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Enhancing Sustainable Land Management and Climate-Resilient Agri-food Systems in Côte d'Ivoire (LARACI) Funding Proposal

Annex 22a: Greenhouse gas emission reduction - narrative

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Contents

1 Introduction and overview of mitigation impacts

This annex (22a) includes a narrative elaboration of the methodology used and assumptions applied for the calculation of the mitigation benefits (Core indicator 1) of the LARACI project. This narrative is accompanied by an excel spreadsheet (Annex 22b) which comprises further information about the methodology for assessing greenhouse gas (GHG) emission reduction of the Enhancing Sustainable Land Management and Climate-Resilient Agri-food Systems in Côte d'Ivoire (LARACI) project.

1.1 Project objectives

The LARACI project aims to initiate a paradigm shift towards climate-smart agriculture (CSA) for improved food and nutrition security and income generation for farming communities under existing and projected climate change scenarios, and for a reduced GHG footprint. This will be achieved through improving climate-related risk management, reducing GHG emissions, and promoting CSA practices focusing on three key crops: yam, rice, and cassava.

The LARACI project's key targets include:

- Strengthening national agrometeorological systems to provide timely climate information and advisory services.
- Enhancing the capacity of extension services to support CSA implementation.
- Increasing access and ability to leverage financial tools to improve access to climate risk mitigation resources.
- Developing integrated systems for sustainable land management and agroforestry.
- Scaling CSA practices to support resilient agri-food systems particularly in key value chains such as rice, cassava, and yam.

1.2 Overview of results per activity and total

The project is expected to reduce GHG emissions by a total of 606,212 tCO_2eq by the end of the project, including a reduction of 553,111 tCO_2eq in rice-based systems, a reduction of 36,155 tCO_2eq in cassava-based systems, and a reduction of 16,947 tCO_2eq in yam-based systems. This will be accomplished by using technologies that significantly reduce greenhouse gas emissions while enhancing agricultural yield and resilience to climate change.

2 Methodology used

2.1 Name and source of the methodology/tool used:

The estimation of GHG emissions across rice, cassava, and yam value chains was based on internationally recognized methodologies adapted to specific interventions and production contexts.

- Rice value chain
  Baseline emissions were quantified using the static chamber and gas chromatography technique, which directly measures methane (CH_4) fluxes from rice fields, while CSA-induced emissions were estimated using multiple complementary approaches:

- The Clean Development Mechanism (CDM)-approved methodology, AMS-III.AU (Methane emission reduction by adjusted water management practice in rice cultivation), was applied for alternate wetting and drying (AWD), system of rice intensification (SRI), and mid-season drainage practices.
- The static chamber and gas chromatography technique was applied to assess the mitigation effects of biochar on CH_4 and N_2O emissions.
- Life Cycle Assessment (LCA) was used to evaluate emissions along the rice postharvest chain, particularly for the GEM (Grain quality enhancer, Energy-efficient, and durable Material) parboiling technique, capturing emissions from energy use and process efficiency.

▪ Cassava and yam value chains
GHG emissions from cassava and yam production systems were estimated using the IPCC Tier 1 methodology for N_2O emissions from crop residues, as outlined in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use (AFOLU), Chapter 11. This approach applies the default IPCC emission factor (0.01 kg N_2O–N per kg N input) to nitrogen inputs from crop residues, with standard conversion factors to derive N_2O and CO_2-equivalent emissions.

Together, these methodologies ensure robust, transparent, and comparable estimates of GHG emissions across crops and interventions, allowing for the quantification of both baseline emissions and CSA-induced mitigation benefits.

2.2 Justification for selection of methodology

The methodologies selected for estimating GHG emissions in rice, cassava, and yam value chains were chosen to ensure accuracy, credibility, and international comparability.

For the rice value chain, the static chamber and gas chromatography technique was applied to provide direct and reliable measurements of CH_4 and N_2O fluxes, while the CDM-approved methodology AMS-III.AU ensured alignment with internationally validated approaches for assessing mitigation from water management practices such as AWD, SRI, and mid-season drainage. In addition, the use of Life Cycle Assessment (LCA) for the GEM parboiling technique allowed for a comprehensive evaluation of postharvest emissions.

For cassava and yam, the IPCC Tier 1 methodology was applied as it offers a standardized and transparent framework for estimating nitrous oxide (N_2O) emissions from crop residues, consistent with national GHG inventory guidelines and suitable in contexts with limited country-specific emission factors. Collectively, these methods balance scientific rigor with practicality, providing robust, transparent, and policy-relevant estimates of both baseline emissions and the mitigation impacts of climate-smart agriculture interventions.

2.3 Justification for custom-made methodology

The estimation of GHG emissions across rice, cassava, and yam value chains relied exclusively on internationally recognized methodologies and tools, ensuring scientific credibility, comparability, and transparency. No custom-made methodologies were applied.

3 Scope and boundaries

3.1 Definition of project boundary (geographic, temporal, and sectoral)

The LARACI project will be implemented in Côte d'Ivoire, with interventions focused on the central regions of N'Zi, Moronou, Iffou, La Mé, and Gbêkê, which were identified by national stakeholders due to their high vulnerability to climate change and environmental degradation. The project will run over a five-year period, during which interventions will target three critical value chains—rice, cassava, and yam—given their central role in national food security, economic livelihoods, and potential for both climate resilience and GHG mitigation. The boundary thus encompasses the geographic focus on central Côte d'Ivoire, the temporal scope of five years, and the sectoral emphasis on the rice, cassava, and yam value chains, specifically addressing production, processing, and value chain practices that impact climate resilience, GHG emissions, and sustainable land management. Total targeted area by the project is 48,000 ha (Rice), 30,000 Ha (Cassava) and 80,000 Ha (Yam).

3.2 Baseline vs. project scenario definition

In the baseline scenario, farmers follow conventional "business-as-usual" (BAU) management practices, which are characterized by low and declining yields, limited income, soil fertility depletion, land degradation, and rising GHG emissions. In the project scenario, farmers adopt a suite of climate-smart agriculture (CSA) practices tailored to the cassava, yam, and rice value chains, which increase yields and income, enhance soil health, improve resilience to climate risks, and reduce GHG emissions, creating a sustainable and climate-resilient agrifood system.

3.3 GHGs considered

The project mitigation potential is assessed by estimating emissions of three GHGs: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

3.4 Demonstration of additionality

CSA adoption in the target regions remains limited under business-as-usual conditions despite agronomic and environmental benefits. This is driven by structural barriers where farmers face constrained access to finance and income volatility linked to seasonal production and climate variability. Farmers therefore rationally prioritize short-term risk avoidance over longer-term productivity gains. Institutional constraints compound these challenges: extension coverage remains limited, with one advisor serving thousands of farmers, and climate information systems being unevenly accessible. With all these barriers, CSA adoption would not scale in the absence of the intervention. Knowledge and upfront capital costs associated with new practices further inhibit autonomous uptake, requiring external support to overcome initial adoption thresholds. Once practices are adopted, farmers are incentivized to maintain them as they experience direct productivity and resilience benefits, supporting post-project persistence without ongoing subsidy.

4 Baseline scenario

4.1 Description of "business-as-usual" (BAU) practices

In the targeted central regions of Côte d’Ivoire, farmers currently follow conventional, BAU practices across the rice, cassava, and yam value chains, which are characterized by low productivity, declining soil fertility, and increased vulnerability to climate change.

- **Rice**
  Farmers typically maintain continuously flooded fields throughout the growing season, use older seedlings, and practice dense planting with sole reliance on inorganic fertilizers. Traditional water and soil management, such as the absence of mid-season drainage, contributes to iron toxicity and reduced yields (Dossou-Yovo et al., 2020). Postharvest processing is usually done with inefficient parboiling methods using firewood, resulting in high energy consumption, lower grain quality, and high GHG emissions (Ndindeng et al., 2018).

- **Cassava**
  Cultivation of cassava is largely based on sole cropping, with no intercropping with legumes, leading to nutrient depletion and soil fertility loss. Fertilizer application is often uniform and non-site-specific, and planting and harvesting schedules follow fixed calendars rather than adapting to climate variability and change. Farmers predominantly use local, low-yielding, or disease-prone cassava varieties propagated from their own materials without rapid multiplication techniques (Gnahoua et al., 2016).

- **Yam**
  Yam production is commonly based on traditional mounding with low planting density, inefficiently using available land and inputs. Conventional staking methods or no staking are practiced, resulting in limited soil fertility improvement and inadequate erosion control. Farmers rely on traditional yam varieties with low nutrient use efficiency and propagate planting materials from farmer-saved tubers or setts, which multiply slowly and often carry pests or diseases (Kouakou et al., 2023).

These BAU practices limit agricultural productivity, exacerbate land degradation, and contribute to GHG emissions, highlighting the need for the adoption of climate-smart agricultural interventions.

4.2 Assumptions and data sources for emissions under baseline conditions

Baseline GHG emissions for rice-based systems were estimated assuming current “business-as-usual” practices, including continuous flooding during cultivation and traditional parboiling postharvest methods. CH_4 emissions from continuously flooded rice fields were estimated using a static chamber approach (Qin et al., 2016). Key parameters included reference gas density (0.717 kg/m^3), slope of gas concentration under continuous flooding (0.177 ppm/min), chamber temperature (26.2 °C), chamber height (1.2 m), and an average growing season duration of 150 days. Standard conversion factors were applied to scale measurements to t CO_2e/ha, accounting for the radiative forcing of CH_4 over a 100-year horizon (34 CO_2e/ppm) (Myhre et al., 2013) and temperature conversion from Celsius to Kelvin (273.15). The resulting baseline emission from continuous flooding was calculated at 10.2 t CO_2e/ha, consistent with reported values for lowland rice in Côte d'Ivoire (Iboko et al., 2025).

For postharvest emissions associated with traditional rice parboiling, assumptions included fuelwood consumption of 1 t/ha/year and an emission factor of 1.5 t CO_2 per t of fuelwood (Ndindeng et al., 2015). Rice losses of 0.334 t/ha from the traditional parboiling method were also considered, using an emission factor of 0.5 t CO_2 per t of rice (FAO, 2014). The combined baseline emissions for traditional parboiling were estimated at 1.667 t CO_2e/ha/year. These data sources reflect current farmer practices and internationally recognized emission factors, providing a robust basis for comparison with project scenarios implementing climate-smart interventions. The emission factor of 0.5 t CO_2 per t of rice losses (FAO, 2014) represents the life-cycle CO_2 emissions associated with the production of rice that is ultimately lost, including emissions from cultivation, processing, and associated energy inputs required to produce that quantity of rice. It does not explicitly estimate methane (CH_4) or nitrous oxide (N_2O) emissions from the physical decomposition of lost rice but rather accounts for the embedded carbon footprint of producing rice that is not consumed. In our analysis, emissions related to post-harvest rice losses are calculated independently from in-field methane emissions from rice cultivation. Field emissions (e.g., CH_4 from flooded rice fields and N_2O from soil processes) are estimated separately using established methodologies for rice production systems. The 0.5 t CO_2/t factor is applied only to the quantity of rice lost during parboiling and post-harvest handling, thereby capturing the upstream emissions associated with wasted production. This approach avoids double counting because: i) in-field emissions are accounted for under the rice cultivation component of the baseline, and ii) post-harvest loss emissions reflect the carbon footprint of producing rice that is not utilized, rather than additional emissions from field processes. Consequently, reductions in post-harvest losses are treated as independent mitigation benefits from improved parboiling technologies, while methane reductions from improved water or crop management in rice fields are assessed separately.

5 Project scenario

5.1 Description of improved practices/technologies

The technologies that will be promoted by LARACI have been prioritized during stakeholder consultation workshops based on their potential to increase land productivity, climate change resilience, and reduce GHG emissions as well as their alignment with the farmers' biophysical and socio-economic conditions.

5.1.1 Rice-based systems

The mitigation of greenhouse gas emissions from rice-based systems will be achieved through the promotion of practices such as alternate wetting and drying, the system of rice intensification, the combined use of biochar and nitrogen fertilizer, mid-season drainage, and the GEM parboiling technique.

- **Alternate wetting and drying (AWD)**
  Rice farming under the traditional continuous flooding consumes vast amounts of water, contributing to water scarcity in irrigated areas. Additionally, continuous flooding creates anaerobic soil conditions that promote CH_4 emissions. Farmers also face declining water availability due to competing demands from other sectors. Alternate Wetting and Drying (AWD) is a water-saving irrigation method that allows fields to dry intermittently rather than being continuously flooded, reducing water use and methane emissions while maintaining or improving yields (Dossou-Yovo and Saito, 2021).

- **System of Rice Intensification (SRI)**
  Traditional rice cultivation practices often involve transplanting older seedlings, high seeding rates, continuous flooding, and heavy reliance on chemical fertilizers. These practices reduce resource-use efficiency, exacerbate GHG emissions, and lower soil health over time. SRI addresses these challenges by using younger seedlings (8–12 days old), wider spacing, and intermittent irrigation to optimize root development and tillering. This method reduces seed, water, and fertilizer requirements while increasing yields. It also enhances soil health through the use of organic matter and decreases methane emissions (Dossou-Yovo et al., 2022).

- **Combined application of biochar and nitrogen fertilizer**
  Over-reliance on inorganic nitrogen fertilizers leads to soil acidification, nutrient leaching, low nutrient use efficiency, and increased N_2O emissions. Smallholder farmers often lack access to integrated soil fertility management strategies, resulting in yield stagnation. Biochar, when combined with nitrogen fertilizer, improves soil structure, increases nutrient retention, and enhances microbial activity, thereby boosting fertilizer efficiency. This practice reduces GHG emissions and increases rice yields sustainably (Iboko et al., 2024).

- **Mid-season drainage**
  Continuous flooding in rice systems not only wastes water but also creates an anaerobic environment that intensifies iron toxicity and reduces plant vigor. Iron toxicity is a major abiotic stress in many African rice-growing regions, leading to yield losses of up to 60% (Sikirou et al., 2015). Mid-season drainage involves temporarily removing water during the tillering stage, which improves soil aeration, reduces iron toxicity, suppresses methane emissions, and enhances root health. It also increases water productivity by breaking continuous flooding cycles (Dossou-Yovo et al., 2023).

- **GEM parboiling**
  Traditional parboiling methods used in Côte d’Ivoire are energy-intensive, laborious, and inefficient, relying heavily on firewood and generating high levels of indoor air pollution. They often produce inconsistent rice quality with broken grains, poor color, and off-flavors, limiting market opportunities. The GEM (Grain quality enhancer, Energy-efficient, and durable Material) parboiling system addresses these challenges by using rice husks as fuel, reducing firewood use and GHG emissions. It ensures uniform steaming, leading to higher-quality parboiled rice with improved nutritional value, better market prices, and safer working conditions, especially for women processors (Ndindeng et al., 2015).

5.1.2 Cassava-based systems

The mitigation of greenhouse gas emissions from cassava-based systems will be achieved through cassava-legume intercropping, a tailored version of the AKILIMO agronomic advisory service for site-specific fertilizer recommendations and optimum planting and harvesting time, and improved cassava seed systems.

- **Cassava legume intercropping**
  Intercropping of cassava and legumes allows for more efficient use of the land cleared or prepared for the cultivation of cassava. In addition, cassava may use some of the nitrogen fixed by the legume crops. Although cassava yields are often reduced in intercropping systems, the land equivalent ratio (LER) is often larger than 1. The legume intercrop also contributes to reduction in soil erosion (Delaquis et al., 2018). The spatial arrangement of cassava and legumes can be modified to make the management of the companion crop more convenient or to allow for two subsequent companion crops (Pypers et al., 2011). Whether a second intercrop is possible depends on the vigor, growth habit, and size of the cassava crop during the period of the second legume crop (Kreye et al., 2020). For farmers, intercropping also provides an additional, early available source of cash generation until the cassava crop is ready for harvest after about 12 months. Cassava–legume intercropping enhances biological nitrogen fixation, reduces dependence on synthetic fertilizers, and lowers associated greenhouse gas emissions.

- **AKILIMO: Site-specific agronomic recommendations**
  AKILIMO is a tailored agronomic advisory service that provides site-specific recommendations for cassava production by integrating soil characteristics, local climate conditions, and nutrient requirements. Using the AgWise framework of the CGIAR Excellence in Agronomy Initiative, the tool generates optimized fertilizer recommendations that improve nutrient-use efficiency and reduce unnecessary input costs. By promoting targeted application of nitrogen and other essential nutrients, AKILIMO helps to minimize nitrogen losses to the environment, thereby reducing N_2O emissions. In addition, efficient nutrient management enhances soil health, supports higher cassava root yields, and ensures that land is used more productively, potentially sparing other areas from agricultural expansion and associated land degradation. Evidence from the ACAI project in Nigeria and Tanzania shows that AKILIMO site-specific recommendations increased cassava yields by up to 21% (ACAI Project Report, 2022).

- **AKILIMO: Optimized planting and harvesting time**
  Beyond nutrient management, AKILIMO also delivers tailored recommendations on the optimal planting and harvesting time for cassava, helping farmers align crop cycles with seasonal rainfall patterns and shifting climate conditions. By incorporating insights from the El Niño–Southern Oscillation (ENSO) phenomenon, AKILIMO enables farmers to make climate-informed decisions that increase resilience to weather variability. Adjusting planting schedules reduces risks of drought or flooding, and loss of fertilizer through nitrification and denitrification processes, thereby increasing fertilizer use efficiency.

- **Improved cassava seed systems**

  The ability of cassava to withstand difficult growing conditions and long-term storability of roots underground makes it an ideal candidate crop to address food insecurity and economic vulnerability that many countries in sub-Saharan Africa face due to climate change. Cassava production can only be raised sustainably, if farmers have access to climate-smart/resilient improved varieties, production technologies are made available, and the planting material supply system is strengthened and sustained. Climate-resilient and high yielding cassava varieties are more resilient to temperature and precipitation, making them more adaptable to changing climate conditions. They are also more resilient to drought, pests, and diseases. In this perspective, promising widely adaptable and high-yielding genotypes varieties from IITA's cassava breeding program will be released and recommended to support climate change adaptation strategies. The recommended genotypes have been thoroughly evaluated for their climate resilience and alignment with different product profiles well suited to food security. The widespread adoption of high-yielding varieties will contribute to reducing deforestation and/or the need to expand farmland and greenhouse gas emissions following the concept of sustainable intensification. The implementation of the planting material entrepreneur model will facilitate access to seeds and lower GHG associated with transportation.

5.1.3 Yam-based systems

The mitigation of GHG emissions from yam-based systems will be achieved through efficient planting arrangements for improved use of resources, climate-smart staking, nutrient uptake, and nutrient use efficient yam varieties and yam seed systems.

- **Efficient plant arrangements for improved use of resources**

  Replacing mounds by ridges makes crop management more efficient and allows for the use of appropriate planting densities, i.e. an increase to 10,000 to 10,416 plants ha^{-1} on ridges from 4,000 to 6,000 plants ha^{-1}on mounds (Danquah et al., 2022). Yam tubers harvested from ridges tend to be smaller than those harvested from mounds, but this may be an advantage for the export market. The direct benefit for farmers is harvesting a higher number of yam tubers from the same area. Based on evidence from testing in Ghana, combined planting on ridges with seed-tuber treatment and inorganic fertilizer application, use of the trellis system for staking and weed management leading to improve cost benefit ratios compared to conventional practice (mounding, no fertilizer, no seed-tuber treatment, conventional vertical staking) by a factor of 1.3 to 1.9 at three test sites in Ghana (Frimpong et al. 2020). Efficient plant arrangement such as replacing mounds with ridges and adopting optimal planting densities can reduce nitrous oxide (N_2O) emissions through more efficient fertilizer use and enhance soil carbon sequestration by minimizing soil disturbance and promoting greater biomass return to the soil.

- **Climate-smart staking - climate smart soil health and fertility improvement**

  Yam requires fertile soil and performs best when staked to support climbing. While tree-based systems for annual cropping failed to be adopted, the introduction of *Gliricidia sepium* as fallow species in yam systems has potential to furnish improved soil properties and stakes during the fallow phase. The leguminous tree contributes to improved soil fertility via nitrogen fixation and reduces the risk of climate change-related soil erosion via the mulch application from pruning in a crop that is usually characterized by low planting densities. Gliricidia is easily established from stem cuttings, it grows fast, fixes N2, and is easy to manage (Elevitch and Francis, 2006). Its growth habit of forming long, unbranched shoots, yet allowing for light to reach the soil surface (Carsky et al., 2010), makes it the perfect species to produce yam stakes. Two similar systems will be available for farmer adoption: Gliricidia live stakes and Gliricidia stakes to cut and carry (Otu and Agboola, 1994). The Gliricidia live stake system is based on a high density of Gliricidia stakes being planted as fallow. These stakes grow into a bush and are retained for 3 to 4 years. The fallow is then cleared such that 2 to 3 Gliricidia stakes are retained but stripped of their leaves. Excess shoots are cut off and either used as stakes in other fields (cut and carry), used as fuel wood, or simply left to rot along with the foliage. The yam is planted around the Gliricidia and trailed to the shoots to be used as climbing support. After the yam harvest, the site is left to regrow the Gliricidia. In the context of this project, we assume that 100,000 producers will benefit from a 16% yield increase using the Gliricidia stakes compared to using bamboo or other non-leguminous/live staking materials.

- **Improved yam seed systems**
  Work on yam seed systems will support the adoption of technologies of high ratio propagation of quality seeds and the establishment of a formal system to get genetic gains faster to farmers. There are no specialized seed yam producers in the traditional yam production systems. Techniques that can be applied for rapid multiplication include the Semi Autotrophic Hydroponics (SAH), minisetts, and leaf bud cuttings (LBC). LBCs of disease-free mother plants are used by seed entrepreneurs to produce seeds, increasing the multiplication rate of yam from 1:3 to 1:300. This will make planting materials more readily available.

- **Nutrient uptake and nutrient use efficient yam varieties**
  Selection of responsive genotypes available from IITA based on evaluation of their performance under the conditions of the target region varieties/genotypes will be assessed through gender integrated participatory citizen science-based variety selection methods such as tricot to facilitate and enhance uptake of improved varieties and accelerate realization of their climate change adaptation and mitigation potential. Efficient nutrient use reduces over-application of fertilizers, decreasing N_2O emissions, while improved biomass production contributes to greater soil organic carbon sequestration, enhancing the overall climate resilience of yam-based farming systems.

5.2 Emission reductions or removals attributable to the project

Over the five-year implementation period, the LARACI project will achieve substantial reductions in GHG emissions across rice, cassava, and yam value chains. Rice-based systems accounted for the largest share, with cumulative reductions of 3,042,108 tCO_2eq, mainly driven by the adoption of water-saving practices, biochar, and climate-smart postharvest technologies. Cassava systems contributed an additional 198,851 tCO_2eq reduction, reflecting gains from legume intercropping, tailored agronomic and site-specific advisory services, optimum planting and harvesting time, and improved seed systems. In yam systems, mitigation was initially negative due to the limited adoption of improved practices; however, from Year 3 onward, increased uptake of climate-smart agronomic measures including efficient plant spacing, climate-smart staking, nutrient-efficient varieties, and improved seed systems shifted yam to a net emissions sink, with cumulative reductions of 567,817 tCO_2eq. Altogether, the three value chains delivered a net emission reduction of 3,808,776 tCO_2eq, highlighting the potential of integrated climate-smart interventions to transform smallholder farming into a positive force for climate change mitigation.

6 Emission factors and data sources

6.1 List of emission factors used (e.g., tCO_2eq per hectare per year)

- **Rice**

  The estimation of GHG emissions under AWD, SRI, combined biochar and nitrogen fertilizer, and mid-season drainage in rice value chains was carried out using a set of standardized factors and methodologies. Baseline emissions were derived from continuously flooded rice fields without organic amendments (EFBL,c = 10.2 t CO_2eq/ha/season). CSA-induced emission estimates were then adjusted using specific scaling factors (SF) that capture differences in water management regimes, pre-season conditions, and organic amendment applications.

  - Scaling factor for water regime during cultivation (SFp,w): Reflects the impact of different water management practices, such as AWD, mid-season drainage, or intermittent flooding applied in system of rice intensification practice.
  - Scaling factor for pre-season water management (SFp,p): Accounts for field conditions before the cultivation period (e.g., whether the pre-season is flooded or non-flooded, and its duration).
  - Scaling factor for organic amendments (SFp,o): Adjusts for both the type and amount of organic material applied, such as compost or biochar, which can influence methane (CH_4) emissions.

  Greenhouse gas (GHG) emissions from the GEM (Gasifier-Enhanced Mechanized) parboiling technique were estimated using emission factors associated with both fuelwood consumption and rice losses during parboiling. The methodology accounts for two major emission sources:

  - Fuelwood use: GEM parboiling requires 0.5 t/ha of fuelwood, with an emission factor of 1.5 t CO_2 per ton of wood.
  - Rice loss: Postharvest rice loss during parboiling was estimated at 0.1336 t/ha, with an emission factor of 0.5 t CO_2 per ton of rice.

- **Cassava and yam**

  Greenhouse gas (GHG) emissions in cassava and yam systems were estimated using nitrogen inputs, biomass allocation, and established emission factors. Nitrogen fixation from cassava alone was estimated at 20 kg N/ha, while groundnuts contributed 50 kg N/ha when intercropped. For cassava monocropping, nitrogen input was 12 kg N/ha, compared to 20 kg N/ha in cassava–groundnut intercrops, with biomass allocation ratios of 60% to cassava and 40% to groundnuts. Nitrous oxide (N_2O) emissions were calculated using the default emission factor of 0.01 kg N_2O–N per kg N input, consistent with IPCC guidelines. Global warming potential (GWP) was set at 265 kg CO_2eq per kg N_2O, while carbon dioxide conversion was based on a carbon-to-carbon dioxide factor of 3.67. The carbon content of cassava and yam dry matter was assumed to be 0.3%.

6.2 Source and reliability of data (peer-reviewed literature, government data, etc.)

The estimation of GHG emissions in rice, cassava, and yam value chains relied on a combination of peer-reviewed scientific studies, standardized methodologies, and internationally recognized guidelines.

- **Rice value chain**: Baseline emission factors and scaling factors were primarily derived from the Clean Development Mechanism (CDM) methodology AMS-III.AU and peer-reviewed studies specific to West African rice systems. Direct field measurements using static chambers and gas chromatography (e.g., Iboko et al., 2024, submitted) were employed for technologies such as biochar and nitrogen fertilizer application, ensuring site-specific reliability. The use of standardized CDM methodologies enhances comparability across interventions, while field-based studies strengthen contextual accuracy. The estimation of GHG emissions from the GEM parboiling technique was based on a combination of peer-reviewed studies, project monitoring data, and internationally recognized emission factors. Fuelwood emission factors (1.5 t CO_2 per ton of wood) were derived from default values provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 2: Energy). Data on fuelwood consumption and rice loss during GEM parboiling (0.5 t/ha of wood and 0.1336 t/ha of rice, respectively) were sourced from field measurements and performance monitoring of GEM units by AfricaRice in West Africa.
- **Cassava and yam value chains**: Emission estimates were based on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 4: AFOLU, Chapter 11), particularly the Tier 1 methodology for N_2O emissions from crop residues. Default IPCC emission factors (0.01 kg N_2O–N per kg N input), global warming potentials (265 kg CO_2e per kg N_2O), and standard carbon conversion coefficients were applied. Supplementary data on nitrogen fixation, biomass allocation, and crop yields were sourced from peer-reviewed agronomic literature and government statistics relevant to West Africa.

Overall, the integration of internationally recognized methodologies (CDM, IPCC), peer-reviewed research, and localized field measurements provides a robust foundation for estimating CSA-induced GHG emissions.

7 Calculation of emission reduction

7.1 Step-by-step presentation of calculations:

The estimation of GHG emission reductions from CSA interventions follows a stepwise calculation framework to ensure transparency and reproducibility. The main steps are outlined below:

- Number of direct beneficiaries
- Average cultivated area per farmer per year (ha)
- Total targeted area (ha) by multiplying the number of direct beneficiaries by the average cultivated area per farmer
- Yield increment induced by CSA technology (t/ha) by estimating the additional yield obtained compared to the baseline
- Increase in biomass after CSA deployment (t/ha) as a ratio of the yield increment induced by CSA technology and the harvest index
- Increase in carbon in additional biomass (t/ha) by multiplying the biomass increment after CSA deployment by the carbon content in the biomass
- Carbon sequestration in CO_2-equivalent terms (tCO_2eq/ha/year) by converting the additional carbon into CO_2-equivalent using the molecular weight ratio of CO_2 to C (44/12)
- Total carbon sequestration (tCO_2eq/year) by multiplying the carbon sequestration with the total targeted area in a given year
- CSA-induced GHG emission reduction (tCO_2eq/year) by estimating GHG emission reductions from specific CSA practices (as described in Section 6)
- Leakage, which was considered as zero in estimation as no significant difference in leakage occurs following the use of the improved practices compared to the business-as-usual practices. Leakage was assumed to be zero because the CSA interventions are implemented within existing rice production areas and value chains and focus on improving management practices, productivity, and resource-use efficiency rather than expanding cultivated land or shifting activities elsewhere. The promoted practices—such as improved rice management and enhanced post-harvest processing—reduce emission intensity per unit of production without displacing agricultural activities or creating incentives for land-use change outside the project boundary. As a result, the risk of activity-shifting or market leakage is considered negligible, and the assumption of zero leakage is consistent with mitigation accounting approaches for efficiency-improving agricultural interventions implemented on existing farmland.
- Total reduced emissions (tCO_2eq/year) by deriving from total carbon sequestration, the CSA-induced reductions in GHG, and leakage

This systematic framework provides a transparent and replicable method for quantifying emission reductions, ensuring consistency with IPCC guidelines and carbon accounting standards.

7.2 Year-by-year and cumulative figures (over project lifespan)

The LARACI project achieved progressive reductions in GHG emissions over its five-year implementation period, reflecting the gradual scaling of CSA practices among beneficiaries.

- In Year 1, total emission reductions amounted to 12,313 tCO_2eq, corresponding to the initial phase of CSA adoption.
- In Year 2, reductions increased about five-fold to 62,611 tCO_2eq, as adoption rates expanded.
- In Year 3, the project achieved 133,743 tCO_2eq reduced, coinciding with the uptake of improved management practices across a wider area.
- Emission reductions continued to grow in Year 4 and Year 5, reaching 184,041 tCO_2eq and 213,504 tCO_2eq, respectively, as adoption by all direct beneficiaries was approached.

A negative emission reduction observed for yam systems in Years 1 and 2. This reflects the initial transition phase during early adoption of CSA practices, when emission increases associated with improved production practices temporarily outweigh the mitigation benefits. At 33% area coverage in Year 1 and 50% in Year 2, the mitigation benefits from improved nutrient use efficiency and better plant performance are not yet fully realized at scale. From Year 3 onward, as adoption expands from 66.7% to 100% of the target area and improved practices become fully established, gains in productivity, nutrient use efficiency, and biomass accumulation generate net positive emission reductions. The negative values in Years 1 and 2 therefore represent a short-term transition effect inherent to the scaling-up phase, while the positive values from Year 3 onward reflect the full mitigation benefits once CSA practices are widely adopted across the project area. This pattern is consistent with the phased implementation design of the project and does not affect the robustness of the central lifetime estimate of 3,808,776 tCO_2eq.

Over the project implementation timeline, the cumulative reduction reached 606,212 tCO_2eq, underscoring the transformative potential of CSA innovations in mitigating GHG emissions from smallholder production systems.

7.3 Summary of emission reductions by source/activity

TABLE 1: ANNUAL AND CUMULATIVE GREENHOUSE GAS EMISSION REDUCTIONS FROM RICE, CASSAVA, AND YAM VALUE CHAINS

	Total Emissions Reduction Rice	Total Emissions Reduction Cassava	Total Emissions Reduction Yam	Total
Year 1	55.311	3.615	(46.614)	12.313
Year 2	82.967	5.423	(25.779)	62.611
Year 3	110.622	7.231	15.890	133.743
Year 4	138.278	9.039	36.725	184.041
Year 5	165.933	10.846	36.725	213.504

8 Uncertainty and sensitivity analysis

8.1 Discussion of key assumptions

Several simplifying assumptions were applied in the analysis, including:

- Progressive adoption of CSA practices by beneficiaries, reaching 100% adoption in Year 5. The assumption of 100% adoption by Year 5 refers specifically to the direct project beneficiaries who will receive sustained technical, institutional, and financial support throughout the project implementation period. The project design includes extensive measures that are expected to significantly accelerate adoption, including strengthened climate information services, capacity building of extension agents, farmer training, demonstration and validation of CSA technologies, improved access to high-quality inputs and planting materials, strengthened farmer organizations, and improved access to financial services and markets. These integrated interventions—implemented through Components 1, 2, and 3—are designed to systematically remove key barriers to adoption (information, capacity, input availability, infrastructure, and finance). Therefore, the assumption reflects the expected uptake among farmers directly supported by the project after progressive scaling during the implementation period, rather than adoption across the wider farming population. It is used as a simplifying modeling assumption to estimate the project's potential mitigation impact under full implementation, while recognizing that actual adoption rates may vary depending on local conditions and farmer responses.

- Standardized emission factors for N_2O, CH_4, and CO_2, primarily derived from IPCC default values and CDM methodologies.
- Constant yield increments and biomass response to CSA practices, assuming average environmental and management conditions across the project area.
- Zero leakage, reflecting the assumption that adoption of CSA practices does not displace emissions elsewhere.

These assumptions were necessary to provide consistent and comparable estimates but may not fully capture local heterogeneity in farming practices, climate variability, or adoption behavior.

8.2 Uncertainty ranges

Uncertainty arises from both methodological and empirical sources:

- Emission factors: IPCC Tier 1 default factors (e.g., 0.01 kg N_2O–N per kg N input) carry inherent uncertainty.
- Yield response: Yield increments from CSA practices can vary substantially depending on climate, soil fertility, and farmer management.
- Scaling factors: For rice methane emissions, scaling factors applied to account for water management practices may vary with season, irrigation infrastructure, and soil properties, potentially introducing uncertainty into CH_4 reduction estimates.

8.3 Sensitivity tests (e.g., if yields or adoption rates vary)

A sensitivity analysis was conducted to test the robustness of the emission reduction estimates under alternative assumptions. Two scenarios were run directly from the Annex 22b model reported below.

8.3.1 Scenario 1: Reduced adoption trajectory (75% area coverage cap)

Under the central estimate, area coverage reaches 100% by Year 5, consistent with the project's phased implementation plan. Under this sensitivity scenario, area coverage is capped at 75% in Years 4 and 5, reflecting a more conservative assumption about the pace of CSA adoption among smallholder farmers in the five target regions.

TABLE 2: COMPARISON OF THE RESULTS OF THE CENTRAL AND REDUCED ADOPTION TRAJECTORIES

	Central estimate (tCO_2eq)	Scenario 1 (75% cap) (tCO_2eq)	Difference (%)
Year 5 total (tCO2eq)	606,212	539,580	-11%
Lifetime total (tCO2eq)	3,808,776	3,119,894	-18%

Even under this more conservative adoption trajectory, LARACI delivers material and credible emission reductions over the project lifetime, with the central estimate representing a mid-range rather than optimistic projection.

8.3.2 Scenario 2: N2O emission factor sensitivity

The central estimate applies the IPCC Tier 1 default N_2O emission factor of 0.01 kg N_2O-N per kg N input. This value sits at the conservative end of the published IPCC range of 0.003 to 0.03, which is appropriate for the smallholder rainfed systems in the target regions. Given that the default factor is already positioned conservatively within the IPCC range, the central estimate is not subject to material upward revision on emission factor grounds. The project team therefore considers the central estimate robust with respect to emission factor uncertainty for the specific production systems and management practices promoted under LARACI.

8.3.3 Conclusion

The sensitivity analysis confirms that the project's mitigation claim is robust under a range of plausible alternative assumptions. Under the most conservative scenario tested, a 75% adoption cap reducing lifetime emission reductions by 18% to 3,119,894 tCO_2eq, the scale of mitigation remains significant and the project's contribution to GCF's mitigation objectives is maintained. The central estimate of 606,212 tCO_2eq by Year 5 and 3,808,776 tCO_2eq over the project lifetime therefore represents a credible and well-evidenced mid-range projection.

9 Monitoring, reporting, and verification (MRV)

9.1 Overview of MRV plan for tracking GHG impacts

The LARACI project will implement an MRV framework to ensure transparent tracking of GHG mitigation outcomes across rice, cassava, and yam value chains. The MRV plan is designed to:

- Monitor progress in adoption of CSA practices and their corresponding impact on yields, soil health, and GHG emissions.
- Report emissions reductions annually and cumulatively against the baseline scenario, enabling comparisons of “business-as-usual” versus CSA adoption scenarios.

The MRV system will operate over the five-year project horizon, with continuous data collection from field trials, farmer adoption surveys, and selected site-specific measurements, ensuring accountability and credibility in quantifying emission reductions.

9.2 Indicators, data collection tools, roles, and responsibilities

Key performance indicators (see table 3) will be used to track both CSA adoption and GHG outcomes:

TABLE 3: INDICATORS THAT WILL BE USED TO TRACK CSA ADOPTION AND GHG OUTCOMES

INDICATOR	DESCRIPTION	CROP / VALUE CHAIN
CSA adoption rate (%)	Percentage of farmers implementing prescribed CSA practices	Rice, Cassava, Yam
Yield increase (t/ha)	Difference between project scenario and business-as-usual yields	Rice, Cassava, Yam
GHG emissions reduction (t CO_2e/ha/year)	Reduction in CO_2, CH_4, and N_2O emissions due to CSA practices	Rice, Cassava, Yam
Soil organic carbon increase (t C/ha)	Carbon sequestration from improved soil management	Rice, Cassava, Yam
Efficient input use	Reduction in synthetic fertilizer and water use	Rice, Cassava, Yam
Postharvest efficiency	Reduction in energy consumption and losses during processing	Rice

9.2.1 Data collection tools and methods

- Field measurements using static chambers, gas chromatography, and soil sampling for CH_4, N_2O, and CO_2 fluxes.
- Remote sensing and GIS mapping for monitoring cultivated area, crop type, and adoption extent.
- Farmer surveys and participatory monitoring to assess uptake of CSA practices and yield improvements.
- Project records for inputs, labor, and postharvest processing data.
- Emission factor tables and standardized calculation spreadsheets to convert activity data into CO_2-equivalent emissions.

9.2.2 Roles and responsibilities

TABLE 4: RESPONSIBILITLIES BY ACTORS

ACTOR	RESPONSIBILITIES
Project Monitoring Unit (PMU) and M&E Function	Coordinate MRV activities, data compilation, quality assurance, and reporting.
Field Agronomists / extension officers	Collect field-level data on CSA adoption, yields, and soil conditions; support farmer reporting.
GHG measurement specialists	Conduct direct measurements of CH_4, N_2O, and CO_2 using standardized protocols.
Farmer Groups	Participate in data collection, maintain records of CSA practices, and report crop management activities.

9.3 Quality assurance and verification of MRV data

The MRV plan incorporates robust measures to ensure data quality, regular data collection, and independent verification. Data quality will be assured through standardized protocols, training, and cross-checks. **F**ield agronomists and GHG measurement specialists will follow internationally recognized methods for measuring CH_4, N_2O, and CO_2 fluxes, and all data collected from farmer surveys and project records will be systematically verified for completeness and consistency by the Project Monitoring Unit (PMU) and M&E function. Data collection will occur continuously throughout the project, with field measurements and soil sampling conducted at regular intervals (e.g., crop growth stages or monthly for flux measurements) in selected farmers' fields, while farmer surveys and participatory monitoring will be conducted at least annually to capture CSA adoption and yield performance.

For independent verification, periodic third-party audits will be conducted by qualified external experts who will review MRV methodologies, sample measurement procedures, and reported emission reductions. Remote sensing and GIS analyses will complement field verification to cross-check adoption extent and land-use changes. Together, these measures guarantee that the MRV system produces reliable, verifiable, and reproducible GHG emission reduction data over the five-year project period.

TABLE 5: MRV MATRIX FOR TRACKING CSA ADOPTION AND GHG MITIGATION OUTCOMES

INDICATOR	FREQUENCY	DATA SOURCE / METHOD	QA/QC MEASURES
CSA adoption rate (%)	Annual	Farmer surveys; participatory monitoring	Standardized survey protocols, cross-checks by PMU, training of enumerators
Yield increase (t/ha)	Annual	Field measurements; farmer records	Standard measurement protocols, random sampling verification, PMU review
GHG emissions reduction (t CO_2e/ha/year)	Monthly (field measurements) / Annual (aggregate reporting)	Static chambers, gas chromatography, soil sampling; emission factor calculations	Standardized flux measurement protocols, calibration of instruments, third-party audits
Soil organic carbon increase (t C/ha)	At start and end of cropping season	Soil sampling and laboratory analysis	Standard laboratory protocols, duplicate samples, PMU verification
Efficient input use	Annual	Project records of fertilizer, water, and energy use	Record verification, cross-checks with farmer reports, PMU oversight
Postharvest efficiency	Annual	Project records of processing energy use and losses	Standard data templates, PMU review, independent audit

9.4 Alignment with Côte d'Ivoire's national MRV framework and GHG inventory

Although Côte d'Ivoire's national MRV system and greenhouse gas inventory framework remain under development, the LARACI project-level MRV system has been designed from inception to align with and actively support the evolving national framework. Alignment is ensured through four concrete mechanisms. First, the project will establish early coordination with MINETE, the institution responsible for national GHG inventory compilation and climate reporting, from the inception phase onward, ensuring that project-level methodologies and reporting formats are compatible with national requirements as they develop. Second, emission quantification under LARACI applies IPCC Tier 1 and where feasible Tier 2 methodologies, consistent with the methodological approach used in Côte d'Ivoire's national GHG inventory, ensuring that project-generated data can be directly integrated into national reporting without methodological conversion. Third, the project's MRV platform will be designed in a manner that facilitates data transfer to national inventory systems. Fourth, the MEL function includes an explicit mandate to strengthen MINETE's capacity on climate impact monitoring and MRV, ensuring that the national institutional capacity to absorb and use project-generated mitigation data is built in parallel with the project's own MRV system. These arrangements ensure that LARACI not only reports credibly to GCF but also makes a tangible contribution to the development of Côte d'Ivoire's national climate reporting infrastructure.