planning where aggregate data on agricultural land use and management practices are available but where field measurements of GHG and carbon stock changes are missing. This approach is instrumental to inform agricultural investment, project, and policy planners about challenges and opportunities associated with achieving and accounting for GHG emission reductions in agricultural development projects.

Keywords

Climate change mitigation; agriculture; greenhouse gases; GHG emission intensity

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Acronyms

CCAFS	CGIAR Research Program on Climate Change, Agriculture and Food Security
CH_4	Methane
CO_2	Carbon dioxide
EX-ACT	EX-Ante Carbon balance Tool (EX-ACT)
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouse gas
GWP	Global warming potential
IPCC	Intergovernmental Panel on Climate Change
LED	Low emission development
N_2O	Nitrous oxide
$tCO_2e/ha/yr$	Tonnes of carbon dioxide equivalents per hectare per year
UDP	Urea deep placement
USAID	United States Agency for International Development

1. Introduction

This paper presents the methodology to estimate impacts of agricultural interventions on greenhouse gas (GHG) emissions and carbon sequestration, used in an analysis of several development projects supported by the United States Agency for International Development (USAID) and presented as a series of case studies. The case studies resulted from a partnership between the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), the Food and Agriculture Organization of the United Nations (FAO), and USAID. This partnership aimed to frame a strategic approach to low emission development (LED) in the agriculture sector, outline LED practices likely to both increase yields and reduce GHG impacts, and highlight considerations that organizations should address if they are considering how to estimate impacts of agricultural development projects on GHG impacts, or how to use such estimates.

This document is structured in three parts:

1. Sampling frame and data collection.
2. Description of the GHG estimation method, including the main results indicators, the boundaries of the analysis, the baseline scenario, and, briefly, the GHG emission and carbon sequestration calculations used.
3. Detailed explanations of specific calculations used to estimate GHG emissions and carbon sequestration.

This rapid assessment technique is intended for contexts where aggregate data are available on agricultural land use and management practices but where field measurements of GHG and carbon stock changes are not available. It provides an indication of the magnitude of GHG impacts and compares their strength among different field activities or cropping systems. The proposed approach does not deliver plot, or season-specific, estimates of GHG emissions.

This method may guide future estimates of GHG impacts under data scarcity, as is characteristic for environments where organizations engage in agricultural investment planning. Actors interested in ex-post verification of changes in GHG emissions resulting from interventions should collect field measurements needed to apply process-based models.

2. Sampling frame and data collection

We used a two-step process to select projects for analysis. During the pilot phase, the sampling frame included USAID-financed agriculture projects in three countries: Bangladesh, Colombia, and Mali. To identify these countries, the project team used convenience sampling based on interest to ensure geographic diversity and the availability of USAID implementing partners for interviews. During phase two, the sampling frame consisted of USAID-financed agricultural projects in countries that are the focus of the Feed the Future initiative. In total, we selected 30 projects likely to have a direct influence on GHG emissions and carbon sequestration through critical case sampling. These projects covered a comprehensive set of possible impact pathways on GHG emissions and carbon sequestration in agriculture, forestry, and land use.

Because this method relies on information gathered from key informants, we designed a semi-structured questionnaire to ensure comparable data collection across projects. Key informants were USAID partner organizations that were implementing the agriculture projects. A comprehensive set of GHG emission and carbon sequestration impacts in agriculture, forestry, and land use has been considered, including GHG impact pathways identified in the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (2006) and selected additional GHG sources (see sections 3 and 4 of this working paper).

The analysis for each project followed these five steps:

Collect project documents. The research team established a database of available project documentation, including project design documents (official documents that served as the basis for project approval and funding), project monitoring reports (quarterly or annual updates on activities and objectives), and other publicly available materials, including project websites.

Capture key information from project documents. We reviewed available information and captured key information in a database. This information clarified each project's objectives as well as the need for and content of project-specific data requests.

Request project-specific data. We identified data gaps central to the GHG analysis and submitted written data requests to USAID's implementing partners. By reviewing the questions in advance, the implementing partners were able to gather and share relevant project intervention data during the interviews.

Interview implementing organizations. Typically, a team of individuals representing the implementing partners participated in the interview with FAO and CCAFS researchers. These individuals provided data about changes in agricultural practices, annual yields, and postharvest loss. Implementing partners collected yield and postharvest loss data through interviews with beneficiary households, household surveys, postharvest loss reports, rough estimates, and other various sources. The analysis team conducted face-to-face interviews in Bangladesh, Colombia, Ethiopia, and Mali and remote interviews in other countries.

Interview follow-up. During the interview, the analysis team identified outstanding data needs that are central for the comprehensive project GHG assessment. Implementing organizations provided outstanding data during a brief follow-up period.

We describe below how our estimates of GHG impacts rely critically on information collected during this five-step process. The results depend upon the ability of the implementing partners to provide sound estimates of their activities, and the skill with which the research team facilitates these interviews and uses information from the project documents. Even where this process works very well, it yields coarse estimates, which are appropriate and useful for some purposes but not others.

3. Components of the GHG estimation methodology

This section summarizes critical components of the methodology used to estimate GHG emissions and carbon sequestration resulting from selected USAID agriculture projects. The first section describes FAO's GHG estimation tool, EX-Ante Carbon balance Tool (EX-ACT), which we used to calculate GHG emissions and carbon sequestration. The second section identifies the main results indicators used in the GHG assessment and specifies various aspects of the activity data, including baseline scenario development and geographical and temporal boundaries. Finally, we discuss GHG emission leakage—that is, the potential of activities previously within the project area to move to some other location where their influence on GHG emissions (and other social and economic factors) may persist.

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

We estimated USAID project impacts on GHG emissions and carbon sequestration with the FAO EX-ACT (Bernoux et al. 2010; Bockel et al. 2013; Grewer, Bockel, and Bernoux 2013).

FAO developed the EX-ACT appraisal system to estimate the impact of agriculture and forestry development projects, programs, and policies on GHG emissions and carbon sequestration. EX-ACT estimates carbon stock changes (emissions or sinks of carbon dioxide, or CO_2) as well as GHG emissions (CO_2, N_2O, CH_4) per unit of land, expressed in equivalent tonnes[2] of CO_2 per hectare and year (tCO_2e/ha/yr).[3] The combined impact from all GHG emissions and carbon sequestration is referred to as the carbon balance, or GHG impact of a project or management practice. EX-ACT enables project designers to estimate GHG impacts and prioritize project components that achieve high mitigation benefits.

EX-ACT follows the accounting structure and logic outlined in IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006) as well as chapter 8 of the Fourth Assessment Report from Working Group III of the IPCC (Smith et al. 2007) in cases where specific mitigation options were not covered in IPCC 2006 guidelines. We used estimates of embodied GHG emissions for farm operations, producing and transporting inputs, and establishing irrigation systems and other infrastructure from Lal (2004). GHG emissions from electricity generation needed for production are based on data from the International Energy Agency (USDE 2007).

The EX-ACT tool combines information on the extent of human activity (called activity data, e.g., crop area and management practices) with coefficients quantifying the GHG emissions per unit activity (called GHG emission factors or carbon stock change factors) (IPCC 2006). The equation used to calculate GHG emissions is:

GHG emissions = (activity data) * (GHG emission factor).

[2] 1 tonne = 1 metric ton

[3] GHG emissions of livestock production systems are estimated per livestock head and expressed in equivalent tonnes of CO_2 per head and year (tCO_2e/head/yr).

The next chapter describes the GHG estimation method for different GHGs and carbon pools in more detail. Although the IPCC designed its GHG accounting guidance for national level estimates, it is also widely used for GHG accounting at the project level or in other contexts where GHG field measurements are scarce.

The IPCC developed a tiered system of GHG impact estimates that reflects regional specificity, spatial resolution, and complexity of the method. If used appropriately, higher tier levels can yield more accurate GHG estimates with lower associated uncertainty.

The team used Tier 1 and Tier 2 methods for the GHG emission calculations in this study. Tier 1 emission factors are readily available international factors, commonly differentiated by rough agro-ecological zones. Tier 2 standards use higher temporal and spatial resolution and more disaggregated activity data to correspond with coefficients for specific countries or regions and specialized land use or livestock categories.

3.2 Main indicators and tools

We used FAO's EX-ACT appraisal system to estimate GHG emission and carbon sequestration values per area, while carrying out complementary calculations to derive GHG impacts by practice and product. The three main indicators used are (1) total project GHG emission impacts, (2) GHG emissions per unit of output (GHG emission intensity), and (3) GHG emissions by agricultural practice. Below, we explain each of the three main indicators identified in Table 1 along with the tools we used for the analysis.

Table 1. Main GHG indicators and tools

Main indicator	Total project GHG emission impacts (total emissions for overall project)	GHG emission intensity of agricultural production (emissions per unit of production)	GHG emission impacts by agricultural practice (emissions by intervention practice)
Tool	EX-ACT	EX-ACT + GHG emission intensity calculation	EX-ACT + practice level calculation

3.2.1 Total project GHG emission impacts

The estimated GHG emission impact refers to increases or reductions in net GHG emissions associated with project interventions as compared with no project interventions. A negative value for the project total means the project will lead to reduced GHG emissions and/or increased carbon storage as compared with the no-project scenario—indicating a favorable outcome for the project with respect to climate change mitigation benefits.

3.2.2 GHG emission intensity of agricultural products

GHG emission intensity is the total GHG emissions per unit of output (e.g., GHG per hectare or head of livestock) divided by the effective annual yield (annual yield minus postharvest loss).[4] Project implementation may raise GHG emissions and production simultaneously. The increases in GHG emissions, however, may be (1) proportionately lower than the increase in agricultural production or (2) lower than the increase in GHG emissions that would have resulted from increasing agricultural production elsewhere. Increasing agricultural output through land expansion to natural lands typically drives carbon losses.

Although EX-ACT can compute simple GHG emission intensities across a single value chain, it does not provide GHG emission intensities for multiple production systems across a project. To calculate GHG emission intensity for this effort, we extracted disaggregated GHG impacts from EX-ACT submodules to create a GHG results dataset. The dataset includes general information on the project, including country, climate zone, moisture regime, and soil type. The dataset documents the type of crop and improved management practice applied, the area of land or number of animals affected, and associated crop yields and postharvest loss percentages. Next, the team combined the disaggregated GHG impacts from EX-ACT with yield and postharvest loss data obtained from implementing partners during interviews.

3.2.3 GHG emission impacts by agricultural practice

Providing GHG impact estimates for each identified agricultural practice allows project designers to understand GHG emission sources and consider them for future intervention packages. To analyze impacts, the researchers clarified whether improved management practices were applied in combination or in isolation, since this influences the generated GHG

[4] GHG emission intensity can also be defined differently. For example, the amount of GHG emissions per quantity of calories or protein produced are alternative approaches. For a discussion of different metrics for assessing GHG emissions and productivity, see Garnett (2011).

impacts. In addition to assessing documented practice combinations, the hypothetical GHG impact from adopting all observed new practices in isolation was calculated.

EX-ACT does not calculate practice-level GHG impacts. To calculate these impacts, the team extracted disaggregated GHG impacts from EX-ACT submodules to create a central GHG results dataset. This is similar to the process described in the preceding paragraph on GHG emission intensity data.

Interpreting the emission impacts of adopting particular agricultural practices requires that several factors be taken into account. First, increased soil carbon storage occurs only over a limited period of time. EX-ACT assumes carbon stocks in soils will reach equilibrium roughly 20 years after growers adopt a new practice (Bernoux et al. 2010). Second, avoided emissions of methane (CH_4) and nitrous oxide (N_2O) are permanent, whereas increased soil carbon can decompose and return to the atmosphere. Therefore, when interpreting the impacts of shifting agricultural management, it is a good practice to consider whether main impacts stem from changes in carbon stocks or changed GHG emissions.

3.3 Activity data

Activity data are mainly based on project monitoring reports or estimates by implementing partners. Data referred predominantly to the situation prior to project start or estimated targets at project completion, and the assumption that the project would meet those targets. And although many projects had selected monitoring data that were readily available, the data usually did not refer to the time of project completion and only covered a limited set of the required activity data. Estimates of achievements at project completion are associated with uncertainties. If implementing organizations would state at later stages of project implementation that estimated project targets utilized for this analysis cannot be achieved, the GHG estimates identified in this analysis would need to be updated accordingly.

Implementing partner organizations usually lacked any data describing the baseline scenario, indicating the most likely development of project communities for the case that no project would have taken place. In the following subsections, we describe how the baseline scenario was developed and how geographical and temporal boundaries of the analysis were established.

3.3.1 Baseline scenario

Determining the baseline scenario is a critical component of estimating GHG emissions and determining the additionality of project activities. Additionality refers to the project's capacity to lead to improved GHG impacts than compared to the no-project scenario. Bockel et al. (2013) suggest three methods for developing baseline scenarios: no-change scenario, past trends extrapolation, and future trends modeling.

The no-change scenario assumes that no changes in land use or agricultural practices will occur in the absence of the project (i.e., the status quo). It also assumes that farmers and herders continue current production practices and there is no change in land use, which is adequate for static production contexts. The no-change scenario is simple and transparent, as the continuation of the status quo provides a clear reference point. For small-scale projects, emission estimates typically use the no-change baseline (Bockel et al. 2013).

The past trends extrapolation method assumes that changes in land use and agricultural practices will continue to evolve as they have in the past. This scenario approach extrapolates trends using secondary data (ibid.). For instance, if a deforestation rate of 1% prevailed in the past 10 years without strong annual fluctuations, the baseline scenario approach would assume that this 1% deforestation rate would continue.

The future trends modeling method requires advanced modeling tools that use quantitative input data to simulate possible changes in key drivers of land use change and agricultural practices (e.g., international market prices, government policy, or climate) that generally originate far from the farm field. For instance, increased demand for soybean production or grazing land could lead to a higher profitability of deforestation actions and increase the deforestation rate; whereas forestry protection laws and enforced sanctions for forest conversion may decrease future deforestation rates.

Since determining baseline scenarios is linked to political considerations and different technical approaches, stakeholders have not yet agreed on a consistent international approach.

Owing to limited data availability, large diversity in geographic contexts, and the advantage of having a clear reference point, the team used the no-change baseline scenario for all project analyses. Generating more complex baseline scenarios for small, project-specific locations would entail a high level of uncertainty, driven by both global and local factors.

Although the approach chosen here uses the status quo as a clear and transparent reference point, it has obvious limitations that need to be kept in mind when considering the resulting estimates of additionality (i.e., the estimated change in GHG emissions that occurs specifically as a result of the project). Once the project has ended, available data on development pathways of non-targeted communities can be a good reference point for revisiting the baseline scenario. If communities that were neither targeted by project improvements nor exposed to spillover impacts from project actions can be identified as having experienced a development path that differs strongly from the no-change scenario, the baseline scenario should be reviewed.

3.3.2 Geographic boundaries of the project analysis

For the project analysis, the team estimated GHG impacts within the area targeted directly by project actions. When applicable, the studies differentiate between the project's target zone of implementation and the non-target zones that exhibit clear spillover or externalities from the project (Bockel et al. 2013).

3.3.3 Duration considered for the project analysis

For each project analyzed, the team estimated the average annual GHG impacts of actions occurring during the 20-year time frame after project initiation. Therefore, GHG impacts are comparable between projects of different duration and projects with a different temporal dynamic in generating GHG impacts. Actual project duration varies, but USAID aims for activities to persist beyond the life of any particular award. The analysis assumed that agricultural interventions would continue in a sustained manner for at least 20 years, enabling meaningful cross-project comparison of GHG impacts.

3.4 Leakage of GHG emissions

Emission leakage occurs when activities that produce GHG emissions cease or decline in a target area but then appear or increase in another area, most often because the overall demand driving the activity has not changed. For instance, if a project provides incentives for reducing deforestation on a limited geographical scale while overall strong demand for timber products continues to prevail, deforestation might only shift from the project area to another location. Leakage dynamics are difficult to estimate as part of ex-ante analyses since they require clear hypotheses of leakage dynamics as well as quantitative estimations of their impact strength.

Even after project completion, when monitoring data may be available, leakage often remains difficult to detect. For example, in land use change, it is difficult to justify which share of observed land use change happened as a result of leakage impacts. Moreover, because demand for products often originates with international markets, leakage can occur across large distances and between countries.

In interviews with project implementing partners, the strong presence of localized and direct leakage impacts in the project area was assessed as improbable. The team thus assumed no cases of leakage impacts in this analysis.

The lack of ability to monitor leakage dynamics limits our ability to develop sound macro-economic scenarios and associated GHG emission pathways of the type that would be most relevant to promoting LED. Especially when thinking of long-term impacts that extend beyond the 20-year period of analysis, a variety of complex leakage and overspill impacts can be expected. For example, if the adoption of improved agricultural management practices increases the income generated per hectare, this may provide an incentive to clear natural vegetation for agriculture, assuming sufficient labor and financial resources are available. An integrated macro-economic assessment is necessary to adequately estimate leakage impacts in the long term.

4. Detailed methods for GHG emission and carbon sequestration calculations

This section contains more detailed explanations of the specific GHG emission and carbon sequestration calculations that our team used. We first present the calculation method for CO_2 emissions and carbon sequestration, followed by the calculation method for N_2O and CH_4 emissions.

Table 2 synthesizes GHG calculation methods by type of intervention.

Table 2. GHG calculation methods by intervention

Intervention/Sectoral Scope	Tier	GHG	Method Section (chapter reference)
Avoided forest conversion, avoided land degradation, reforestation	1	CO_2	Above-ground biomass (4.1) Below ground biomass (4.1) Litter and dead-wood (4.1) Soil carbon stocks (4.1)
Perennial crop or agroforestry expansion	1 & 2	CO_2	Above-ground biomass (4.1) Below-ground biomass (4.1) Litter and dead-wood (4.1) Soil carbon stocks (4.1)
Soil management, water management, manure management	1	CO_2	Soil carbon stocks (4.1)
Crop residue burning	2	CH_4, N_2O	Crop residue burning (4.2)
Fertilizer/pesticides	1	CO_2, N_2O	Fertilizer (4.2)
Irrigated rice	1	CH_4, N_2O	Irrigated rice (4.2)
Livestock	1 & 2	CH_4, N_2O	Livestock (4.2)
Grassland	1	CO_2	Soil carbon stocks (4.1)

4.1 Detailed methods for the estimation of CO_2 emissions and carbon sequestration

The subsequent section differentiates the impacts on CO_2 emissions and carbon sequestration by carbon pool. A carbon pool is any part of the earth system that serves as a reservoir for carbon. It is usually characterized by the capacity to release or accumulate carbon; for example, in soils and biomass (Karsenty, Blanco, and Dufour 2003). The GHG emission estimates in this method include five carbon pools: above-ground biomass, below-ground biomass, litter, dead wood, and soils:

1. **Above-ground biomass** consists of the living biomass material above the soil.
2. **Below-ground biomass** consists of all of the live roots below the soil surface.
3. **Litter** consists of all of the non-living biomass with a diameter less than 10 cm (or other diameter set by a country) above the mineral or organic soil surface layers.
4. **Dead wood** consists of all non-living wood not contained in the litter, including woody debris, dead roots up to 2 mm in diameter, and stumps greater than or equal to 10 cm in diameter.

5. **Soil organic carbon** consists of decomposed organic matter in mineral and organic soil layers (Schoene et al. 2007).

Emission calculations for above-ground biomass stocks mainly used default carbon stock change values and growth rates for specific land uses from the IPCC Tier 1 method (IPCC 2006). We assumed carbon content to be 47% of above-ground biomass (ibid.).

In this study, the following interventions impacted above-ground biomass: perennial crop expansion, agroforestry expansion, and land use change (deforestation, afforestation, and forest management). For perennial and agroforestry systems, we estimated above-ground biomass with dedicated calculations for each specific production system using a Tier 2 approach. Implementing organizations provided plant density and species estimates of cultivated perennial crops as well as other conserved trees per hectare. Using tree biomass estimates at tree maturity from the scientific literature, the team calculated the carbon stock changes per hectare. Biomass estimates for other forms of land use correspond to IPCC Tier 1 factors (ibid.).

Table 3 summarizes estimation method information for above-ground biomass. Tables 4–12 summarize estimation method information for other carbon pools in a comparable manner.

Table 3. Estimation method for above-ground biomass

Method basis	Default carbon stock change factors of above-ground biomass or growth rates of above-ground biomass by type of land use (Tier 1, IPCC 2006); for agroforestry systems: tree species-specific calculations of stock changes in above-ground biomass (Tier 2)
Intervention categories	Land use change, perennial crops, agroforestry, deforestation, afforestation, forest management
Calculation details	Default carbon stock change factors (Tier 1, ibid.) were used for most forestry and land use change impacts. Carbon stock change factors in agroforestry and perennial cropping systems were estimated using specific numbers of trees per hectare as reported by implementing partners and estimates of biomass values by tree type from the scientific literature (Tier 2).

Table 4. Estimation method for below-ground biomass

Method basis	Default carbon stock change factors and growth rates of below-ground biomass by type of land use (Tier 1, IPCC 2006)
Intervention categories	Land use change, perennial crops, agroforestry, deforestation, afforestation, forest management
Calculation details	Below-ground biomass was estimated using a ratio (R) of below- to above-ground biomass. R was determined by default values provided by IPCC (ibid.); for example, R is 0.37 for tropical rainforest and 0.27 for tropical mountain systems. The total above- plus below-ground biomass is used in cases when it is not mandatory for calculations to have separate estimates (ibid.).

Table 5. Estimation method for litter and dead wood

Method basis	Default carbon stock change factors for litter and dead wood (Tier 1, IPCC 2006)
Intervention categories	Deforestation, afforestation, forest management, land use change
Calculation details	Litter and dead wood carbon pools are assumed not to change within unaltered forestry areas. Forest management and forest conversion to other uses can lead to changes in these carbon pools. Refined data from the field are seldom available for smaller size carbon pools. All assessments use Tier 1 default values (ibid.).

Table 6. Estimation method for soil carbon stock changes following land use change

Method basis	Default carbon stock change factors for soil organic carbon stocks in mineral soils to a depth of 30 cm based on IPCC Tier 1 method (IPCC 2006).
Intervention categories	Land use change, perennial crop expansion, agroforestry expansion, deforestation, afforestation, forest management
Calculation details	The IPCC Tier 1 values are based on references compiled from a wide range of observations and data from long-term monitoring for soil organic carbon stocks for mineral soils to a depth of 30 cm (ibid.). When soil organic carbon changes occur due to changes in the type of land use, EX-ACT assumes that a new equilibrium in carbon stocks is reached after a 20-year period.

Table 7. Estimation method for soil carbon sequestration on managed agricultural land

Method basis	Soil carbon sequestration rates on managed agricultural land were developed using the default values from the Fourth Assessment Report of the IPCC (Smith et al. 2007).
Intervention categories	Soil management, water management, manure management, perennial crops, agroforestry
Calculation details	Smith et al. (ibid.) provide estimations of annual soil carbon sequestration rates instead of a soil carbon stock difference approach, and therefore do not require information on initial absolute soil carbon stocks. This method assumes that soil organic carbon stock changes during the transition to a new equilibrium occur with a linear pattern. Although soil carbon changes in response to management changes may often be best described by a nonlinear function, the linear assumption provides a good approximation of the total impacts over a multi-year period.

4.2 Detailed methods for the estimation of CH_4 and N_2O emissions

CH_4 and N_2O are naturally present in the atmosphere, but agriculture increases emissions of these GHGs from the biosphere to the atmosphere. CH_4 is released as part of the normal digestive processes of livestock, particularly ruminants, as well as from managed manure storage, crop residue burning, and flooded rice cultivation. N_2O is released when bacteria break down nitrogen fertilizers, organic matter, manure, and urine as well as when farmers burn crop residues. Although this section focuses on CH_4 and N_2O emissions, it also includes indirect CO_2 emissions from production, transport, and storage of synthetic inputs, or from direct burning of fossil fuels.

This section is structured by the processes that function as the source of the aforementioned GHG emissions. Each subsection summarizes the method used for the respective GHG calculations. For the GHG calculations, CH_4 and N_2O emissions were converted into CO_2 equivalent (CO_2e) emissions based on the global warming potential (GWP) of each gas over a 100-year period. All GHG impacts have been converted to CO_2e, assuming a GWP of 34 for CH_4 and 298 for N_2O (Myhre et al. 2013).

The GWP of long-lived GHGs is about the same whether we consider a shorter or longer time horizon. On the other hand, the GWP of short-lived GHGs is much more powerful over short time frames and declines over longer time horizons because less of the gas persists in the atmosphere to trap heat. Time durations of 20 and 500 years are commonly used as alternative reference points. The choice of time frame matters because although long-term climate stabilization targets could be achieved without addressing short-lived gases for some time, these gases can strongly influence peak GHG concentrations in the atmosphere and associated global temperatures in the relatively near term. CH_4, for example, has a 20-year GWP of 86 CO_2e but a 100-year GWP of 34 CO_2e. Clearly, the relative priority placed on reducing CH_4 emissions in the near term would be lower if near-term consequences were irrelevant, which they are not (Howarth 2014). Had we used 20-year GWP values, the benefits from interventions that reduce CH_4 emissions would have been greater compared with interventions that reduce N_2O emissions or increase carbon sequestration.

Table 8. Estimation method for irrigated rice

Greenhouse gases	CH_4, N_2O
Method basis	Estimates of GHG emissions associated with practice changes in irrigated rice projects were developed using the default values from IPCC (2006).
Intervention categories	Flooded rice
Calculation details	Direct N_2O emissions from field application of nitrogen from synthetic and organic sources are estimated using the default emission factor from IPCC (ibid.) for flooded conditions. CH_4 emissions from flooded rice systems are estimated using IPCC (ibid.) with project-specific information on rice crop management practices.

Table 9. Estimation method for crop residue burning

Greenhouse gases	CH_4, N_2O
Method basis	Estimates of GHG emissions from crop residue biomass were estimated using the IPCC Tier 2 method (IPCC 2006).
Intervention categories	Reduced crop residue burning
Calculation details	CH_4 and N_2O emissions from crop residue burning were estimated using IPCC (ibid.). Instead of using global default values, crop residue biomass values are estimated using project-specific information on crop yields (Tier 2). On the basis of such project-specific biomass estimates, the respective quantities of CH_4 and N_2O emissions are calculated using IPCC (ibid.). This emission calculation only includes combustion impacts, as soil carbon impacts due to residue retention are accounted for elsewhere (see above section *soil carbon sequestration on managed agricultural land*).

Table 10. Estimation method for livestock

Greenhouse gases	CH_4, N_2O
Method basis	Estimates of GHG emissions from enteric fermentation, manure management, and manure deposition were developed using IPCC Tier 1 and Tier 2 methods (IPCC 2006) with project-specific data on livestock weight. Mitigation benefits of improved feeding and breeding were used from Smith et al. (2007) (Tier 1).
Intervention categories	Herd weight dynamics, herd size management, improved feeding and breeding
Calculation details	GHG emissions from livestock herds have largely been calculated using Tier 1 methods from IPCC (ibid.). However, information on changes in livestock weight due to project interventions has been taken into account for the various kinds of GHG processes using the Tier 2 approach from IPCC. CH_4 emissions from enteric fermentation were estimated based on a partial Tier 2 approach considering project-specific animal weight using IPCC (ibid.) for cattle and sheep and Dittmann et al. (2014) for camels. For all aspects beyond livestock weight, enteric fermentation has been estimated using Tier 1 methods. For N_2O and CH_4 emissions for manure management, the Tier 2 method from IPCC (ibid.) was used, considering project-specific data on animal weight wherever available. GHG emission reductions from improved feeding practices, the application of dietary additives, or the improvement in breeding practices on livestock-related GHG emissions have been estimated using Smith et al. (2007).

Table 11. Estimation method for fertilizer and pesticides application, production, and transport

Greenhouse gases	N_2O and CO_2
Method basis	Emission estimates from fertilizer application were developed using Tier 1 GHG emission factors (IPCC 2006), with methods from Lal (2004) for fertilizer production and transport. These represent indirect, or off-farm, sources of GHG emissions.
Intervention categories	Fertilizer management, pesticide management
Calculation details	CO_2 emissions due to fertilizer and pesticide production, transport, and storage, as well as from agricultural infrastructure establishment, are estimated using Lal (ibid.). As nitrogen fertilizer production is an energy-intensive process, fertilizer production is a major component of fertilizer-embedded GHG emissions. Field-based N_2O emissions are estimated using the Tier 1 default values from IPCC (2006). The level of nitrogen inputs is estimated based on

	project-specific data for fertilizer application rates for each cropping system.

Table 12. Estimation method for urea deep placement (UDP) at constant fertilization rates

Greenhouse gases	N_2O
Method basis	Currently, insufficient empirical data are available to assess the overall climate change mitigation benefits from UDP within flooded rice systems across diverse conditions. Within this study, we adapted a conservative, preliminary estimate for N_2O emission reductions informed by field measurements by Gahire et al. (2015) for flooded rice systems in Bangladesh.
Intervention categories	Flooded rice
Calculation details	UDP reduces GHG emissions. One source of reduced N_2O emissions is reduced requirements for fertilizer application due to less fertilizer runoff and volatilization. However, many project teams reported that the prevailing low fertilizer application rates of project beneficiaries would not decrease. Thus the reported reductions in GHG emissions per area may underestimate the GHG benefits from UDP in other contexts. As a preliminary, conservative estimate we assumed for this study that UDP in irrigated rice fields reduces direct N_2O emissions by half. This estimate is informed by field measurements from Gahire et al. (ibid.) that report still slightly larger N_2O emission reductions on rice in Bangladesh. Owing to the anaerobic conditions, total N_2O emissions in flooded rice systems are thereby generally lower than in non-flooded cropping systems.

5. Conclusion

Investments in sustainable food systems provide opportunities for reducing future increases in GHG impacts from a growing global population and changing consumption patterns. GHG assessment of agricultural investments in bi- and multilateral lending operations are not commonly practiced as part of project design, monitoring, and evaluation. Data intensity, technical complexity, and cost implications function as important barriers for integrating GHG assessments within investment decisions and policy-making.

The method presented here allows us to assess GHG impacts under data scarcity, using a guided methodological process of reduced technical complexity. The joint evaluation of (1) GHG impacts at project scale and (2) GHG emissions per unit of output (GHG emission intensity) is well placed to identify GHG impacts in a holistic way. It identifies whether the net GHG emission level is reduced and whether more agricultural goods are produced for any given level of GHG emissions. The additional results indicator that quantifies GHG impacts of specific management practices allows the GHG benefits to be attributed to particular practices and technologies.

This rapid assessment technique is well placed for indicating the magnitude of GHG impacts and for comparing GHG impact strength of different field activities or cropping systems. As such, the assessment results are instrumental for informing investment and policy planners when designing LED strategies in agriculture.

Single GHG estimates are associated with large uncertainties, and the method is not adapted to provide refined GHG estimates with high location, crop, or seasonal specificity that is necessary, for example, for carbon markets.

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