



ANNEX 22

Mitigation potential of the project RACINE

Abstract

The project RACINE has an estimated mitigation potential of 15.70 million tCO₂ equivalent (~11% of Cameroon's emissions from deforestation), derived from deliberately conservative, evidence-anchored assumptions; a multi-year baseline growth rate triangulated with remote-sensing data, a Cameroon-specific logistic model for agroforestry removals, and an ex-ante leakage deduction. It results from the carbon removals and emission reductions of the project's activities, especially the intensification of agricultural production on existing plantations to minimize the conversion of forested land, the adoption of organic fertilizers in place of conventional chemical inputs, the adoption of high-carbon agroforestry systems, and the implementation of landscape restoration activities with territorial entities (i.e. communes).

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Purpose and scope

This annex details the methodology used to calculate both the reductions in greenhouse gas (GHG) emissions and the carbon sequestration (removals) resulting from the RACINE project's interventions. Specifically, it explains how emissions avoided are estimated for activities that prevent the expansion of cocoa and coffee plantations into forested land during the project implementation time (~6 years). It also covers how carbon removals through agroforestry practices and landscape restoration are quantified over a longer timeframe (~20 years), to reflect the gradual accumulation of biomass and soil carbon.

The approach is fully aligned with the Green Climate Fund's (GCF) Integrated Results Management Framework (IRMF). This means that the project reports on standardized impact indicators, such as the number of tons of CO₂ equivalent (CO₂e) reduced or avoided as a result of its actions. It also tracks outcomes in the Agriculture, Forestry, and Other Land Use (AFOLU) sector, ensuring consistency with international best practices for climate finance and reporting. This robust methodology allows for transparent monitoring of the project's contribution to climate change mitigation, making results comparable and verifiable within the broader context of GCF-supported initiatives.

Alignment with GCF framework

The RACINE project contributes directly to the key result areas of the Green Climate Fund (GCF), focusing on mitigation. Specifically, it addresses the mitigation result area 4 (**MRA 4 - Agriculture, Forestry and land use**). The project promotes a paradigm shift toward deforestation-free agriculture through several core actions:

- **Sustainable intensification via FODECC's Producer Window:** By providing producers with access to inputs, equipment, and business plans, the project enables higher yields on existing farmland, reducing the pressure to clear new forest areas for cultivation.
- **Geolocation and traceability of all plots (EUDR compliance):** The project ensures that every agricultural plot can be traced and geolocated, aligning with the European Union Deforestation Regulation (EUDR). This requirement helps guarantee that exported cocoa and coffee are not linked to recent deforestation, promoting transparency and accountability in supply chains.
- **Widespread adoption of agroforestry:** By encouraging farmers to integrate trees into their agricultural systems, the project enhances carbon sequestration, improves soil health, and boosts farm resilience to climate shocks, while also supporting biodiversity.
- **Landscape restoration through PLADDT and green municipal investments:** The project supports the development of Local Land Use and Sustainable Development Plans (PLADDT) and invests in communal green infrastructure, fostering the

restoration of degraded landscapes and the long-term sustainability of agroforestry systems.

The project directly supports Cameroon's climate commitments by reducing emissions from Land Use, Land-Use Change, and Forestry (LULUCF) which account for 62% of the country's total emissions through forest conservation and enhanced carbon storage in agroforestry systems. It is consistent with the objectives of major national frameworks, including Cameroon's Vision 2030 (SND30), National Land Use Planning Strategy (SNADDT), the third version of the NDC (CDN 3.0), and the National Climate Plan (PNC 2025). This ensures a coordinated approach to sustainable development, climate resilience, and the achievement of national climate goals.

Methodological approach

This section outlines the principal methodologies and data sources used for estimating greenhouse gas (GHG) emissions and removals within the scope of RACINE project. The approach prioritizes internationally recognized standards, as well as national data, where available, to ensure both rigor and relevance to the local context.

Selected methodology

The methodology used for the estimation of the mitigation potential of the project RACINE is essentially based on the IPCC 2019 refinement of AFOLU guidelines. These guidelines, developed by the Intergovernmental Panel on Climate Change, provide a globally accepted framework for estimating emissions and removals in the Agriculture, Forestry, and Other Land Use (AFOLU) sector. Tier 1 methods use default values, while Tier 2 incorporates country-specific data where available, enhancing accuracy and local relevance.

National data sources used in the assessment include the CAFI funded study on the drivers of deforestation and forest degradation in the Congo Basin, data from the ONACC (National Observatory on Climate Change), MINFOF (Ministry of Forests and Wildlife), FAOSTAT, Global Forest Watch, PAVSGS-2C (IRAD), and studies such as CANNALS, PAIDATA and other studies from the literature. These sources provide the necessary local context and data for the more refined estimations and validation of assumptions. The focus is on ensuring that the methodologies used are both internationally validated and locally applicable, balancing ease of replication with the specificities of the project environment.

Table 1. Mitigation activities of the project RACINE and the methodologies used for the estimation of the mitigation potential

Windows	Mitigation Activities	Methodologies
Producer Window (G1)	Preventing deforestation via intensification	IPCC – Tier 2
	Use of chemical fertilizers to sustain the intensification	IPCC – Tier 2
Agroecological Transition Window	Switching to organic fertilizers	IPCC – Tier 1
	Increasing tree density and carbon stock enhancement	IPCC – Tier 2
Community Window (G2)	Reforestation and landscape restoration	IPCC – Tier 2
	Urban greening and riverbanks protection	Own approach

Gases covered

The principal greenhouse gas considered is carbon dioxide (CO₂), as it is the most significant in the context of land use change and forestry. Methane (CH₄) and nitrous oxide (N₂O) are also assessed, particularly in relation to organic fertiliser use, though they are considered minor and not determinative in this context. The Global Warming Potential (GWP) values are based on the IPCC's Sixth Assessment Report (AR6) over a 100-year time horizon (e.g. N₂O = 273 tCO₂e/t), allowing all GHG emissions to be expressed in terms of carbon dioxide equivalents (CO₂e) for comparability. This is consistent with the GWP values applied in the emission-factor tables and the accompanying calculation workbook.

Project boundary

The project covers eight cocoa and coffee producing regions in Cameroon (Centre, South, East, Littoral, South-West, West, North-West, Adamaoua). Essentially the humid parts of these regions. This delineation ensures that interventions and measurements are focused in the areas with the greatest potential for impact in terms of land use and emissions. Whilst the project will be operating in all these regions, the mitigation potential is limited to the project's operational boundaries, associated to the specific areas where the project operates and the specific mitigation activities implemented:

- Deforestation avoided by enforcing mandatory traceability systems and through the implementation of Local Land Use Plans (PLADDT), which **help prevent illegal or unplanned land conversion**.
- Prevention of agricultural expansion into permanent forest estate areas, **safeguarding existing forest carbon stocks**.
- Agricultural intensification and the valorisation of fallows (improved use of previously cultivated land), **reducing the pressure to clear additional forest land**.
- The promotion of cocoa/coffee agroforestry systems, including the integration of fertiliser trees, shade trees, and native species, which **increase on-farm carbon storage**.

- Landscape restoration efforts led by local councils, which contribute to **increasing forest cover and carbon sinks** at the landscape scale.

Baseline scenario

In the absence of the proposed project, the cocoa and coffee sector would continue along its current trajectory, which presents several significant challenges and risks:

BaU1 - Ongoing deforestation and degradation and very limited intensification

In Cameroun, coffee and cocoa production are responsible for 9% deforestation and 4% forest degradation¹. A large part of this disturbance occurs primarily in forested areas (dense primary and secondary forests)². In 2023, Cameroon has lost 0.2 million ha of forests due to deforestation and 0.68 million ha of forests due to forest degradation. Given the trajectory recorded over the past decades, deforestation and degradation are most likely going to increase during the 6 years of this project implantation.

Baseline emission from coffee and cocoa expansion

The baseline emission from coffee and cocoa expansion over forested lands (E_{AE} , tCO₂e/year) can be estimated by multiplying the total area needed for the expansion of plantations (A_{exp} , ha) with the emission factor (EF) for the conversion of forested land into perennial cropland. A_{exp} is calculated from the actual estimate of coffee and cocoa production (P_0 , ton), the estimated production growth (P_{Gr} , %) and the actual yield (Y_0 , ton/ha) as follow:

$$A_{exp} = \frac{P_0 * P_{Gr}}{Y_0}$$

$$E_{AE} = A_{exp} * EF$$

The emission factor for the transition from forested land into perennial crops (EF), comprising the above ground and belowground biomass, for Cameroon was obtained from [Pirker et al. \(2019\)](#)³.

The Cameroon's Government has the ambition to triple cocoa production by 2030, suggesting an increased production from 320,000 tonnes recorded in 2024 to 960,000 tonnes by 2030. This target implies an annual production growth of 107,000 tonnes, representing 33% of the 2024 production. While this ambition-led projection forms the basis of the estimate, historical production statistics can offer further insight into observed trends. However, reliable historical data on cocoa and coffee production in Cameroon are scarce. A comprehensive assessment by the UN FAO, utilising both empirical data and modelling, provides an overview of cocoa and coffee bean production from 1961 to 2024.

¹ Masolele, R.N., Marcos, D., De Sy, V. et al. Mapping the diversity of land uses following deforestation across Africa. *Sci Rep* **14**, 1681 (2024). <https://doi.org/10.1038/s41598-024-52138-9>

² Global assessment of direct drivers of deforestation and degradation in the Congo Basin from 2015 to 2023 (CAFI-FAO 2025)

³ Pirker J, Mosnier A, Nana T, Dees M, Momo A, Muys B, Kraxner F, Siwe R. Determining a Carbon Reference Level for a High-Forest-Low-Deforestation Country. *Forests*. 2019; 10(12):1095. <https://doi.org/10.3390/f10121095>

According to this analysis, cocoa bean production in Cameroon rose from 122,600 tonnes in 2000 to 320,000 tonnes in 2024, reflecting an average annual growth rate of 4.1%. The significant gap between this historical growth rate and the government’s ambitious target is attributable to the ongoing efforts to strengthen the cocoa sector and the influence of market incentives.



Recent data from the International Cocoa Organisation supports the idea of a notable increase in cocoa production in recent years: output rose from 270,000 tonnes in the 2022/2023 season to 320,000 tonnes in 2023/2024, representing an annual growth rate of 18.5%⁴. This figure provides a more realistic basis for estimating future production and associated impacts. Regarding market incentives, cocoa prices have gradually risen, over the past five years, reaching an unprecedented level of CFA 5,000–CFA 6,000 per kilogram during the 2023/2024 production season. However, this surge comes at a cost: it incentivises producers to expand their output, which in Cameroon is likely to occur through the extension of plantations due to limited scope for yield intensification.

This effect is not immediately apparent in production statistics, as newly established plantations typically require three to six years before becoming productive. A more accurate way to assess this impact is by analysing data on tree cover loss and the expansion of permanent agricultural lands. One of the best option is to explore RADD alerts, radar-based satellite alerts that detect forest disturbances in near-real-time. Between 2020 and 2025, RADD alerts have recorded 781,797.7 hectares of forest loss alerts, corresponding to 156,359 ha of forest loss alerts annually across the country. An important portion of these alerts were recorded in areas identified as highly suitable for cocoa cultivation. The trend is worsening: 2024 marked the highest loss year, with nearly 205,000 ha of Cameroon’s forests deforested. The impacts are particularly stark at the local level. Over the past five years, 64

⁴ ICCO Quarterly Bulletin of Cocoa Statistics, Vol. LI, No.1, Cocoa year 2024/25

subdivisions lost at least 10% of their forest cover, 21 lost more than 20%, five exceeded 30%, and two Kribi II and Bafoussam II lost over 40% of their remaining forests⁵.



From left to right: 2019 Forest Baseline Map (green); High Confidence RADD alerts since 2019 (red); FDP Cocoa Prediction (Blue) Source: *Mighty Earth Cocoa Accountability Map*

To keep the baseline credible and conservative, the central case is anchored on best-available multi-year evidence rather than on a single-year change. The FAO/Our World in Data series indicates a 2000–2024 compound annual growth rate (CAGR) of 4.1% (122,600 t in 2000 to 320,000 t in 2024), which we adopt as the central baseline production growth. The single-year change of 18.5% recorded between the production season 2022/2023 and 2023/2024) is retained only as an upper (high-sensitivity) bound. At the 4.1% central rate this corresponds to 13,051 tons of production increase per year. Unfortunately, the sector is not seeing meaningful improvements in productivity or sustainable intensification practices, leading to a persistent need for more land rather than better yields from existing fields. With the average yield of 0.35 ton/ha⁶, this annual production increase will lead to an expansion of coffee and cocoa plantations over 37,288 ha of dense forests annually and an estimated emission of **8.46 million tCO₂e/year**. The implied conversion of ~37,288 ha/year is triangulated against independent spatial evidence. RADD radar alerts recorded ~782,000 ha of forest-loss alerts nationally over 2020–2024 (~156,000 ha/year; ~4.2% of national forest cover; Mighty Earth, 2025)⁷, and this loss is spatially concentrated in the cocoa belt rather than spread evenly across the country: the Centre region alone, which supplies ~58% of national cocoa (ONCC, 2023)⁸, is among the fastest-losing areas, and subdivisions such as Kribi II and Bafoussam II have lost over 40% of their remaining forest. Cocoa-planted area in Cameroon expanded by ~242% over recent decades (ICCO, 2021)⁹, and across western and central Africa smallholder cropland, within which Cameroon’s predominantly agroforestry cocoa is embedded, is the single largest follow-up land use after deforestation

⁵ [Cocoa Deforestation in Cameroon Report | PDF | Cocoa Bean | Deforestation](#)

⁶ Kamdem, C.-B. (2018). Farmer Field Schools and Cocoa Yield in Cameroon. *Revue d’économie du développement*, 26(4), 99-124. <https://doi.org/10.3917/edd.324.0099>. | UN FAO (2024). Cocoa bean yields, 1961 to 2024. World Data. [Cocoa bean yields, 1961 to 2024](#)

⁷ Mighty Earth (2025). Cameroon on the Brink: Cocoa’s New Deforestation Frontier.

⁸ Office National du Cacao et du Café (ONCC), Cameroon (2023). National cocoa production statistics by region.

⁹ International Cocoa Organization (ICCO) (2021). Quarterly Bulletin of Cocoa Statistics – cocoa production and planted-area data.

(64% of forest loss; Masolele et al., 2024)¹⁰, cocoa forming part of the dominant “arc of commodity crops”. Because cocoa-driven clearing is localised in the humid cocoa zones, a national-average driver share understates its intensity there. The WRI/Global Forest Watch dominant-driver dataset (Sims et al., 2024)¹¹ attributes ~38% of Cameroon’s 2020-2024 tree-cover loss to permanent agriculture, the class capturing conversion to permanent tree crops such as cocoa, equivalent to ~60,000–68,000 ha/year nationally, with a further ~53% attributed to shifting cultivation, within which Cameroon’s predominantly smallholder agroforestry cocoa is partly embedded. On this basis the ~37,288 ha/year implied by the 4.1% central rate is credible and conservative relative to the observed scale and trajectory of forest loss in Cameroon’s cocoa landscapes. For transparency, sensitivity bounds are reported as low 1.5% (RADD-triangulated), central 4.1% (FAO 2000–2024 CAGR) and high 18.5–24% (recent single-year change and government ambition); the full sensitivity table is provided in the accompanying workbook. Baseline LULUCF parameters (the forest-to-perennial-crop emission factor) are kept inventory-consistent and applied identically in the baseline and project scenarios.

BaU2 - Continuous implementation of low-carbon agroforestry systems

As shade species trees, cocoa and coffee in Cameroon are widely grown under agroforestry systems rather than pure monocultures. The tree density applied varies by management style and region. A cocoa plantation in Cameroon has on average 1489 plants/ha of which 321 plants are associated shading trees¹². Although the total C stock of cocoa agroforest in Cameroon is comparable to that of secondary forest, only a small proportion of that carbon is stored in the cacao trees. The average C stock of cacao agroforests ranges from 50.3 tC/ha in young agroforests to 197 tC/ha in old agroforests with cocoa trees storing on average 14.4 tC/ha and shaded trees storing on average 121.1 tC/ha¹³. The baseline scenario here is the annual carbon absorption of an average 25 years cocoa agroforest in Cameroon which was estimated for the agroforests in Cameroon by Silatsa et al. (2017)¹⁴.

¹¹ Sims, M., Stehman, S. V., Tyukavina, A., et al. / World Resources Institute – Global Forest Watch (2024). “Tree cover loss by dominant driver” (1 km, 2001–2024). Accessed 2026 via Our World in Data. <https://www.globalforestwatch.org>

¹² Sonwa, D.J., Weise, S.F., Nkongmeneck, B.A. et al. Structure and composition of cocoa agroforests in the humid forest zone of Southern Cameroon. *Agroforest Syst* 91, 451–470 (2017). <https://doi.org/10.1007/s10457-016-9942-y>

¹³ Norgrove, L. & Hauser, S. T. E. F. A. N. (2013). Carbon stocks in shaded *Theobroma cacao* farms and adjacent secondary forests of similar age in Cameroon. *Tropical Ecology*, 54(1), 15-22. <https://hdl.handle.net/10568/76059>

¹⁴ Silatsa, F.B., Yemefack, M., Ewane-Nonga, N., Kemga, A. & Hanna, R. (2017). Modeling carbon stock dynamics under fallow and cocoa agroforest systems in the shifting agricultural landscape of central Cameroon. *Agroforestry Systems*, 1-14. <https://doi.org/10.1007/s10457-016-9973-4>

Baseline absorption from the continuous implementation of low-carbon agroforestry

The baseline absorption here is the absorption of the current coffee and cocoa plantations (A_{BaU} , tCO₂e/year) and is estimated for each year following IPCC recommendations using the following formula:

$$A_{BaU} = S * C * \frac{44}{12}$$

Where S is area in hectare of the agroforest, C is the carbon increment of a traditional agroforest in Cameroon obtained from Silatsa et al. (2017) and the 44/12 is the conversion factor to move from C to CO₂e.

With this low-carbon agroforestry setting, the total absorption of the plantations is around 11.13 million tCO₂e/year absorbed by all the plantations of the 700,000 coffee and cocoa producers.

BaU3 - Limited green investments at the communal level

Despite Cameroon's rich forest resources and strong national climate commitments, green investments at the communal level, particularly in afforestation, reforestation, natural regeneration, and forest conservation, remain severely limited. Most climate and forest financing is centralized or absorbed by large, externally driven projects, leaving communes with minimal access to funding, technical expertise, and implementation support. Although communes are legally responsible for local development and natural resource management, they lack dedicated mechanisms to finance long-term forest restoration. As a result, communal forests and degraded lands are often under-managed or exploited for short-term gains, with little investment in regeneration, conservation, or carbon sequestration.

Existing local initiatives are generally small, fragmented, and time-bound, led mainly by NGOs and unable to generate lasting ecological or institutional impact. This investment gap contributes to continued forest degradation, weak climate resilience, and missed opportunities for green jobs and ecosystem services. Targeted communal-level green investment programs are therefore critical to translate national commitments into local action, strengthen community forest governance, and position forest restoration as a driver of climate resilience and inclusive local development. **The baseline scenario here is that no such investments will be done over the next 6-20 years.** The baseline scenario results in substantial greenhouse gas emissions due to ongoing deforestation, carbon loss from forest conversion, and unsustainable land management. These emissions are projected to continue or even increase if no intervention is implemented to address the root causes in the cocoa and coffee sector.

Project scenario

The project RACINE envisions a transformative shift within Cameroon's coffee and cocoa sector by promoting sustainable, climate-smart agricultural practices. Building upon the challenges identified in the baseline scenario, the project introduces targeted interventions designed to both reduce greenhouse gas emissions and enhance carbon sequestration. Key strategies include intensifying agricultural production on existing plantations to minimise the conversion of forested land, encouraging the adoption of organic fertilisers in place of conventional chemical inputs, expanding high-carbon agroforestry systems, and implementing reforestation, regeneration and conservation activities.

MA1 - Agricultural intensification

The RACINE project intends to increase the yield of coffee and cocoa plantations by 20%, suggesting a production increase from 0.35 ton/ha to 0.42 ton/ha. This increase is expected to be achieved through the use of chemical fertilizers (i.e. 600 kg/ha/year of NPK 15:15:15 and 100 kg/ha/year of Urea 46%). The project intends to reach 50% of coffee and cocoa producers (i.e. 350,000 producers) with this support on intensification. If half of the producers achieve 20% of yield increase, the need for new forested lands over which to expand the plantations will be reduced, leading to a reduced emission.

Emission resulted from agricultural expansion in the context of RACINE (i.e. with intensification)

The emission resulted from agricultural expansion under the context of RACINE project can be estimated based on the area of expansion needed under the context of the project (A_{exp}). This later is estimated as the sum of the area needed for expansion by 50% of producer producing without the intension support from the project, with a yield (Y_0) of 0.35 tons/ha and the area needed for expansion by 50% of producer producing with the intension support from the project, with a yield (Y_1) of 0.42 tons/ha. The calculations involve the actual estimate of coffee and cocoa production (P_0 , ton), the estimated production growth (P_{Gr} , %) as follow:

$$A_{exp} = \left(\frac{P_0 * P_{Gr}}{2 * Y_0} \right) + \left(\frac{P_0 * P_{Gr}}{2 * Y_1} \right)$$

$$E_{AI} = A_{exp} * EF$$

EF is the emission factor for the transition from forest to perennial crops, comprising the above ground and belowground biomass ([Pirker et al. 2019](#)).

With the intensification, the yield of cocoa plantations is expected to increase from 0.35 tons/ha to 0.42 tons/ha (20% increase). If 700,000 producers produce at a yield of 0.35 tons/ha, this represents a total area of 914,286 ha. The 50% of producers supported to achieve this 20% increase in yield therefore represent a total of 457,143 ha covered. In the baseline scenario, we showed that an annual production increase of 13,051 tons is expected to occur over the next years due to the actions of all the 700,000 producers. This means that for 50% of producers, an annual production increase of 6,526 tons is expected,

representing a total of 18,644 ha needed with the baseline yield of 0.35 tons/ha. With the 20% of yield increase (i.e. 0.42 tons/ha), the 6,526 tons will only require 15,537 ha of expansion which in addition to 18,644 ha of expansion realized by the 50% of producers who are not supported for the intensification leads to a total of 34,181 ha of expansion compared to the 37,288 ha of expansion in the baseline scenario (i.e. 3,107 ha of avoided deforestation).

The estimated emissions in this context is estimated at 7.75 million tCO₂e/year, compared to the 8.46 million tCO₂e/year observed in the baseline scenario, suggesting an emission reduction of 0.71 million tCO₂e/year (gross). Because cocoa is a high-value, demand-elastic export crop that can drive rebound rather than land-sparing (Byerlee et al. 2014; Ceddia et al. 2014), a conservative 15% ex-ante leakage (rebound) deduction is applied as the central case (sensitivity 10–40%), credited to the project's strong governance controls (mandatory polygon geolocation and EUDR traceability, PLADDT zoning, conditional and penalised subsidies). The reported avoided-deforestation impact for MA1 is therefore 0.60 million tCO₂e/year at the central rate (3.61 MtCO₂e over the 6-year project lifetime; the 10–40% bounds give roughly 0.42–0.63 million tCO₂e/year). Ex post, leakage is measured following AFOLU good practice (VCS AFOLU; VM0006): a reference region (leakage belt) surrounding the intervention areas is monitored for displaced forest clearing, combined with market and expansion indicators (national cocoa-area statistics and RADD tree-cover-loss trends in cocoa-suitable zones); a proportional deduction is applied if displacement or project-attributable expansion is detected. Monitoring the supported plots alone is treated as insufficient, because rebound and market-mediated leakage occurs off the project plots.

MA2 - Use of chemical fertilizers to sustain intensification

The emission reduction that will be secured by the project RACINE through the intensification will consist of the use of chemical fertilizers (NPK and urea). However, the use of fertilizers contributes to GHG emissions mainly through (i) direct N₂O emissions from managed soils, (ii) indirect N₂O emissions (via volatilization, leaching and runoff), (iii) CO₂ emissions from urea hydrolysis and (iv) upstream emissions from fertilizer manufacturing and transport. The first three are here called on-farm emissions. In Cameroon, many farmers use NPK fertilizers (i.e. NPK 15:15:15) to boost yields, though usage levels vary widely. Urea is also widely used. Urea (CO(NH₂)₂) contains 46% nitrogen, making it the most concentrated and widely used nitrogen fertilizer in Cameroon. In the framework of the project RACINE, coffee and cocoa producers will be supported to obtain and apply 600 kg/ha/year of NPK 15:15:15 and 100 kg of Urea/ha/year to achieve the 20% increase in their production without expanding their plantations.

Emissions resulted from the use of chemical fertilizers

The emissions resulted from the use of chemical fertilizers (E_{CF} , tCO₂e/year) was estimated using IPCC formulas for emissions from managed soil. We combined on-farm emissions with upstream emissions. The first one was calculated based on the CO₂e from direct (N_2O_{Direct}) and indirect ($N_2O_{Indirect}$) soil N₂O emissions and the CO₂ emission from Urea application (CO_{2Urea}). The later was calculated based on the CO₂e from fertilizers manufacturing and transportation. The following formulas were therefore used (see Chapter 11 of the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories):

$$E_{CF} = CO_2e_{N_2O_{Direct}} + CO_2e_{N_2O_{Indirect}} + CO_{2Urea} + CO_2e_{manufacturing} + CO_2e_{transport}$$

$$CO_2e_{N_2O_{Direct}} = (N_{NPK} + N_{Urea}) * EF_a * \frac{44}{28} * 273$$

$$CO_2e_{N_2O_{Indirect}} = (N_{NPK} + N_{Urea}) * EF_b * \frac{44}{28} * 273$$

$$CO_{2Urea} = Q_{Urea} * EF_c * \frac{44}{12}$$

Where N_{NPK} and N_{Urea} are the total quantities of nitrogen inputs on the soil, resulted from the application of NPK and urea respectively and Q_{Urea} is the total quantity of urea that will be used annually. The CO₂e emission from fertilizer manufacturing ($CO_2e_{manufacturing}$) was estimated for each component of the concerned fertilizers using the following formula:

$$CO_2e_{manufacturing} = (Q_N * EF_{N-m}) + (Q_P * EF_{P-m}) + (Q_K * EF_{K-m}) + (Q_{Urea} * EF_{Urea-m})$$

Where Q_N , Q_P , Q_K and Q_{Urea} are the quantity of Nitrogen, Phosphate, Potash and urea that will be used by the coffee and cocoa producers and EF_{N-m} , EF_{P-m} , EF_{K-m} and EF_{Urea-m} are the corresponding emission factors for the manufacturing of the corresponding fertilizers.

The CO₂e emission from the transportation of fertilizers was estimated considering a national distribution over an average (D) of 100 km distance from the purchased location using the following formula:

$$CO_2e_{transport} = (Q_{NPK} + Q_{Urea}) * D * EF_t$$

Where EF_t is the emission factor for heavy-duty truck. Emission factors are derived from IPCC AFOLU guidelines (2006 with 2019 Refinement) for on-field emissions, and from widely used life-cycle assessment default ranges for fertiliser manufacturing and transport (see Table 2 and Table 3 below). Tier 2 climate-specific emission factors were applied for humid tropical conditions¹⁵.

In Cameroon, many farmers use NPK fertilizers (e.g., NPK 15:15:15 and similar blends) to boost yields Urea is also widely used. Urea (CO(NH₂)₂) contains 46% nitrogen, making it the most concentrated and widely used nitrogen fertilizer in Cameroon. Nevertheless, fertilizer

¹⁵ Hergoualc'h, K., Mueller, N., Bernoux, M., Kasimir, A., van der Weerden, T. J., & Ogle, S. M. (2021). Improved accuracy and reduced uncertainty in greenhouse gas inventories by refining the IPCC emission factor for direct N₂O emissions from nitrogen inputs to managed soils. *Global Change Biology*, 27, 6536–6550. <https://doi.org/10.1111/gcb.15884>

usage among producers varies significantly and is often insufficient due to cost limitations. While some producers do apply fertilizers, robust farm-level data on actual quantities are not available. We therefore adopt a deliberately conservative baseline of zero synthetic fertilizer use. This is the conservative choice for net mitigation accounting: it attributes the full fertilizer-related emissions to the project (counted as negative mitigation under MA2) and assumes no pre-existing baseline emissions to offset against them, thereby avoiding any overstatement of the project's net benefit. Actual application rates will be recorded during implementation and the baseline updated if monitoring shows material pre-project use. In the framework of the project RACINE, coffee and cocoa producers will be supported to obtain and apply 600 kg/ha/year of NPK 15:15:15 and 100 kg of Urea/ha/year to achieve the 20% increase in their production without expanding their plantations. This will be done during the first 3 years of project implementation than a transition to organic fertilizers will be achieved for the 3 remaining years. The target for this support is 50% of the 700,000 producers and therefore 50% of the 914,286 ha (i.e. 320,000 tons produced with an estimated yield of 0.35 ton/ha), corresponding to a total of 350,000 producers and 457,143 ha to be covered. This represents a total of 274,286 tons of NPK and 45,714 tons of urea per year.

Table 2. Emission factors (Tier1 and Tier2) for the different sources of emission from managed soil as defined by IPCC

Emission source	Gas	Emission factor	Unit	Applies to	Notes
Direct soil emissions (Tier 1)	N ₂ O-N	0.01	kg N ₂ O-N / kg N applied	All fertilisers	IPCC default EF ₁
Direct soil emissions (Tier 2 – dry climate)	N ₂ O-N	0.005	kg N ₂ O-N / kg N applied	All fertilisers	IPCC 2019 Refinement
Direct soil emissions (Tier 2 – wet climate)	N ₂ O-N	0.014	kg N ₂ O-N / kg N applied	All fertilisers	IPCC 2019 Refinement
Direct soil emissions (Tier 2 – wet climate, synthetic fertilizer)	N ₂ O-N	0.016	kg N ₂ O-N / kg N applied	Urea, NPK	Recommended for humid Cameroon
Direct soil emissions (Tier 2 – wet climate, organic fertilizer)	N ₂ O-N	0.006	kg N ₂ O-N / kg N applied	Urea, NPK	Recommended for humid Cameroon
Indirect soil emissions (volatilisation + leaching)	N ₂ O-N	0.00325	kg N ₂ O-N / kg N applied	All fertilisers	Tier 1 default combined
Urea hydrolysis (field CO ₂)	CO ₂	0.73	kg CO ₂ / kg urea	Urea only	Based on 0.20 kg C/kg urea
Global Warming Potential (AR6, 100 yr)	N ₂ O → CO ₂ e	273	kg CO ₂ e / kg N ₂ O	All N ₂ O	AR6 metric

The EF for indirect soil emissions is a shorthand value inspired by the IPCC defaults as follow: (Fraction volatilised × EF for redeposition)+(Fraction leached/runoff × EF for leached N)

Only the nitrogen fraction drives soil N₂O emissions under IPCC managed-soils methods. This therefore represents 136 Kg of nitrogen deposition on the soil per hectare and per year (90 Kg from the use of NPK and 46 Kg from the use of Urea). This represents a total nitrogen quantity of 41,143 ton/year from NPK and 21'029 ton/year from urea. In addition to the nitrogen, the NPK contains 15% of phosphate and 15% of potash, representing for each a total of 41,143 ton/year that needs to be accounted for the calculation of upstream emissions.

Table 3. Emission factors (Tier1 and Tier2) for the different component of the fertilizers considered in the RACINE project from the commonly used LCA default values (the mid values was considered in this assessment)

Fertiliser component	Emission factor (low)	Emission factor (mid)	Emission factor (high)	Unit	Dominant driver
Nitrogen (N)	4	5	6	kg CO ₂ e / kg N	NH ₃ synthesis energy
Phosphate (P ₂ O ₅)	0.8	1.2	1.5	kg CO ₂ e / kg P ₂ O ₅	Mining + processing
Potash (K ₂ O)	0.4	0.6	0.7	kg CO ₂ e / kg K ₂ O	Mining energy
NPK (average, mass-based)	0.9	1.1	1.4	kg CO ₂ e / kg fertiliser	N dominates
Urea (product-based)	1.5	1.7	2	kg CO ₂ e / kg urea	Natural gas use

After calculations, and using a single consistent transport assumption of 100 km of national distribution to the farm (heavy-duty truck), a total additional emission of approximately 1.00 million tCO₂e/year is expected from the use of chemical fertilizer in the framework of the RACINE project.

MA3 - Switching from chemical to organic fertilizers

The project RACINE intends to implement agroecological transition progressively. A first focus will be on the coffee and cocoa producers to whom supports were provided to achieve the intensification of their production through the use of chemical fertilizers. With these producers, the project intends to completely replace chemical fertilizers that lead to emission by organic fertilizers that are emission-free or insignificant. The goal is to achieve this transition on a total of 90,000 ha of plantations that have received support for the intensification through chemical fertilizers, corresponding to approximately 45,000 producers. This support will start from year 4 after chemical fertilizers usage by the producers. We assume no upstream emissions here, suggesting that locally produced bio organic fertilizers will be highly promoted by the project. The baseline here corresponds to the total emissions resulted from the use of chemical fertilizers over 90,000 ha, calculated as in MA2.

Emissions reduction resulted from the transition chemical to organic fertilizers

The emissions reduction resulted from the transition chemical to organic fertilizers (E_{C-O} , tCO₂e/year) is calculated as the difference between the emissions resulted from the use of chemical fertilizers on the target area of 90,000 ha (E_{CF} , tCO₂e/year) and the emissions resulted from the use of organic fertilizers (E_{OF} , tCO₂e/year). E_{CF} was obtained using the approach and formulas described in MA2 and E_{OF} was estimated using IPCC formulas for emissions from managed soil, considering only on-farm emissions. The following formulas were therefore used (see Chapter 11 of the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories):

$$E_{C-O} = E_{CF} - E_{OF}$$

$$E_{OF} = CO_2e_{N_2O_{Direct}} + CO_2e_{N_2O_{Indirect}}$$

$$CO_2e_{N_2O_{Direct}} = N_{OF} * EF * \frac{44}{28} * 273$$

$$CO_2e_{N_2O_{Indirect}} = N_{OF} * EF * \frac{44}{28} * 273$$

Where N_{OF} is the total quantity of nitrogen inputs on the soil, resulted from the application of the organic fertilizer annually. This quantity of nitrogen should be equivalent to the corresponding quantity of nitrogen needed on 90,000 ha if 600kg of NPK and 100 kg of urea were applied. Emission factors are derived from IPCC AFOLU guidelines (2006 with 2019 Refinement) for on-field emissions, and from widely used life-cycle assessment default ranges for fertiliser manufacturing and transport (see Table 2 and Table 3 above). Tier 2 climate-specific emission factors were applied for humid tropical conditions¹⁶.

On this 90,000 ha, with 600 kg of NPK and 100 kg of urea applied per hectare and per year, a total quantity of 54,000 tons of NPK and 9,000 tons of urea. The overall quantity of nitrogen deposition on soil therefore corresponds to 12,240 tons per year (i.e. 8,100 tons for NPK and 4,140 tons for urea). The counterfactual synthetic-fertilizer emissions on these 90,000 ha amount to approximately 0.187 MtCO₂e/year; deducting the residual field N₂O emissions of the organic fertilizers (~0.049 MtCO₂e/year), the transition avoids approximately 0.139 MtCO₂e/year from year 4 of implementation onward.

Accounting boundary for organic inputs. The exclusion of upstream emissions for organic fertilizers is justified on three grounds: (i) the feedstock consists of crop residues, animal manure and green waste that would otherwise decompose in situ, generating comparable or higher CH₄/N₂O emissions without any energy input; (ii) composting is carried out on-farm or within the community with no industrial processing; and (iii) transport distances are below 5 km, generating negligible CO₂. Life-cycle assessments of on-farm composting (Boldrin et al. 2009; Komilis & Ham 2004) confirm upstream emissions of 5–15% of equivalent synthetic-fertilizer emissions. Nonetheless, a conservative 10% upstream buffer on the nitrogen-equivalent of organic inputs is retained in the high-sensitivity scenario of the workbook. An MRV trigger applies: if feedstock sourced from forest or fallow clearing is detected through geo-tagged biomass-procurement records, the corresponding upstream emissions will be quantified and deducted from the MA3 impact for that reporting period.

MA4 - Carbon stock enhancement in coffee and cocoa plantations

In the baseline scenario, we showed that cocoa plantations in Cameroon have on average 1489 plants/ha of which 321 plants are associated shading trees (Sonwa et al. 2007). The project RACINE envisions to achieve a peak carbon-absorption increment of about 3 tons of carbon per hectare per year (the maximum of a logistic growth curve) over 90,000 hectares of cocoa and coffee agroforests through the introduction of 400 additional fast-growing shaded trees.

¹⁶ Hergoualc'h, K., Mueller, N., Bernoux, M., Kasimir, A., van der Weerden, T. J., & Ogle, S. M. (2021). Improved accuracy and reduced uncertainty in greenhouse gas inventories by refining the IPCC emission factor for direct N₂O emissions from nitrogen inputs to managed soils. *Global Change Biology*, 27, 6536–6550. <https://doi.org/10.1111/gcb.15884>

Absorption resulted from the implementation of high-carbon agroforestry

The absorption resulted from the implementation of such high-carbon agroforestry system (A_{HCa} , tCO₂e/year) can be estimated as follow :

$$A_{HCa} = S * T * \frac{44}{12}$$

Where S is area in hectare of the agroforest, T is the target carbon increase from the project and the 44/12 is the conversion factor to move from C to CO₂e. This relationship sets the per-hectare design target; the realized annual removals are distributed over the 20-year horizon using the Cameroon-specific logistic growth model of Silatsa et al. (2017), as described below.

The advantages of fast growing native trees are that can they have higher absorption rate per year. With this high-carbon agroforestry setting, an average of 0.619 million tCO₂/year emissions will be absorbed annually on average by the enriched plantations of the 45,000 coffee and cocoa producers targeted in the transition window (approximately 12.38 million tCO₂e over the 20-year horizon). Following Silatsa et al. (2017), who found that carbon-stock accumulation in Cameroonian cocoa agroforests is best described by a logistic growth function ($R^2 = 0.92-0.94$), MA4 is modelled as a net-additionality logistic using the study's fitted cocoa large-tree parameters (asymptote $a = 119.2$ tC/ha, $b = 27.3$, $c = 0.20$): $C(t) = A / (1 + 27.3 \cdot e^{(-0.20 \cdot t)})$. The added trees raise the large-tree carrying capacity in proportion to tree density (existing $321 \rightarrow 721$ trees/ha; Sonwa et al. 2007), so the added cohort matures toward $A = 119.2 \times (400/321) \times f$, where f is a conservative competition factor set to 0.40 — keeping the added cohort's peak rate near the 3 tC/ha/year design target and well below Silatsa's fitted whole-system rate. Because the existing mature trees follow the same trajectory with and without the project, they cancel out and only the carbon of the 400 added trees is credited (net additionality). Removals ramp up from about 0.15 million tCO₂e/year in the early years to a peak of about 0.98 million tCO₂e/year around year 17, averaging 0.619 million tCO₂e/year. This is a Tier 2 approach using country-specific tree densities (Sonwa et al. 2007) and the Cameroon-specific logistic of Silatsa et al. (2017), benchmarked against Cardinael et al. (2018) and to be confirmed against primary species-specific data during implementation.

Consistency with a small-stature, multi-strata enrichment. The 400 additional trees per hectare are small-to-medium multi-strata trees (service, fruit and light-canopy native species), not large emergent timber. The competition factor $f = 0.40$ therefore represents not only inter-tree competition but also the smaller mature stature and partial survival of this added cohort. The resulting credited carbon is deliberately modest at the tree level: an added-cohort asymptote of ~ 59 tC/ha (≈ 0.15 tC, or ~ 0.5 tCO₂e, per added tree at full maturity), of which ~ 37.5 tC/ha (≈ 0.09 tC per tree) accrues within the 20-year horizon, at a peak rate near 3 tC/ha/year (~ 7 kg C per tree per year) around year 16. These per-tree values are characteristic of small/medium agroforestry trees and are conservative relative to large shade or timber trees, ensuring the MA4 estimate is not inflated by an over-large tree assumption. Credited removals remain net-additional and are adjusted ex post to the surviving standing stock.

Compatibility of MA4 with the MA1 intensification objective. MA4 enrichment is applied to the 90,000 ha of the agroecological-transition window, a subset (~20%) of the plots supported under MA1–MA3. Because the added trees are small-to-medium multi-strata species rather than dense large-canopy shade, they raise the associated-tree stratum (321 → 721 trees/ha) while keeping canopy cover within the range that sustains cocoa productivity. Cameroonian cocoa is traditionally a multi-strata, shade-grown agroforest (Sonwa et al. 2007¹⁷; Jagoret et al. 2018¹⁸), and the evidence shows that intermediate shade combined with adequate soil fertility, which MA1–MA3 supply through fertilizer and then organic inputs, sustains yields comparable to low-shade systems while improving drought, pest and price resilience (Blaser et al. 2018¹⁹; Asare et al. 2019²⁰). The two activities are therefore complementary rather than contradictory. As a conservative safeguard, on-farm cocoa yield on the enriched plots is monitored under the MRV plan, and the MA1 avoided-deforestation credit for those plots is adjusted downward if the targeted 20% yield gain is not realised under the enriched canopy.

MA5 - Absorption through reforestation and landscape restoration

The project RACINE also targets significant carbon absorption through reforestation and landscape restoration initiatives. By restoring degraded lands and establishing new forested areas, the project aims to increase the overall tree cover and enhance ecosystem resilience. These activities involve primarily the planting of native tree species, which contribute to long-term carbon sequestration. Community involvement and local partnerships are prioritized to ensure the sustainability and effectiveness of restoration efforts. Through these interventions, RACINE expects to further augment the carbon sink potential of the region while supporting local livelihoods and environmental health. The project will support the establishment of 8,000 ha of new agroforestry plantations through performance-based payments to the communes.

Absorption resulted from the establishment of new agroforestry plantations

The absorption here is the absorption of the newly established agroforestry plantations (A_{agr} , tCO₂e/year) and can be estimated from the aboveground (AGB_{inc} , tC/ha/year) and belowground (BGB_{inc} , tC/ha/year) biomass increment of agroforestry plantations, the change in soil organic carbon (ΔSOC , tC/ha/year) and the total area of the established plantation (A_{agr} , ha).

$$A_{agr} = A_{pla} * (AGB_{inc} + BGB_{inc} + \Delta SOC) * 3.667$$

AGB_{inc} and BGB_{inc} of agroforestry plantations are obtained from [Cardinael et al. \(2018\)](#).

¹⁸ Jagoret, P., Snoeck, D., Bouambi, E., Ngnogue, H. T., Nyassé, S. & Saj, S. (2018). Rehabilitation practices that shape cocoa agroforestry systems in Central Cameroon: key management strategies for long-term productivity. *Agroforestry Systems* 92:1185–1199.

¹⁹ Blaser, W. J., Oppong, J., Hart, S. P., Landolt, J., Yeboah, E. & Six, J. (2018). Climate-smart sustainable agriculture in low-to-intermediate shade agroforests. *Nature Sustainability* 1:234–239.

²⁰ Asare, R., Markussen, B., Asante, R. A., Anim-Kwapong, G. & Ræbild, A. (2019). On-farm cocoa yields increase with canopy cover of shade trees in two agro-ecological zones in Ghana. *Climate and Development* 11(5):435–445.

Here, we assume that the plantations will be established on bare lands and agricultural lands. With these parameters, the total carbon sequestration is estimated at 0.09 million tCO₂e/year (1.77 MtCO₂e over the 20-year horizon). The aboveground and belowground biomass increments are taken from Cardinael et al. (2018) and the soil organic carbon change from Fonkeng et al. (2024); the constant annual increment over 20 years is justified by the IPCC 2019 Refinement / Requena Suárez et al. (2019) linear-accumulation approach for young stands. Ex ante, this activity is conservatively calibrated; during implementation it will transition to a fully verifiable approach based on survival census and field biomass plots, with reported removals adjusted downward for observed mortality or reversal.

MA6 - Absorption from urban greening and riverbanks protection

In addition to the major mitigation activities described above, RACINE is also committed to supporting urban greening and the protection of riverbanks as part of its integrated landscape approach. By planting trees and native vegetation along a total of 4,000 km of roads and watercourses, the project aims to reduce the urban heat island effect, protect against erosion, and further enhance carbon sequestration. With trees planted at 5m distance between each other, this represents a total of 800,000 trees planted of which 80% will survive (according IPCC recommendations), representing 640,000 trees. If we assume that the default biomass increment of the default species selected from the IPCC guidelines was obtained from a plantation of 1000 trees/ha in density, this total number of trees would have been planted on 640 ha (S_{est}).

Absorption resulted from urban greening and riverbank protection

The absorption here (A_{ug} , tCO₂e/year) is estimated based on the assumed planted area (S_{est}) and the carbon increment of a fast-growing tree (C_{gr}) as follow:

$$A_{ug} = S_{est} * C_{gr} * \frac{44}{12}$$

The carbon increment of a fast-growing tree was estimated using the IPCC Biomass Default Tables for Section 3.2 Forest Land²¹ with *Gmelina arborea* used as default species. We used the mid value of the species biomass growth (i.e. 32 m³ of dry matter per hectare per year with a wood density of 0.32 ton of dry matter per m³ of fresh wood, representing 4.96 tC/ha/year). Rather than applying this IPCC default as a constant annual rate — which over 20 years would imply about 99 tC/ha, roughly double the species' mature aboveground stock — the removals are modelled with a logistic (sigmoidal) growth curve for the planted fast-growing trees (*Gmelina arborea* proxy): $C(t) = K / (1 + 100 \cdot e^{(-0.66 \cdot t)})$, with $K = 50$ tC/ha of mature aboveground carbon anchored to *Gmelina* field studies (e.g. Onyekwelu 2004). The curve adds a realistic establishment lag (slow years 1–3), peaks around year 7 (about 8.3 tC/ha/year), and saturates near year 15. Over the 640 ha equivalent this gives approximately 0.116 MtCO₂e over the 20-year horizon (on average ~0.006 MtCO₂e/year). Removals begin accruing from the planting year; reported removals are based on surviving trees only (80% survival assumption), with mortality and any reversal deducted in the monitoring period in which they occur.

²¹ https://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/Chp3/Anx_3A_1_Data_Tables.pdf

Mitigation impacts of the project

The following table summarizes the mitigation activities of the project, baseline and project emissions, and their overall impact, demonstrating RACINE's comprehensive strategy for climate action through agricultural transformation and landscape restoration.

Mitigation activities of the project (MA)	EMISSIONS*		Lifetime [year]	IMPACTS**	
	Baseline scenario [MtCO ₂ e/year]	Project scenario [MtCO ₂ e/year]		Mitigation impact [MtCO ₂ e/year]	Total impact [MtCO ₂ e]
MA1 Preventing deforestation and degradation via intensification	8.46 ↑	7.75 ↑	6	0.602 ↓†	3.61 ↓
MA2 Use of chemical fertilizers to sustain the intensification	0	0.996 ↑	3	-0.996 ↑	-2.99 ↑
MA3 Switching to organic fertilizers	0.187	0.049 ↑	6	0.139 ↓	0.83 ↓
MA4 Carbon stock enhancement via increased tree density	0	-0.619 ↓	20	0.619 ↓†	12.38 ↓
MA5 Reforestation and landscape restoration	0	-0.088 ↓	20	0.088 ↓	1.77 ↓
MA6 Urban greening and riverbank protection	0	-0.006 ↓	20	0.006 ↓	0.12 ↓
Total				0.455 ↓	15.70 ↓

* Negative values correspond to removals (↓); **negative values correspond to emissions (↑). † MA1 mitigation impact is reported net of a 15% ex-ante leakage (rebound) deduction (gross avoided = 0.71 MtCO₂e/year). MA2 reflects the corrected transport assumption (100 km); MA3 reflects the corrected avoided = chemical – organic emissions on 90,000 ha. MA4 is modelled with a net-additionality logistic (Silatsa et al. 2017); 0.619 is the 20-year average (annual range ≈0.15–0.98, peak ~year 17); MA4 uses the Silatsa (2017) fitted logistic with a density-scaled asymptote (competition factor $f = 0.40$).

MA4 net-additionality accounting. The MA4 baseline removals are now shown as 0 under a net-additionality accounting boundary: the pre-existing carbon stock of established agroforests (already accounted for in BaU2) is excluded from the crediting boundary, and only the incremental removals from the 400 supplementary trees per hectare are credited. This is numerically equivalent to the gross stock-difference approach previously presented (project –11.75 minus baseline –11.13 = –0.619 MtCO₂e/year) but avoids any appearance of double-counting with BaU2 and aligns with IPCC AFOLU guidance on management change within an existing land-use category.

The first two mitigation activities (MA1 and MA2) are implemented during the six-year project period and their impacts are accounted only over the period in which the interventions take place. MA1 (agricultural intensification and avoided deforestation) generates emission reductions throughout the project implementation period, while MA2 (application of

synthetic fertilizers to support intensification) is implemented during the first three years of the project and results in additional emissions associated with fertilizer use. MA3 represents the progressive replacement of synthetic fertilizers with organic fertilizers on a subset of the supported plantations. This activity begins in project year 4, following the three-year synthetic fertilizer phase under MA2, and continues through year 9, resulting in a six-year mitigation lifetime. Of this six-year lifetime, years 4–6 fall within the six-year implementation period and years 7–9 represent post-project persistence, on the conservative assumption that producers established in the practice sustain it for three years beyond project close. Continued adoption is verified ex post through annual adoption tracking; avoided emissions cease where adoption lapses. No overlap or double counting of mitigation benefits is applied between MA2 and MA3. MA4 (carbon stock enhancement through agroforestry enrichment) begins during project implementation but its carbon removals are accounted over a 20-year period, reflecting the long-term growth dynamics of trees and carbon accumulation. Similarly, MA5 (reforestation and landscape restoration) and MA6 (urban greening and riverbank protection) generate removals that continue beyond the project implementation period and are therefore assessed over a 20-year horizon, consistent with GCF guidance for AFOLU mitigation accounting.

Monitoring, Reporting and Verification (MRV)

Monitoring

Inventory conducted on farms will collect detailed primary data on the planting and maintenance of shade trees, including species identification, number of trees planted, and diameter at breast height (DBH). Yield surveys and information on new inputs will also be collected to quantify emissions reductions resulting from improved agricultural practices. This dataset forms the basis for reliable carbon removal and reduction claims.

- **Primary Data Collection for Carbon Accounting:** On-farm inventory will enable the collection of detailed primary data on tree density in plantations.
- **Use of FODECC Monitoring System:** FODECC has established a monitoring framework capable of tracking:
 - Number of shade trees planted,
 - Land use change (LUC), and
 - Adoption of Good Agricultural Practices

These indicators will form the basis for performance-based payments to farmers. Payments will therefore be linked to the implementation of interventions, ensuring a pragmatic and farmer-friendly incentive mechanism.

- **Integration or Parallel Monitoring for Carbon Claims (CAFI Monitoring System):** additional data for credible carbon claims as removals dataset (DBH, species, tree counts) and yield surveys will be integrated into CAFI Monitoring

System (PES Management Tool & GHG Emissions Reduction Estimation Tool). This distinction ensures that CAFI's system underpins payments, while the additional monitoring provides the carbon accounting data for reporting and claims.

- **Representative Sampling Approach:** For the carbon monitoring and to ensure data quality and cost effectiveness, a representative sample of farms will be selected for in-depth data collection. Sampling will be stratified across farm types (agroforestry vs. fallow-based farms, varying levels of existing tree cover) to ensure representativeness of results at landscape level.
- **Frequency of monitoring:** A fixed monitoring schedule is adopted per mitigation activity. Activities tied to annual inputs and land use - MA1 (intensification / avoided deforestation), MA2 (chemical fertilizers) and MA3 (organic fertilizers) - are monitored annually. Biomass and removal activities - MA4 (agroforestry densification), MA5 (reforestation) and MA6 (urban greening) - are monitored on a periodic cycle defined explicitly as every three years, specifically in project years 3, 6, 9, 12, 15, 18 and 20. Field sampling is stratified and sized to achieve a target precision of plus or minus 10% at the 90% confidence level for biomass and removal parameters. QA/QC procedures include double data entry, independent re-measurement of at least 10% of sampled plots, and outlier checks against allometric and yield-table ranges. Data governance is provided through the FODECC and CAFI registries (geolocated farm polygons, input and planting records) with role-based access and version control. This will involve monitoring the adoption of sustainable intensification and its impact on yields using surveys and agroforestry interventions (number of trees left in the plantation, growth rate, canopy establishment) using ground-based data.

MA2 and MA3: field-monitored activity data versus documented accounting parameters. For MA2 and MA3 a clear distinction is drawn between data verified in the field and fixed calculation parameters. Field-monitored activity data, verified through farm input records, farmer surveys, EUDR geo-polygon mapping and adoption tracking, comprise: fertilizer quantities applied (kg NPK/ha/year and kg urea/ha/year), area covered by synthetic fertilizers, area switched to organic inputs, and organic feedstock type and volume. Documented accounting parameters, not field-monitored but fixed from primary literature and audited against their sources, comprise: the IPCC 2019 Refinement soil-N₂O emission factors (direct 0.016 and indirect 0.00325 kg N₂O-N/kg N), the NPK and urea upstream manufacturing emission factors (Wood & Cowie 2004; Fertilizers Europe), the transport emission factor (100 km fixed distance) and the AR6 N₂O GWP of 273. These parameters are verified by documentation audit rather than field measurement.

MA4–MA6: reconciliation of ex-ante annual estimates with three-yearly monitoring. The annual removal values reported for MA4, MA5 and MA6 are ex-ante modelled estimates generated by the logistic growth functions. At each three-yearly monitoring event (project years 3, 6, 9, 12, 15, 18 and 20) a full field inventory measures the standing stock (stem counts, DBH, height and survival), and for MA5 soil organic carbon is sampled. Measured carbon density is compared with the model prediction; where the divergence exceeds 10% the growth curve is recalibrated and the remaining years updated. For the years between monitoring events, interim values are obtained by linear interpolation between the most recent verified data point and the next model estimate and are flagged as “model-based interpolation” in Core Indicator 1 reporting. If year-3 survival falls below 75% for MA4 and MA5, or below 70% for MA6, a replanting obligation is triggered and the model recalibrated downward.

MA5: Soil organic carbon monitoring design. Soil organic carbon under MA5 is monitored following the IPCC 2019 Refinement Tier 2 stock-difference method. Stratified paired plots (treated agroforestry versus an adjacent reference area of the same prior land use) are established in each soil stratum, bare land and degraded agricultural land. Composite soil cores (five per plot, 0–30 cm depth, with bulk-density samples) are analysed by dry combustion (ISO 10694) at an accredited laboratory. Plots are a minimum of 25 m × 25 m and the sampling intensity is sized for ±15% precision at 90% confidence on the SOC change. Baseline sampling is carried out at planting (year 0/1) and resampling at years 5, 10, 15 and 20; the observed SOC change replaces the ex-ante Fonkeng et al. (2024) value from year 5 onward.

Reporting

As part of the root project, reporting will consist of establishing, at a frequency defined for each type of mitigation activity, the basic parameters necessary for estimating emission reductions. These parameters are as follows:

- Implementation of good agricultural practices (GAP) (quantity of inputs and residue management practices, yields).
- Agroforestry enrichment (shade tree planting and maintenance, including species identification, number of trees planted, and diameter at breast height (DBH)).
- Stratification (fallow-based farms, etc.).
- Land Use planning.
- land use change (LUC) avoidance.

These field results, obtained through the implementation of mitigation activities selected as part of the RACINE Project, will be entered into the CAFI GHG tool and will serve as baseline parameters for calculating GHG emission reductions for each mitigation activity.

The reporting of these emission reduction calculations will be presented in a simplified manner in a periodic report (depending on the frequency and period of monitoring of mitigation activities). The outline of this simplified report will include the following sections:

- Presentation of the tool
- Results
- Overall result,
- Results by mitigation activity

Verification

Internal Verification: It will be based on Remote Sensing (FODECC System & CAFI SIG Portal) and Ground-Level Verification (Field Officers). Remote sensing will be combined with ground-level checks to verify the absence of deforestation, consistent with a strict no-deforestation commitment. This will ensure claims of avoided emissions are both accurate and credible.

Independent Verification: The GCF and CAFI will commission an external entity to conduct an independent verification of the results of the RACINE Project.

This entity will be responsible for ensuring the technical, fiduciary, environmental, and social compliance of the reported results. This includes ensuring physical results (activities, areas, beneficiaries), climate results (tCO₂e), financial flows, E&S safeguards, governance and risks.

Leakage and displacement monitoring

Leakage is assessed activity by activity following AFOLU good practice (VCS AFOLU; VM0006). For MA1 (avoided deforestation through intensification) the residual rebound/displacement risk is the most material: it is quantified ex ante by a 15% deduction (central; 10–40% sensitivity) and measured ex post over a reference region (leakage belt) around the intervention areas, together with market and expansion indicators (national cocoa-area statistics and RADD tree-cover-loss trends in cocoa-suitable zones), because rebound and market-mediated leakage occur off the project plots rather than within them. The 15% central rate reflects the project's strong governance controls (mandatory geolocation and EUDR traceability, PLADDT zoning, conditional and penalised subsidies), which the evidence identifies as the decisive factor between land-sparing and rebound for high-value export crops such as cocoa (Byerlee et al. 2014; Ceddia et al. 2014). For MA2, the upstream manufacturing and transport emissions are accounted within the activity boundary (and are therefore not leakage); the residual leakage is input reallocation, diversion of subsidised fertiliser to non-project plots, monitored by reconciling input-distribution records with on-plot application. For MA3, the leakage risk is unsustainable sourcing of compost feedstock from forests or fallows; the project requires on-farm or local feedstock, monitors its origin, and deducts the corresponding removals if forest or fallow sourcing is detected. For MA4–MA6, the residual displacement risk is judged Low to Very-low after the controls set out in the Uncertainty and risk management table and is not quantified ex ante.

Assumptions and sensitivity analysis

Baseline scenario

Ongoing deforestation and degradation and very limited intensification

In the reference scenario, the increase in cocoa and coffee production is mainly based on the expansion of land area, due to low yields and limited intensification. This dynamic leads to continued deforestation and degradation of forests and fallow land, in line with the trends observed in the reference documents.

- Increased production of cocoa: 4.1% per year (FAO 2000–2024 CAGR, central case; sensitivity 1.5% low / 18.5–24% high)
- Production increase: ~13,051 tonnes of increased production per year (central case)
- Annual expansion rate (ha/year): ~37,288 hectares of dense forest per year (central case)

Continuous implementation of low-carbon agroforestry systems

Low-carbon agroforestry systems remain marginal in the baseline. Their adoption is sporadic, unstructured and unsupported by financial or MRV mechanisms, which severely limits their contribution to carbon sequestration and degradation reduction.

- Number of trees per hectare: an average 1,489 plants/ha of which 321 plants are associated shading trees
- Average absorption of 5 kg of CO₂e/tree/year for coffee and cocoa and 2.5 kg of CO₂e/tree/year for the natural associated shading tree in Cameroon
- Average absorption of the plantations is around 6.6 tCO₂e/ha/year.

Limited green investments at the municipal level

Municipal green investments are low and insufficient to influence land use dynamics. Municipalities lack the means to integrate binding climate targets into spatial planning or to effectively control agricultural expansion or rebound effects.

- The assumption here is that no such investments will be made in strengthening community forest governance and forest restoration over the next 6-20 years.

Project scenario

Emission reduction from agricultural intensification

The project enables sustainable agricultural intensification on existing plots, reducing expansion pressure and generating emission reductions through avoided deforestation, in line with the 'avoided conversion' approach recognised by the GCF.

- Projected yield: Half of the producers achieve a 20% increase in yield of coffee and cocoa plantations, suggesting a production increase from 0.35 tonnes/ha to 0.42 tonnes/ha.
- The use of chemical fertilisers (i.e. 600 kg/ha/year of NPK 15:15:15 and 100 kg/ha/year of Urea 46%).
- Supported producers: 50% of coffee and cocoa producers (i.e. 350,000 producers)
- Practice adoption rate: 100% in supported plantations.

Use of chemical fertilisers to sustain intensification

The use of chemical fertilisers is included as a transitional assumption to support productivity gains. Associated emissions (mainly N₂O) are fully accounted for and deducted from gross emission reductions.

- Input requirements: coffee and cocoa producers will apply 600 kg/ha/year of NPK 15:15:15 and 100 kg of urea/ha/year to achieve the 20% increase in their production through the project's support.

Switching from chemical to organic fertilisers

The project promotes a gradual transition to organic fertilisers, reducing emissions from inputs while improving soil fertility and the sustainability of production systems.

- Completely replace chemical fertilisers that lead to emissions with organic fertilisers that are emission-free or insignificant, on a total of 90,000 hectares of plantations that have been intensified through the use of chemical fertilisers.

Carbon stock enhancement in coffee and cocoa plantations

The systematic introduction of agroforestry systems increases carbon stocks in the biomass and soils of cocoa and coffee plantations, generating measurable and verifiable net removals.

- Increased of the number of shading and accompanying trees with 400 additional fast-growing trees to be added in each supported plantation.

Absorption through reforestation and landscape restoration

Reforestation and restoration of degraded landscapes generate additional CO₂ absorption by restoring carbon stocks that would continue to decline in the baseline scenario.

- Establishment of 8,000 ha of new agroforestry plantations through performance-based payments to the communes.

Absorption from urban greening and riverbank protection

Urban greening and riverbank protection contribute to modest but robust additional absorption, while strengthening local climate resilience and the territorial coherence of the project.

- Planting trees and native vegetation along 4,000 km of roads and watercourses.

Overall uncertainty of the mitigation estimate. Combining the independent low/central/high ranges of the principal parameters of each activity (by quadrature) gives an overall mitigation estimate of approximately 15.70 MtCO₂e central, within a range of about 5.9 to 37.3 MtCO₂e. The range is dominated by the MA1 production-growth assumption and the MA4 logistic-model parameters (asymptote and competition factor). The central estimate is conservative relative to the mid-point of this range. The principal uncertainty inputs and the resulting scenario totals are set out below; the full parameter-by-parameter analysis is provided in the workbook (Sensitivity and uncertainty tab).

Table. Uncertainty inputs by mitigation activity (low / central / high).

MA	Parameter	Low	Central	High	Unit
MA1	Cocoa production CAGR	1.5%	4.1%	18.5%	%/yr
MA1	Ex-ante leakage deduction	10%	15%	40%	%
MA1	Forest-to-crop emission factor	190	226.85	260	tCO ₂ e/ha
MA2/MA3	NPK manufacturing EF	0.9	1.1243	1.4	kg CO ₂ e/kg
MA2/MA3	Urea manufacturing EF	1.5	1.7	2.0	kg CO ₂ e/kg
MA3	Upstream organic buffer	10%	0%	0%	% of synth. N-eq.
MA4	Silatsa asymptote a	80	119.2	150	tC/ha
MA4	Competition factor f	0.55	0.40	0.25	—
MA4/MA5/MA6	Survival rate	central -5pp	80%	central +5pp	%
MA5	AGB increment (Cardinael 2018)	1.4	1.82	2.3	tC/ha/yr
MA5	SOC increment (Fonkeng 2024)	0.05	0.12	0.22	tC/ha/yr
MA6	Gmelina K asymptote	35	50	65	tC/ha

Table. Scenario totals (MtCO₂e over project lifetime).

MA	Activity	Low	Central	High	Range driver
MA1	Avoided deforestation	~0.38	~3.61	~17.8	Production CAGR + leakage
MA2	Chemical fertilizers	~-3.47	~-2.99	~-2.59	LCA EF bounds
MA3	Organic transition	~0.59	~0.83	~1.06	EF + upstream buffer
MA4	Agroforestry densification	~7.20	~12.38	~18.5	Silatsa a + factor f
MA5	Reforestation	~1.23	~1.77	~2.31	Biomass increment CI
MA6	Urban greening	~0.07	~0.12	~0.19	K asymptote + survival
TOTAL	All activities	~5.9	~15.7	~37.3	MA1 + MA4 dominate

Uncertainty and risk management

Mitigation Activities	Potential leakage type	Anti-leakage measures	Residual leakage level
Preventing deforestation via intensification	<i>Rebound effect</i> : increased yields and incomes may encourage some producers to open new plots elsewhere (fallow land or forests), outside the areas directly supported.	• Strict prohibition on post-2020 extension (alignment with EU regulations) • Mandatory polygonal geolocation of all farms • Periodic remote sensing (detection of openings) • Conditionality of subsidies and penalties (exclusion in case of non-compliance) • Municipal zoning via PLADDT	Low - a 15% ex-ante leakage (rebound) deduction is applied; residual risk is strongly controlled by spatial and regulatory safeguards (mandatory farm polygons, periodic remote sensing) and trued-up ex post (proportional deduction if detected new clearing in monitored polygons exceeds 5% of supported area in a monitoring period)
Use of chemical fertilizers to sustain the intensification	Indirect displacement of environmental impacts: increase in upstream emissions (fertiliser production/transport) or on other plots if inputs are reallocated.	• Quantitative monitoring of inputs at plot level • Accounting for and deducting N₂O emissions in MRV • Capping of fertiliser doses • Mandatory coupling with agroecological practices	Low - associated emissions are integrated and neutralized in the carbon footprint
Switching to organic fertilizers	Shifting pressure on biomass: excessive collection of plant residues or organic matter from other areas (fallow land, forests).	• Technical supervision of biomass volumes harvested • Promotion of local composting (agricultural residues, organic waste) • Prohibition of harvesting in sensitive forest areas • MRV monitoring of fertilization practices	Low - localized risk controlled by technical supervision
Increasing tree density and carbon stock enhancement	Relocation of agricultural activities or harvesting (wood, biomass) to other areas if densification reduces the perceived productive space.	• Integrated agroforestry (trees + crops on the same plot) • Selection of multi-purpose species (shade, fertility, fruit trees) • Monitoring of tree density by remote sensing Municipal zoning prevents conversion elsewhere	Low - densification takes place without excluding agricultural activity
Reforestation and landscape restoration	Spatial leakage: restoration activities may displace agricultural uses to unrestored areas if productive needs are not compensated.	• Selection of degraded or unproductive areas • Restoration integrated into PLADDT • Planned productive alternatives (intensification, agroforestry) • Inter-municipal territorial monitoring	Low to very low - targeted restoration integrated into planning
Urban greening and riverbanks protection	Marginal shift in land use (gardening, riverside farming) to adjacent unprotected areas.	• Clear demarcation of protection zones • Community awareness • Integration into Municipal Development Plans (PCD) and municipal management • Remote Sensing and Ground-Level Verification (fixed zones)	Very low - limited and localized impact, no systemic effect