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Methodology:

Adoption of nitrogen stabilizers to transition to low-carbon agriculture

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Table of contents

List of definitions

Additionality	Refers to the concept that any GHG project should result in greenhouse gas emissions mitigation (GHG reductions or removals) that would not have occurred without the project. In other words, the project's positive impact on reducing or removing emissions should be "additional" to what would have happened under the baseline scenario.
Ammonia volatilization	The process by which ammonia (NH_3) gas is released into the atmosphere from ammonium-containing fertilizers (e.g., urea). This can lead to indirect GHG emissions when ammonia is subsequently converted to nitrous oxide (N_2O) in the environment.
Baseline scenario	The baseline scenario represents the emissions that would occur based on the business as usual agricultural management practices. In other words, this includes fertilizer management and other relevant activities, without the use of nitrogen stabilizers.
Carbon dioxide equivalent - CO_2e	A metric used to compare the emissions of various greenhouse gases based on their Global Warming Potential (see GWP definition). It expresses the impact of different gases in terms of the equivalent amount of CO2, facilitating a standardized approach to assessing overall greenhouse gas emissions.
Carbon credit (emission reduction certificate)	A carbon credit represents at least 1 tonne of CO2 (tCO_2), or 1 tonne of CO2e (tCO2e) reduced or removed for a certain period of time. One tonne (metric ton) (t) equals 1000 kg. For carbon equivalency, Proba uses the AR-5 assessment from UNFCCC[1].
Conservativeness	When there is uncertainty or a choice between two or more assumptions, values, methodologies, or procedures, the option that is more likely to result in lower estimates of GHG emission reductions or removals must be selected. This approach ensures that claimed climate benefits are not overestimated.
Cradle-to-gate	A life cycle assessment boundary that includes all greenhouse gas emissions associated with a product's life cycle stages up to the point it reaches the project's location. This includes emissions from raw material extraction, production, and transportation to the project's location. It excludes emissions from field application or any subsequent stages beyond the project's location.

[1] https://ghgprotocol.org/sites/default/files/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_0.pdf

Crediting period	The "crediting period" refers to the specific duration of time during which a GHG project is eligible to generate and issue emission reduction certificates for the GHG emissions it reduces or removes. This period is predefined and ensures that the project's emissions impact is monitored, verified, and credited only within that set timeframe. A crediting period can be renewed once or multiple times.
Cumulative N_2O emissions	Total N_2O emissions calculated over a specific period, leveraging direct or indirect methods. This means these can be calculated with either direct flux measurements using specialized equipment (e.g., gas chambers, spectrometers) or estimated using emission factors or models.
Denitrification	A microbial process in which nitrate (NO_3^-) is reduced stepwise to nitrogen gas (N_2), typically under anaerobic conditions in soil. During this process, nitrous oxide (N_2O) can be produced as an intermediate product and may accumulate instead of fully being reduced to N_2.
Emission factors	Emission factors are coefficients that quantify the amount of greenhouse gases released into the atmosphere per unit of activity, substance, or process. They are essential tools in calculating emissions and facilitating the estimation of a project's total greenhouse gas emissions. The Intergovernmental Panel on Climate Change (IPCC) has established a three-tier system for the development and application of emission factors (Tier 1, Tier 2, and Tier 3). These tiers are presented in Appendix A.1 Tier definitions.
Enhanced Efficiency Fertilizers (EEF)	Fertilizers developed to regulate the release of N from fertilizers, allowing for improved N uptake and utilization by plants, thereby lowering losses and increasing crop productivity per unit of fertilizer.
Land Management Unit (LMU) / Field level	A Land Management Unit (LMU) is a clearly defined area of land under consistent management, where fertilizer application and nitrogen stabilizer use can be directly monitored and attributed. The LMU level allows GHG emissions and reductions to be accurately measured and linked to specific land parcels, each with defined boundaries and documented management practices. It is aligned with the GHG Protocol's *Land Sector and Removals Guidance* definition [2].
GHG project	Activity or activities that alter the conditions of a GHG Baseline and which cause GHG emissions reductions or GHG removals. The intent of a GHG project is to convert the GHG impact into emission reduction certificates.

[2] https://ghgprotocol.org/land-sector-and-removals-guidance

Global Warming Potential (GWP)	The time-integrated radiative forcing resulting from a pulse emission of a specific greenhouse gas, relative to the radiative forcing from a pulse emission of an equivalent mass of carbon dioxide (CO_2) (Woolf et al., 2021). It provides a common scale to compare the climate impact of different gases over a specific time horizon, typically 100 years.
Insetting	Insetting refers to the practice of implementing sustainability interventions within a company's own value chain to reduce greenhouse gas (GHG) emissions or enhance carbon sequestration. Unlike offsetting, which typically involves purchasing carbon credits for activities outside the value chain, insetting focuses on reducing emissions directly linked to the company's operations, suppliers, or production processes.
IPCC	The Intergovernmental Panel on Climate Change is a United Nations body, assessing science related to climate change to provide policymakers with regular scientific updates.
Leakage	In the context of a GHG project, leakage refers to the unintended increase in greenhouse gas emissions outside the project boundaries as a direct result of the project's activities.
Nitrate leaching	The vertical movement of nitrate through soil profile into deep layers along with irrigation water or rainfall. This process can lead to groundwater contamination (e.g., because nutrients and cations can be leached). and the indirect emission of nitrous oxide (N_2O) when nitrates are converted by microbial activity in anaerobic conditions.
Nitrification	A microbial process in which ammonia (NH_3) in fertilizers is oxidized to nitrite (NO_2^-) and then to nitrate (NO_3^-). This process can produce nitric oxide (NO) and nitrous oxide (N_2O) as by-products.
Nitrogen stabilizers mixtures	Fertilizers mixed with nitrogen stabilizers before application, either at the field level or through distribution channels.
Nitrogen Use Efficiency (NUE)	Nitrogen Use Efficiency (NUE) refers to the effectiveness with which crops utilize applied nitrogen for growth and yield. It can be defined as biomass production (or crop yield) per unit of N applied to the crop.
Offsetting	Offsetting refers to the practice of compensating for greenhouse gas (GHG) emissions by supporting projects outside a company's value chain that reduce or remove emissions. This is typically achieved by purchasing carbon credits from verified initiatives.
Product Carbon Footprint (PCF)	The total amount of greenhouse gases (GHGs) emitted directly or indirectly by a product throughout its life cycle. It is typically measured in

	units of carbon dioxide equivalents (CO_2e) to account for the varying global warming potentials (GWP) of different GHGs.
Project Overview Document (POD)	A document that offers a detailed summary of a GHG project's key elements, including governance, emission calculations, risk management, methodologies, and monitoring processes (see Proba Standard).
Stabilized Nitrogen (N) Fertilizer	Fertilizers incorporated with a nitrogen stabilizer (nitrification inhibitor (NI), urease inhibitor (UI), or both. The treatment with nitrogen stabilizers can occur either during or after the fertilizer production process.
Proba Standard	The Proba Standard aims at controlling and reducing the risks related to GHG projects, their climate impact (emission reduction) and the corresponding issuance of emission reduction certificates and subsequent claims. It does so by relying on and aligning with internationally recognized standards frameworks and initiatives such as the Core Carbon Principles by the ICVCM and the ICROA Code of Best Practice. The Proba Standard sets out detailed procedures for identification and validation of GHG projects, and verification of emission reductions and removals, based on ISO 14064-2 . More information about the Proba Standard can be found at https://proba.earth/document-library.
Project boundaries	The project boundaries of a GHG project delineate the spatial, temporal, and operational limits within which the GHG emissions, reductions, and removals are quantified and monitored, encompassing specific activities, sources, sinks, and reservoirs related to the project.
Sourcing Region	A geographically distinct area characterized by common environmental, climatic, and land use conditions. It may encompass an entire country, a jurisdiction, or a specific part of it, and is typically defined by administrative boundaries, agroecological zones, or sourcing areas. It is aligned with the GHG Protocol's *Land Sector and Removals Guidance* definition [3].
Nitrate runoff	The horizontal movement of water across the soil surface, carrying with it dissolved and particulate nutrients from fertilizers as well as (fine) soil particles to nearby water bodies. Runoff can result in surface water pollution and contribute to eutrophication. Additionally, when nitrogen compounds in runoff reach water bodies, they can undergo microbial activities which result in indirect emissions of nitrous oxide (N_2O).
Tier 1, 2 and 3	In the context of greenhouse gas (GHG) emissions reporting and

[3] https://ghgprotocol.org/land-sector-and-removals-guidance

	inventory management, data and methodologies are categorized into three tiers (Tier 1, Tier 2, and Tier 3), as defined by the Intergovernmental Panel on Climate Change (IPCC). These tiers represent varying levels of accuracy, data specificity, and complexity. For more information see Appendix A.1 Tier definitions.
Verification and Validation Bodies (VVBs)	Third-party assurance entities, preferably ISO-accredited, are responsible for verifying that a project's activities and claims of emissions reductions and/or removals are conducted in accordance with established standards and methodologies, ensuring their accuracy and credibility.

List of abbreviations

AR6	IPCC Sixth Assessment Report
EEF	Enhanced Efficiency Fertilizers
EF	Emission Factor
GHG	Greenhouse Gas
IFA	International Fertilizer Association
IPCC	Intergovernmental Panel on Climate Change
KPI	Key Performance Indicators
LCA	Life Cycle Assessment
LMU	Land Management Unit level
MRV	Monitoring, Reporting, and Verification
NI	Nitrification Inhibitor
NH_3	Ammonia
N_2O	Nitrous Oxide
NO_3^-	Nitrate
NO	Nitric oxide
NO_2^-	Nitrite
NUE	Nitrogen Use Efficiency
PCF	Product Carbon Footprint
POD	Project Overview Document
SDG	Sustainable Development Goal
SOC	Soil Organic Carbon
UI	Urease Inhibitor
UINI	Combination of Urease and Nitrification Inhibitors
VVB	Verification and Validation Body

1 Introduction

1.1 Background

Fertilizers are important in agriculture, supplying critical nutrients like nitrogen, phosphorus and potassium to crops. They enhance soil fertility and are key to feeding the global population by boosting crop yields.

The production and application of nitrogen fertilizers contribute to greenhouse gas (GHG) emissions, especially nitrous oxide (N_2O), a greenhouse gas (GHG) with a Global Warming Potential 273 times more potent than CO_2 (IPCC, 2021). This impact is a major concern for climate change due to the global warming potential of these emissions. It is essential to reduce N_2O emissions associated with the application of inorganic and organic nitrogen-containing fertilizers. The use of nitrogen stabilizers is identified as an effective strategy to reduce nitrogen losses and related emissions in agricultural systems (Gao & Cabrera Serrenho, 2023).

Nitrogen stabilizers are compounds added to nitrogen containing inorganic or organic fertilizers, to reduce nitrogen loss and GHG emissions by slowing down specific biological processes. These stabilizers act as chemical agents that delay the microbial or enzymatic processes responsible for nitrogen losses, such as ammonia volatilization and nitrate leaching. The key products involved are urease inhibitors (UI) for urea containing fertilizers, nitrification inhibitors (NI) for urea and/or ammonium containing fertilizers, and their combinations (UINI) for urea containing fertilizers.

- Urease inhibitors work by blocking the active site of the urease enzyme, which slows down the conversion of urea into ammonia (NH_3). This process reduces the amount of nitrogen lost to the atmosphere as NH_3, helping to slow down ammonia volatilization (Cantarella et al., 2018).
- Nitrification inhibitors slow down the conversion of ammonium to nitrite and subsequently to nitrate, effectively reducing nitrate leaching and the production of nitrous oxide (N_2O).

As such, applying nitrogen stabilizers on the fields, along with the commonly-used N additions, can lead to a reduction of GHG emissions. Key impacts of nitrogen stabilizers include:

- <u>Reduction in direct N_2O emissions</u>: Nitrogen stabilizers reduce direct N_2O emissions by slowing processes like nitrification, minimizing N_2O formation in the soil.
- <u>Reduction in indirect N_2O emissions</u>: Nitrogen stabilizers reduce indirect N_2O emissions by slowing down ammonia (NH_3) volatilization from urea through urease inhibitors (UI) and by

inhibiting the nitrification of ammonium through nitrification inhibitors (NI). These mechanisms reduce nitrogen losses as ammonia (via UI) and nitrate (via NI), thereby limiting the processes that contribute to indirect N_2O emissions.

- **Increase of crop yields through Nitrogen Use Efficiency (NUE)**: Nitrogen stabilizers can enhance NUE due to reduction of N losses which improves the availability of nitrogen to plants. This may lead to higher crop yield[4] for the same nitrogen input. As a result, the same amount of fertilizer can produce more output, reducing emissions per unit of agricultural product.
- **Cradle-to-gate emissions of nitrogen stabilizer:** On the other hand, the production and transportation of nitrogen stabilizers results in (cradle-to-gate) GHG emissions, which must also be accounted for.

1.2 Applicability of the methodology

- This methodology is globally applicable to projects that introduce nitrogen stabilizer containing products (see section 1.3 Eligible products) to managed soils and meet the applicability, eligibility and additionality requirements presented in this document.
- This methodology is applicable to both offsetting and insetting projects. In alignment with emerging SBTi guidance, insetting projects should prioritize direct mitigation, where the intervention can be physically linked to specific emissions sources within the company's value chain through a robust chain of custody model. Where such traceability is not yet possible, indirect mitigation may be used as an interim measure, provided it supports the transformation of the relevant value chain over time. Section 1.4 Additionality, explains the requirements for these different types of projects.
- Project developers must be able to demonstrate that without the intervention (e.g., baseline scenario), there would be human-induced net N additions to soils (e.g., inorganic and/or organic fertilizers), which would lead to direct and indirect emissions.
    - The baseline fertilizer (i.e. the product that would be used in the absence of the N stabilizer) may contain multiple nutrients (e.g., nitrogen, phosphorus, and potassium) and come in various formulations (e.g., DAP, MAP, NPK blends, ammonium sulfate nitrate, etc.). All these fertilizer types are within the scope of this methodology. However, the impact of the N stabilizer is attributed only to the nitrogen (N) component of the product.

[4] For the purposes of this methodology crop yield is the same as crop productivity or biomass production

- Project developers must demonstrate that nitrogen inputs are applied at appropriate rates based on regional agronomic guidelines or best practices, ensuring baseline fertilization is neither excessive nor deficient and aligned with standard agricultural management for optimal nitrogen use efficiency (NUE). This ensures that projects are not rewarded for applying excessive nitrogen compared to common regional practices, which could artificially inflate emission reductions due to the stabilizer's effect on the excess nitrogen.
    - To ensure that the project's baseline (as defined in section 3 Baseline Scenario) accurately reflects **nitrogen use efficiency (NUE)**, project developers must do a *Performance Test*. This includes calculating the NUE based on the total N fertilizer input and crop yield data. The reported NUE must be compared to historical or regional benchmark NUE values to verify that the baseline practices are following the region's guidelines. The usage of the regional NUE is preferred. However, if no such information is available, then the historical NUE based on the log of farmers can be used. The following data and equation must be provided and used for the calculation:
        - Total fertilizer applied per hectare (kg N/ha)
        - Total crop yield per hectare (t/ha)
        - Equation:

$$NUE = \frac{Crop\ Yield\ (t/ha)}{Total\ Fertilizer\ N\ applied\ (kg\ N/ha)} \tag{1}$$

    - In case a regional spatial boundary approach is taken, where nitrogen stabilizers are sold across a region (see 2.3 Spatial Boundaries), the project developer must provide the regional NUE based on a relevant source such as peer-reviewed scientific studies, government agricultural extension reports, industry best practices, or other recognized sources.
- Project developers must be able to prove that because of the intervention (e.g., project), the introduction of the nitrogen stabilizer leads to the reduction of the net GHG emissions, which are in scope of this methodology (see section 2.1 Scope of activities).
- For both the **baseline** and **project intervention**, project developers must provide scientific proof of the emission factors (EFs) related to the specific characteristics and activities of the project.

- This scientific proof must be sourced from one of the following: 1) the IFA Emission Factor Database for Nitrogen Stabilizers[5], 2) a relevant meta-analysis, or 3) original scientific literature.
- The EFs used must be retrieved from studies that meet specific quality criteria, and project developers must demonstrate that the characteristics and activities of both the baseline and project intervention are consistent with the key environmental factors and management practices described in the supporting scientific evidence. The quality criteria and variables are detailed in the appendix A.2 Emission Factor Selection Criteria based on Scientific Studies. Where this alignment is demonstrated, even a single study may be leveraged to generate the EF applied at the project or baseline level.
- At a Sourcing Region-level spatial boundary, a representative average emission factor (Tier 2 - type [6]), derived from aggregated region-specific EFs, may be used, provided that it is based on sufficient data and accurately reflects the agroecological conditions of the region.
- Crops, cropping systems, and agroecologies for which there is no supporting scientific evidence of the impact of N stabilizers on the GHG emissions, are not applicable under this methodology.

- This methodology is applicable to projects that introduce changes to management practices on top of the usage of nitrogen stabilizers (e.g., adopting improved tillage methods, introducing cover crops, or similar)[7] **if one of the following conditions are met**:
  1. The project intervention is supported by scientific evidence and the relevant EF derived from this scientific studies are used, **OR**
  2. There is sufficient scientific proof that these practices (that come on top of the introduction of nitrogen stabilizers) do not negatively affect the stabilizer-induced reduction of emissions (bare minimum).
- This methodology can work **synergetically** with other GHG methodologies or programs that target emissions reductions or removals in areas outside the scope of this methodology. For instance, a program could combine the application of nitrogen stabilizers with a soil management practice designed to sequester CO_2, thereby achieving complementary climate benefits while ensuring that the integrity of the emission reductions from activities under this

[5] The IFA Emission Factor Database for Nitrogen Stabilizers is currently under development
[6] Explanation of the Tier approach can be seen in the appendix A.1 Tier definitions
[7] This methodology aims to support multiple interventions on the fields (which might be the case for many projects), however it is crucial that these interventions do not negatively affect the impact of the N stabilizers (or on the other hand the N stabilizers do not interfere with other interventions already in place). For this reason the conditions were added.

methodology is maintained. In case this methodology is used in conjunction with other methodologies or programs then the project developer must:
  - explicitly mention that in the POD and
  - demonstrate that benefits are not quantified more than once (to mitigate the risk of double counting the impact of nitrogen stabilizers across two projects)
  - provide a separate monitoring framework to ensure that combined interventions do not undermine stabilizer effectiveness in long-term consistency
- The project developer must be transparent and report on additional activities that happen along with or because of the introduction of N stabilizers, which can lead to material changes of emissions on the field. Some (non-exhaustive) examples of such activities:
  - Switching from low-emission fuel to high-emission fuel for field operations
  - Increasing the number of tractor passes or field operations (e.g., separate pass for applying the stabilizer)
  - Switching to a fertilizer product with higher embedded emissions per kg of nutrient applied
  - Adding irrigation events (e.g., fertigation with stabilizers) that consume energy or water
- This methodology has been developed in accordance with the Proba Standard, ensuring that all guidelines, principles, and requirements outlined in the standard are fully adhered to. Users of this methodology are expected to follow the Proba Standard to ensure consistency, credibility, and compliance with the broader framework established by Proba.

1.3 Eligible products

1.3.1 Types of nitrogen stabilizers

- In this methodology, the eligible products are nitrogen stabilizers, specifically urease inhibitors (UI), nitrification inhibitors (NI), and combinations of both (UINI).
- Other enhanced efficiency fertilizer products, such as control or slow-release fertilizers, biostimulants and bio-inhibitors (BI) are currently **excluded** from this methodology.
- <u>Solid vs liquid forms:</u> Both solid and liquid formulations of nitrogen stabilizers are eligible. The selection should be based on the active ingredient, its proven effectiveness in either form and its compatibility with the carrier fertilizer type to ensure proper integration and efficiency in reducing nitrogen losses.

- **Method of application:** The following methods of integrating nitrogen stabilizers into fertilization practices are eligible:
    - stabilized N fertilizers: Fertilizers pre-treated with nitrogen stabilizers during manufacturing to ensure uniform distribution.
    - Nitrogen stabilizers/fertilizers mixtures: Fertilizers mixed with nitrogen stabilizers before application, either at the field level or through distribution channels.
    - Post-application treatment: Nitrogen stabilizers applied separately after fertilization to control nitrogen transformations in the soil.

1.3.2 Regulatory compliance

For nitrogen stabilizer products to be eligible they must be registered in the country or region where they are being applied. In addition, compliance to regional guidelines is essential to ensure that the application rate is in line with local regulations.

In regions like the U.S. and Europe, there are regulatory bodies that provide guidelines and information regarding which products are approved for use in agriculture. For example, in the U.S., UI are regulated under the Association of American Plant Food Control Officials (AAPFCO)[8], while NI falls under the jurisdiction of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)[9]. Both regulatory bodies provide oversight and guidance on the use of various fertilizer products, including products such as nitrogen stabilizers.

In the EU, Regulation (EU) 2022/1519[10], which amends Regulation (EU) 2019/1009, establishes the requirements for compounds to be classified under Product Function Categories (PFCs) and comply with EU fertilizer regulations. Specifically PFC5[11] describes the approved nitrogen stabilizer products, such as NI and UI, that can be used in fertilizers.

The regulation outlines the composition requirements for stabilized N fertilizers, including:

- For NI: The inhibitor content is based on the total nitrogen present in the form of ammonium nitrogen and urea nitrogen (e.g., in EU the fertilizer-product must contain minimum 50% of total N in the form ammonium and urea).

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[8] http://www.aapfco.org/
[9] https://www.epa.gov/enforcement/federal-insecticide-fungicide-and-rodenticide-act-fifra-and-federal-facilities
[10] Regulation - 2019/1009 - EN - EUR-Lex
[11] This category includes stabilizers such as nitrification and urease inhibitors, and outlines composition and performance requirements to ensure both environmental safety and agronomic efficacy

- For UI: The inhibitor content is based on the urea nitrogen content (f.i. in EU the fertilizer-product must contain minimum 50% of total N in form of urea)
- Application rate: Application (or dose) rate is part of the registration under regional and/or national fertilizer regulations and is critical to ensuring their effectiveness in reducing GHG emissions and maintaining or improving NUE. The actual application rate of the stabilizer must fall within the range recommended by the producer of the stabilizer, as well as the range mandated by the regulation. Producers of nitrogen stabilizers establish recommended dose rates through extensive experiments across diverse environmental conditions. These rates can be expressed as a percentage of active ingredient (AI) linked to the corresponding nitrogen form (e.g., % on NH_4-N for nitrification inhibitors, % on urea-N for urease inhibitors). These details, including the total fertilizer application rate, AI percentage, and supporting documentation, must be provided in the Project Overview Document (POD) demonstrating their efficacy under the specific conditions (of the project).

1.4 Additionality

Additionality refers to the concept that a GHG reduction project should result in emissions reductions beyond what would have occurred under a "business-as-usual" scenario or existing regulations, ensuring the reductions are truly "additional" and not simply complying with mandatory requirements.

Depending on whether the project developer aims to use the generated claims (emission reduction certificates) in either offsetting or insetting scenarios, different requirements apply.

For the offsetting scenario the project developer must prove the following three aspects of additionality:

- Regulatory additionality: The project developer must prove that the introduction of the use of nitrogen stabilizers was not caused by local, regional or national regulations. To achieve that, the project developer must prove that there is a) no regulation enforcing the use of nitrogen stabilizers and b) there is a lack of financial incentive of regulatory directives to realize the proposed intervention. If subsidies are available, the project developer must show that available funding does not cover the financial gap to realize the intervention.
    - If a regulation is implemented and actively enforced during the crediting period that mandates the use of nitrogen stabilizer products, the crediting period for the project will end at that point, as the project would no longer meet the criteria for additionality.

- Prevalence: The project developer must prove that the introduction of the use of nitrogen stabilizers is not a common practice in each region included within the project area. Common practice is defined as per the guidelines of the Standard that the project developer follows. For reference, CDM defines common practice as greater than 20% adoption [12].
- Financial additionality: The project developer must prove that the financial incentive from carbon finance will lead to the increased adoption of the nitrogen stabilizers by the farmers.

For the insetting scenario, the project developer must demonstrate regulatory additionality by confirming that the use of nitrogen stabilizers is not mandated by the regulation. In addition, the Project Overview Description (POD) must be transparent and document information on:

- Prevalence additionality: An explanation must be provided that the use of nitrogen stabilizers is not a common practice within the company's sourcing region, crop system, or market segment relevant to the intervention.
- Financial additionality: An explanation must be provided carbon finance is positively affecting the adoption of nitrogen stabilizers within the company's sourcing region, crop system, or market segment.

1.5 Crediting period

The crediting period is the timeframe during which a validated project can generate emission reduction certificates. After the end of the crediting period, the project needs to be validated again, to ensure that additionality is still present and to re-assess the baseline.

For GHG projects utilizing nitrogen stabilizers, the crediting period can be set up to a **maximum of 7-years**. This duration strikes a balance between providing enough time for projects to demonstrate their environmental impact and maintaining flexibility for project adjustments and improvements (e.g., new technologies or regulations).

Note: The crediting does not “force” farmers in the project to use nitrogen stabilizers, but allows them to generate emission reduction certificates if they do. For example, if a farmer applies nitrogen stabilizers in only 4 out of 7 years, they would receive emission reduction certificates only for those years.

[12] Twenty percent is the precedent for a common practice threshold established in Section 18 of the CDM Methodological tool: Common practice. (https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-24-v1.pdf)

Retroactive crediting

This methodology allows for retroactive crediting, in the case the application of nitrogen stabilizers was introduced within a maximum of **two years** prior to the submission of the validation of the POD.

In such cases, the crediting period will begin at the moment the intervention was first implemented, provided that the project developer can fulfill the requirements set by this methodology (e.g., proof of additionality, baseline, scientific evidence, documentation etc.) and in addition demonstrate that the intervention was implemented with the intention of utilizing carbon finance.

1.6 Co-benefits & no harm principle

This methodology does not prescribe any calculation methods for quantifying additional benefits resulting from the application of nitrogen-based fertilizers, enriched with nitrogen stabilizers. Project developers are recommended to report on co-benefits for credibility purposes.

Proba encourages GHG projects to contribute to at least one or more UN Sustainable Development Goals, and expects that project developers will consider these when preparing and designing a project.

If the project developer aims to claim one or more co-benefits, these must be clearly defined in the Project Overview Document (POD), along with how the impact is achieved, measured (e.g., through KPIs[13]). In this case, relevant KPIs must be selected by the project developer and monitored throughout the years.

For instance, the SDG Impact Assessment Tool offers a structured approach to help assess and align projects with the SDGs[14].

Some examples that could be relevant with this type of project include:

- Zero hunger (SDG 2): Numerous studies indicate that the use of urease and nitrification inhibitors enhances crop yields while simultaneously reducing N_2O emissions (Wang et al., 2021, Meng et al., 2020, Ding et al., 2018). In doing so, these projects contribute to improving food production while promoting sustainable agricultural practices, aligning with SDG 2, which aims to ensure food security and sustainable food production for a growing global population.

[13] KPIs (Key performance indicators) measure a company's success vs. a set of targets, objectives, or industry peers
[14] http://sdgimpactassessmenttool.org

- **Clean water and sanitation (SDG 6):** By reducing nitrogen leaching into groundwater and surface water, the application of nitrogen stabilizer improves water quality, protecting freshwater ecosystems and ensuring cleaner water supplies (Qiao et al., 2015).
- **Climate action (SDG 13):** By reducing nitrous oxide emissions, these projects reduce GHG emissions and directly contribute to climate change mitigation, aligning with global goals and efforts to combat climate change.
- **Life on land (SDG 15):** Reduced nitrogen runoff can lead to healthier soils and ecosystems. This also contributes to SDG 15 by supporting sustainable use of terrestrial ecosystems and avoiding land degradation and biodiversity loss. For example, Akiyama et al. (2010) stated that NIs significantly reduce nitrogen losses through nitrate leaching and emissions, which can help maintain soil fertility and reduce environmental degradation.

Project developers must adhere to the "*Environmental and Social do no harm principle*" by conducting thorough assessments to identify and evaluate potential environmental and social impacts of their GHG projects.

They must implement appropriate mitigation measures to address any identified potential risks and negative impacts, ensuring that the project does not adversely affect local ecosystems or communities, particularly vulnerable populations.

Continuous monitoring and adaptive management strategies must be employed to ensure ongoing compliance with this principle throughout the project lifecycle. This process must be clearly defined and explained in the Project Overview Document (POD).

1.7 Risks

The project developer must provide a risk analysis outlining all the possible risks associated with the GHG project. Moreover, the project developer must devise and present a mitigation strategy for those risks. Some of the risks that should be addressed are the following:

- Events which may occur during the crop season, and may lead a) to decreased crop yields or b) additional applications of fertilizers and nitrogen stabilizers must be thoroughly explained and documented as part of the verification cycle. Such events can negatively impact the emission reductions of the project. Examples of such events include, but are not limited to, diseases, pests, extreme weather events[15] (e.g., heavy thunder storms and halestorms).

[15] The IPCC defines extreme weather events as occurrences outside the historical range of variability, such as droughts, heatwaves, floods, and storms, which can disrupt agricultural activities and nutrient cycling processes (IPCC, 2021).

- In case the nitrogen stabilizer is not incorporated into the fertilizer during manufacturing (stabilized N fertilizer), but rather sold separately from the fertilizer, then there is a risk that the nitrogen stabilizer is not actually used (e.g., resold).
- The crop producer might not actually apply the reported amount of product, either as an unintentional action or miscalculation or a deliberate error or falsification.
- Nitrogen stabilizer overdose could induce eco-toxicological side effects for plant growth and incur greater economic costs (Macadam et al., 2003; Yang et al., 2016). This is especially a risk for cases where the nitrogen stabilizer is not incorporated into the fertilizer. To prevent this, evidence of proper application rate of N stabilizer or, if that is not possible, monitoring of N dynamics is recommended.
- The crop yield might be incorrectly measured or reported.
- Over time, it is possible that microbial adaptation may reduce the effectiveness of nitrogen stabilizers. However, a study by Duff et. al. showed that non-target bacterial and fungal communities were not significantly affected by long-term inhibitor treatments, supporting the notion that these nitrogen management strategies can mitigate emissions without disrupting overall microbial diversity and composition (Duff et al., 2022). In addition, they found that the effect of fertilisation on the microbial community is greater than the impact of N inhibitor use. Overall, it is recommended that the project developer is transparent on this risk, and investigate if it is relevant for their particular circumstances. If this is the case, then an adaptive response mechanism (such as adjusting dosage of stabilizers) could be considered.
- If the emission factors were selected directly from scientific literature, which was funded by the fertilizer industry, there might be a risk of conflict of interest.

1.8 Leakage & permanence

1.8.1. Leakage

Leakage in the context of a GHG project is the net increase in GHG emissions that occur outside the project boundary, directly resulting from the project's activities (IPCC, 2006). For interventions in scope of this methodology, this happens when there is a decrease in yield within the project area, leading to increased production elsewhere to meet demand. If the yield decreases, it is assumed that production will need to shift to other areas, potentially resulting in more N_2O emissions due to the additional fertilizer application or land use in those areas.

The use of nitrogen stabilizers alongside the same quantity of fertilizer is expected (at least) to maintain the same crop yields. Crop producers are unlikely to implement and maintain a project practice that results in yield declines, since their livelihoods depend on crop harvests as a source of income.

Nevertheless, to ensure leakage is not occurring, the following nitrogen use efficiency (NUE) check must be done to prevent leakage:

At the end of the crediting period, the project developer must:

- Demonstrate that the NUE has not declined by more than 10% in the project scenario by:
  - comparing average with-project NUE (excluding years with extreme weather events) during the project period to average baseline NUE during the historical period (farmer log based approach), **OR**
  - comparing the ratio of average baseline NUE to average regional crop yield during the historical period with the ratio of average with-project NUE to average regional NUE during the project period (market based approach) [16].
- When none of the above options can be proven, then:
  - that specific intervention becomes ineligible for future crediting, **and**
  - the project developer must adjust the project intervention to make sure that the NUE increases, so that there is no leakage. It is expected that this adjustment will probably happen *during* the crediting period, if the crop producer identifies a crop yield decline, thus fixing the crop yield issue, and preventing the leakage to happen in the first place.

1.8.2 Permanence

The intervention focuses on the *reduction* of direct and indirect N_2O emissions. Once the nitrogen stabilizers have delayed nitrogen loss and crops have utilized the nitrogen more efficiently, the potential for nitrogen to escape as direct and indirect N_2O is reduced permanently for that growing cycle.

Since these reductions are tied to specific agricultural cycles, rather than carbon sequestration, the risk of reversals is not applicable.

[16] To demonstrate that crop yields have not declined by more than 10%, project developers can employ remote sensing (e.g., NDVI-based crop productivity assessments) or similar methods, beside self-reported farmer logs to generate realistic insights.

2 Project boundary

2.1 Scope of activities

The activities that are in scope of this methodology, which can lead to the reduction of net GHG emissions, are the following:

- Introduction of the use of nitrogen stabilizers, while keeping the fertilizer nitrogen application rate the same
  - Optional: This methodology allows for the inclusion of other management practices in addition to the use of nitrogen stabilizers, provided there is scientific evidence demonstrating that these practices do not lead to an increase in GHG emissions. For instance, combining different agricultural practices, such as no-tillage, cover crops, or changing fertilizer types, might create synergistic or antagonistic effects on N_2O emissions (Fuertes-Mendizábal et al 2019, Pokharel and Chang 2021). Therefore, it is essential that the implementation of these practices is backed by scientific evidence to ensure they do not negatively impact the effectiveness of nitrogen stabilizers in reducing N_2O emissions.

As mentioned in section 1.2 Applicability, this methodology can work **synergetically** with other GHG methodologies or programs that target emissions reductions or removals in areas outside the scope of this methodology.

2.2 GHG sources

In this methodology, the impact of both direct and indirect N_2O emissions resulting from the application of fertilizers and nitrogen stabilizers is in scope. These emissions are the primary GHG emissions source considered in the project, as they directly result from the transformation of nitrogen in the soil after the fertilizer application.

The indirect emissions must be accounted for in both the baseline and the project. That is because in certain cases the introduction of the use of nitrogen stabilizers (specifically NI) might, on the one hand decrease the direct N_2O emissions but on the other hand increase the (NH_3 volatilization) indirect emissions (Wu et al., 2021).

Moreover, cradle-to-gate emissions must be accounted for both the baseline fertilizer and the project fertilizer. The project fertilizer may refer to either a stabilized N fertilizer or a combination of a conventional fertilizer and a separately applied stabilizer.

While it is acknowledged that there are other GHG sources on agricultural fields, such as CO_2 emissions from soil respiration or methane (CH_4) emissions from organic matter decomposition, these sources are not expected to be affected by the nitrogen stabilizers (Chen et al., 2023). Therefore, these emissions are considered out of scope for the purposes of this methodology, as they do not directly contribute to the emission reductions associated with the use of nitrogen stabilizers.

It is also acknowledged that the introduction of nitrogen stabilizers can influence bioecological cycles and affect microbial community dynamics, potentially leading to impacts beyond direct and indirect N_2O emissions—such as changes in soil nutrient availability and other indirect emissions. However, these negative effects are assumed to be minimal compared to the reduction in N_2O emissions. It is the responsibility of the project developer to confirm that this holds true for their specific project and to transparently report any such effects if relevant under their environmental conditions and management practices. The GHG sources that are in scope are presented in Table 1.

Table 1: GHG sources in scope

	Activity/Source	***GHG***	***Included***	***Justification***
Baseline	Direct N_2O emissions resulting from the application of inorganic and/or organic fertilizers	CO_2	No	Out of scope
		CH_4	No	Out of scope
		N_2O	Yes	N_2O is the major emitted GHG from the use of N fertilizer.
	Indirect N_2O emissions resulting from the application of inorganic and/or organic fertilizers (volatilisation, leaching)	CO_2	No	Out of scope
		CH_4	No	Out of scope
		N_2O	Yes	Volatilisation of ammonia (NH_3) and leaching/runoff of N, mainly as NO_3^-, which can be transformed to N_2O in the future
	Production emissions of inorganic fertilizers used	CO_2e	Yes	Relevant to compare with the production emissions of the stabilized N fertilizer

Project	Direct N_2O emissions resulting from the application of fertilizers in combination with nitrogen stabilizers	CO_2	No	Out of scope
		CH_4	No	Out of scope
		N_2O	Yes	N_2O is the major emitted GHG from the use of N fertilizer
	Indirect N_2O emissions resulting from the application of fertilizers in combination with nitrogen stabilizers (volatilisation, leaching)	CO_2	No	Out of scope
		CH_4	No	Out of scope
		N_2O	Yes	Volatilisation of ammonia (NH_3) and leaching/runoff of N, mainly as NO_3^-, which can be transformed to N_2O in the future
	Cradle-to-gate emissions of inorganic fertilizers used	CO_2e	Yes	Relevant to compare with the production emissions of the stabilized N fertilizer
	Cradle-to-gate emissions of the nitrogen stabilizer	CO_2e	Yes	The emissions related to the production of the stabilizer product must be accounted for

Effect of crop yield increase on GHG emissions:

It is possible that the crop yield increases, as a result of the introduction of the use of nitrogen stabilizers. This is an *additional benefit* which:

- Does not impact the reduction of the GHG emissions per hectare (see section 5. Net reduction of GHG emissions).
- Does impact the reduction of GHG emissions per tonne of crop, which is relevant for the Product Carbon Footprint of the crop.

2.3 Spatial boundaries

The spatial boundaries of a project are defined by the geographic area where the activities impacting GHG emissions take place. These boundaries must include the entire area influenced by the application of fertilizers and nitrogen stabilizers. The two possible levels of spatial boundaries are:

- **Land Management Unit (LMU) level**: The primary boundary are the fields where fertilizers in combination with nitrogen stabilizers are applied and a specific crop type is cultivated (similar to *LMU* and including *Harvested area* as per the GHG Protocol [17]).
- **Sourcing Region level:** Instead of monitoring emissions at the individual LMU level, these spatial boundaries rely on average regional data to estimate the impact on the emissions. In essence, the Sourcing Region level tracks the replacement of conventional fertilizer(s) that would be used in the region, by the stabilized N fertilizer product. The regional boundary accounts for the collective impact of N stabilizer use in a broader landscape. This approach aggregates data from multiple fields, farmers, or cooperatives within a defined region (similar to *Sourcing region* as per the GHG Protocol). The quantification can be based on aggregated EF data from scientific studies (see 4 Calculation of GHG emissions approaches 1 or 2). To achieve that, project developers must stratify the region based on the most relevant environmental factors and management practices (see A.2.1 Alignment with the key environmental factors and management practices).
- The project developer must collect average regional data such as:
  - baseline fertilizers used (which will be replaced by the stabilized N fertilizer)
  - crop types
  - stabilized N fertilizer sale volume
  - nitrogen application rates
  - crop yields
  - Optional: average environmental factors or management practices in the region, which can help select a more specific EF

Sourcing region type of projects can be used when LMU field level type of data can not be accessed. In this case, aggregated emission factors must be used (as explained in section 4 Calculation of GHG emissions), which is expected to come with a higher (compounded) uncertainty when aggregating for regional EFs, thus being on the conservative side. As such, project developers are expected to be incentivized in opting for LMU based projects due to the higher emission reduction potential, caused by the lower uncertainty. This is aligned with SBTi's and GHGp's directions of moving towards field level projects which can offer more transparency and traceability.

Project developers must justify the spatial boundaries based on factors such as the size of the agricultural operation and the type of crops being cultivated.

[17] https://ghgprotocol.org/land-sector-and-removals-guidance

Boundaries must be set in a way that captures all relevant emissions sources and potential leakages. Local and regional regulations, as well as environmental sensitivity[18], must also be considered when defining these boundaries.

If a project includes multiple scenarios—such as different crops, fertilizer types, or nitrogen stabilizer formulations—the project developer must explicitly define the scope of these scenarios within the Project Overview Document (POD). This ensures clarity on what combinations of fertilizers, crops, and management practices are included in the project scope.

During verification, where the actual implementation of the project is assessed, the reported scenarios must be grouped based on similar management practices. The emission impact must then be calculated separately for each group to maintain methodological consistency and accuracy in reporting.

2.4 Temporal boundaries

The temporal boundaries define the start and end of the monitoring and reporting process.

For Land Management Unit level projects:

- The boundaries follow the entire cultivation cycle of the target crop and can vary based on the timing of fertilizer application.
- **Starting of the Temporal Boundaries:**
  - Is defined as the date of the first application of the fertilizer.
- **Ending of the Temporal Boundaries:**
  - Is defined as the final harvest date of the target crop within the participating field [19] .
- The project developer must select and justify the temporal boundaries based on the crop's fertilizer application schedule, which can vary by region. A crop calendar must be consulted to determine the specific timeline for each region. An example resource for this is the USDA Foreign Agricultural Service[20], which provides crop calendar charts for various regions and major crops. However, it is critical to supplement these sources with local, region-specific

[18] Environmental sensitivity refers to the vulnerability of ecosystems or regions to environmental impacts, such as water or air pollution, soil degradation, or biodiversity loss.
[19] Note: It is acknowledged that the nitrogen can remain in significant portions in the soil till after the harvesting period, thus being at risk for later conversion and N losses as N_2O emissions. At the same time, the stabilized N fertilizer can remain in the soil after the harvest, thus potentially reducing the emissions that would have otherwise occurred. However, this methodology relies on scientifically validated EFs for both the baseline and project intervention, which cover the same measurement timeframe. In case direct on-field measurements are done to measure the emissions, then it is crucial that the timeframe of the measurement is similar for both the baseline and the project intervention.
[20] https://ipad.fas.usda.gov/ogamaps/cropcalendar.aspx

data when determining the exact temporal boundaries and ensuring that EFs appropriately account for nitrogen dynamics across the entire crop cycle.

For sourcing region level projects:

- The recommended period for the temporal boundaries is **1 year**.

3 Baseline scenario

The baseline scenario represents the emissions that would occur based on the business as usual agricultural management practices. In other words, this includes fertilizer management and other relevant activities, **without the use of nitrogen stabilizers**. The project developer can establish the baseline based on the following two approaches, depending on the spatial level selected:

1. Land Management Unit approach

The baseline scenario at the Land Management Unit (LMU) level is defined as the application of the same nitrogen rate as the project intervention but without the use of a nitrogen stabilizer. Rather than relying on historical fertilizer application records, the baseline reflects current agricultural management decisions. Each season, untreated nitrogen fertilizer serves as the baseline, as it remains a viable and accessible alternative. This approach captures the additional emissions that would occur if a stabilizer were not used, allowing for the calculation of measurable and additional GHG emission reductions with each application. Since this is a counterfactual baseline approach, the baseline is defined every crop cycle.

In case the project intervention includes the reduction of N rate, because the historical NUE was too low, and N was overapplied, then the baseline N rate must be set as the project N rate (with the higher NUE), so that the emission reduction is not overestimated.

2. Sourcing Region level approach

The baseline scenario is defined based on the amount of stabilized N fertilizer sold, with emissions calculated assuming the same nitrogen application rate but without the stabilizer. A key aspect of this approach is identifying and substantiating common agricultural management practices in the region[21]. This includes assumptions about average fertilizer application rates, crop yield, and typical crop management practices for similar crops in the area. By using these factors, an average baseline emission factor can be derived, reflecting the typical emissions associated with untreated nitrogen fertilizer use. Project developers must re-establish their baselines, at least every 2 years during the crediting period.

Where multiple options or data sources are available, conservative estimates must be used, to avoid overestimating the impact of the project interventions [22].

[21] A geographically distinct area characterized by common environmental, climatic, and agricultural features. It may encompass an entire country or a specific part of it and is often defined by administrative boundaries or agroecological zones.

[22] Specifically, the project developer must select the emission factors, fertilizer application rates and any other relevant data so that the total baseline emissions are not overestimated and the total project emissions are not underestimated.

4 Calculation of GHG emissions

The project developer must calculate the **total GHG emissions** for both the baseline and project scenario. To achieve that, they need to use the equations presented in this section. Baseline and project emissions for each activity step must be transformed into tonnes of CO_2e for each verification period.

The total (baseline or project) emissions can be calculated as the sum of the subsequent activities.

If only one intervention takes place in the project, then:

$$E = \sum_{a=i}^{v} E_a \tag{2a}$$

If multiple interventions take place in the project, then:

$$E = \sum_{x} \sum_{a=i}^{v} E_{a,x} \tag{2b}$$

Where:

E	=	Total (baseline or project) GHG emissions (tCO_2e)
$E_{a,x}$	=	Emissions of activity a for the intervention x (tCO_2e).

The approaches four for quantifying baseline and project emission factors are listed in Table 2. In cases where more than one EF-data reference approach is allowed for a given activity, then the same approach must be used to calculate both the project and baseline scenarios. Regarding the prioritization of the EF sources, the project developers must prioritize granular data compared to aggregated data whenever possible (Tier 3 > Tier 2 > Tier 1). Specifically for the EF selection, Approach 3 (see Table 2) is the preferred approach, followed by 2 then 1, depending on the availability of data and the practicality in the implementation (also see A.1.1. Prioritization of EF sources and Tiers).

Table 2: Summary of equations used to calculate the total emissions and approaches to retrieve the EF

Activity & equation	**Approach 1: *IFA Emission Factor Database for N Stabilizers***	**Approach 2: Emission factors from scientific literature**	**Approach 3: Direct measurement**	**Approach 4: LCA /PCF data**
(i) Direct N_2O emissions $E_i = (FIN \cdot EF_{in,direct\_N2O}) + (FON \cdot EF_{org,direct\_N2O}) \cdot 44/28 \cdot A \cdot GWP_{N_2O}$	X	X	X	
(ii) Indirect ammonia volatilization $E_{ii} = (FIN \cdot NH_3\ volatilized_{in}) + (FON \cdot NH_3\ volatilized_{org}) \cdot EF_{.indirect\_v} \cdot 44/28 \cdot$	X	X	X	
(iii) Indirect leaching and runoff of N $E_{iii} = (FIN + FON) \cdot EF_{indirect\_l} \cdot Nleaching \cdot 44/28 \cdot A \cdot GWP_{N_2O}$	X	X	X	
(iv) Stabilizer cradle-to-gate emissions $E_{iv} = EF_{ST} \cdot FST \cdot A$		X		X
(v) Fertilizer cradle-to-gate emissions $E_v = EF_{IN} \cdot FIN \cdot A$		X		X

4.1 EF-data reference approaches

Approach 1: Use of the IFA Emission Factor Database for Nitrogen Stabilizers

For the quantification of GHG emissions (direct and indirect N_2O emissions), EFs originating from the IFA Emission Factor Database can be used. The IFA Emission Factor Database for Nitrogen Stabilizers consolidates global data related to fertilizer emissions and the effectiveness of nitrogen stabilizers[23]. This database provides EFs derived from studies that align with current agricultural practices and environmental conditions. It offers validated EFs for a variety of scenarios, ensuring consistency and accuracy in GHG quantification while minimizing uncertainties.

The database is developed through a structured, transparent process. The procedure includes the selection of relevant scientific studies based on predefined quality criteria, ensuring that only high-quality, peer-reviewed studies are considered. The database will be updated regularly to reflect new findings and improve the accuracy of the emission factors.

Approach 2: Emission factors retrieved from scientific studies

For the quantification of GHG emissions (direct and indirect N_2O emissions), EFs originating from available scientific literature can be used. Documented emissions of N_2O must be supported by emission factors that are among others characterized by lower uncertainties than Tier 1 EF[24]. Definitions of Tier 1, 2, and 3 EF are described in detail in the Appendix A.

Tier 2 emission factors must meet specific criteria to be considered valid and applicable for use by project developers in this GHG methodology. These criteria ensure that the EFs reflect the characteristics of the project and are derived from scientific studies of high experimental quality standards.

Project developers can extract EF from scientific studies that are relevant to their environmental factors and management practices and aggregate them to create relevant Tier 2 - type of EF. Along with the EF, the project developers must calculate the compounded uncertainty or standard deviation of the EF. This can be done based on the GHG protocol's tool [25]. Such approach is especially necessary for Sourcing Region type of projects, where aggregated EF specific to their project might not be available.

[23] The *IFA Emission Factor Database for Nitrogen Stabilizers* is currently under development
[24] The use of generic Tier 1 emission factors (such as IPCC) is only applicable for the determination of indirect N_2O emissions for this methodology
[25] https://ghgprotocol.org/sites/default/files/2023-03/ghg-uncertainty.pdf

The guidelines for selecting suitable EFs are organized into three main sections, which the project developer must follow:

1. **Alignment with the influential environmental factors and management practices (with high relative importance) of the study:** Emission factors must be selected based on their relevance to both the project's key environmental factors and management practices from the referenced studies to ensure consistency and applicability.
2. **Utilization of meta-analyses papers:** To address quality concerns with meta analysis, a procedure must be followed to explain how emission factors from these studies are used and to outline the steps for extracting EFs from their raw data, ensuring they align with the specific conditions of the project.
3. **Experimental design (of studies/trials):** The experimental trials/scientific studies used for EF extraction must follow high experimental design quality criteria/standards.

Note: Details and specific instructions for each of these sections are explained in the Appendix A.2.

When a range of possible emission factors is provided (f.i. based on a meta-analysis), the methodology requires that the selected EF must have a confidence level of at least 90%. This means that the EF value chosen must fall within the range where there is greater than 90% certainty that it accurately represents the true emission factor under the specified conditions.

This procedure must be thoroughly presented/documented in order for third-party “Verification and validation bodies (VVBs)” to investigate and assess the suitability of the selected EFs during the implementation and reporting stages of the project.

Approach 3: Direct measurements

This approach is focusing on the utilization of project-specific emissions/emission factors that are derived from direct measurement on the field (e.g., using chambers), which provide actual data that reflect field conditions. The measurement methods must be conducted by qualified scientific teams and the process must follow the guidelines presented in the Appendix A.2.3 Experimental design (of studies/trials).

A detailed explanation of the methods used to calculate and account for uncertainties must be included (uncertainty analysis).

Approach 4: LCA or PCF data

This approach utilizes LCA or PCF data to evaluate the GHG emissions associated with the fertilizer and nitrogen stabilizer products. It captures emissions generated across all stages, from raw material extraction and chemical synthesis to manufacturing, production, and transportation, up to the point where the products reach the farm gate (cradle-to-gate).

The project developer is responsible for providing a PCF report related to the stabilized product. If such a PCF is unavailable, the developer may use an available PCF that best represents the project's characteristics and conditions.

The reports must comply with internationally recognized frameworks, such as ISO 14040/14044 (for LCA), ISO 14067 (for PCF) or similar, ensuring that results are credible and comparable with each other.

They must be independently verified by a qualified third party to ensure transparency, reliability, and adherence to industry best practices.

4.2 Equation of each activity step

The following equations shall be applied to quantify direct and indirect N_2O emissions for both the baseline and project intervention. The differentiation between baseline and project conditions is reflected in the selection of the appropriate emission factors (EFs) used in the calculation.

(i) Direct N_2O emissions

This approach is based on equations provided by the IPCC[26].

$$E_i = (FIN \cdot EF_{in,direct\_N2O}) + (FON \cdot EF_{org,direct\_N2O}) \cdot 44/28 \cdot A \cdot GWP_{N_2O} \quad (3a)$$

Where:

E_i	=	Direct GHG emissions from managed soils due to fertilizer application (kg CO_2eq)
FIN	=	Quantity of inorganic N fertilizer applied (kg N / ha)
FON	=	Quantity of organic N fertilizer applied (kg N / ha)

[26] https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch11_Soils_N2O_CO2.pdf

		[It should be included only when there is sufficient scientific evidence of its nitrogen content and the related emissions]
$EF_{in,direct\_N2O}$	=	Emission factor for N_2O emissions from N inputs from inorganic fertilizer (kg N_2O-N / kg N input)
$EF_{org,direct\_N2O}$	=	Emission factor for N_2O emissions from N inputs from organic fertilizer (kg N_2O-N / kg N input)
$44/28$	=	Molar mass ratio of N_2O to N applied to convert N_2O-N emissions to N_2O emissions. [It should be applied only when the unit of the reported EF is in kg N_2O-N, rather than kg N_2O]
A	=	Area of the intervention (ha) [27]
GWP_{N_2O}	=	Global warming potential of nitrous oxide (kg CO_2e / kg N_2O) [Based on IPCC AR6, the 100-year GWP for N_2O is 273]

If cumulative emissions are available, then the equation can be adjusted. The same logic can be applied to the equations of the other activities.

$$E_i = EF_{direct\_N2O\_c} \cdot A \cdot GWP_{N_2O} \tag{3b}$$

Where:

$EF_{direct\_N2O\_c}$	=	Cumulative emissions, derived from the periodic flux measurements which are taken over the growing season, and the values are integrated over time. This integration provides the total N_2O emissions for the monitoring period (kg N_2O/ha)

(ii) Indirect emissions originated from ammonia volatilization

$$E_{ii} = (FIN \cdot NH_3\, volatilized_{in}) + (FON \cdot NH_3\, volatilized_{org}) \cdot EF_{.indirect\_v} \cdot 44/28 \cdot A \cdot GWP_{N_2O} \tag{4}$$

Where:

[27] In case a Sourcing Region level approach is used, the emissions are calculated based on the total amount of stabilized N fertilizer distributed. As such the area of the intervention is not relevant.

E_{ii} = Indirect volatilized NH_3 GHG emissions from managed soils due to fertilizer application (kg CO_2eq)

FIN = Quantity of inorganic N fertilizer applied (kg N / ha)

FON = Quantity of organic N fertilizer applied (kg N / ha)
[It should be included only when there is sufficient scientific evidence of its nitrogen content and the related emissions]

$EF_{, indirect\_v}$ = Emission factor for N_2O emissions from volatilized NH_3 originating form inorganic fertilizer (kg N_2O-N / kg NH_3-N volatilized)
[Default, IPCC: 0.01, unless otherwise specified[28]]

$NH_3\ volatilized_{in}$ = Fraction of synthetic fertiliser N that volatilises as NH3 from inorganic fertilizer (kg NH_3-N volatilized)

$NH_3\ volatilized_{org}$ = Fraction of synthetic fertiliser N that volatilises as NH3 Quantity of ammonia volatilization from organic fertilizer (kg NH_3-N volatilized)

$44/28$ = Molar mass ratio of N_2O to N applied to convert N_2O-N emissions to N_2O emissions
[It should be applied only when the unit of the reported EF is in kg N_2O-N, rather than kg N_2O]

A = Area of the intervention (ha)

GWP_{N_2O} = Global warming potential of nitrous oxide (kg CO_2e / kg N_2O)
[Based on IPCC AR6, the 100-year GWP for N_2O is 273]

(iii) Indirect emissions originated from leaching and runoff of N

It must be determined whether leaching emissions are relevant based on soil type, climate, and management practices in the project area.

$$E_{iii} = (FIN + FON) \cdot EF_{indirect\_l} \cdot Nleaching \cdot 44/28 \cdot A \cdot GWP_{N_2O} \quad (5)$$

Where:

[28] If a project developer identifies separate emission factors (EFs) between inorganic and organic nitrogen fertilizers for volatilization-related N_2O emissions, they may apply these differentiated EFs. In such cases, project developers must adjust the corresponding quantification equations accordingly.

E_{iii}	=	Indirect N leaching/runoff GHG emissions from managed soils due to fertilizer application (kg CO_2eq)
FIN	=	Quantity of inorganic N fertilizer applied (kg N / ha)
FON	=	Quantity of organic N fertilizer applied (kg N / ha) [It should be included only when there is sufficient scientific evidence of its nitrogen content and the related emissions]
$EF_{indirect\_l}$	=	Emission factor for N_2O emissions from N leaching/runoff (kg N_2O-N/kg N leaching/runoff) [Default IPCC: 0.011, unless otherwise specified]
$Nleaching$	=	Fraction of total nitrogen inputs (from fertilizer application or mineralization) that is lost through nitrate leaching and runoff (kg N leached/runoff) [Default IPCC: 0.24, unless otherwise specified[29]]
$44/28$	=	Molar mass ratio of N_2O to N applied to convert N_2O-N emissions to N_2O emissions [It should be applied only when the unit of the reported EF is in kg N_2O-N, rather than kg N_2O]
A	=	Area of the intervention (ha)
GWP_{N_2O}	=	Global warming potential of nitrous oxide (kg CO_2e / kg N_2O) [Based on IPCC AR6, the 100-year GWP for N_2O is 273]

(iv) Nitrogen stabilizer cradle-to-gate emissions

$$E_{iv} = FST \cdot EF_{ST} \cdot A \tag{6}$$

Where:

E_{iv}	=	Nitrogen stabilizer cradle-to-gate emissions (kg CO_2eq)
FST	=	Quantity of nitrogen stabilizer applied

- For stabilized N fertilizers = (kg stabilizer / kg fertilizer) × (total fertilizer applied per ha)

[29] If a project developer identifies separate leaching fractions between inorganic and organic nitrogen fertilizers, they may apply these differentiated EFs. In such cases, project developers must adjust the corresponding quantification equations accordingly.

- For nitrogen stabilizer mixtures (which are applied separately) = (kg stabilizer / ha)

EF_{ST}	=	Emission factor for the cradle-to-gate of the nitrogen stabilizer (kg CO_2eq / kg stabilizer)
A	=	Area of the intervention (ha)

(v) Fertilizer cradle-to-gate emissions

$$E_v = EF_{SN} \cdot FSN \cdot A \tag{7}$$

Where:

E_v	=	inorganic fertilizer cradle-to-gate emissions (kg CO_2eq)
FIN	=	Quantity of inorganic fertilizer applied (kg fertilizer / ha)
EF_{IN}	=	Emission factor for the cradle-to-gate of the inorganic fertilizer (kg CO_2eq / kg fertilizer)
A	=	Area of the intervention (ha)

5 Net reduction of GHG emissions

The project developer can *estimate* the GHG emissions reduction of the project during the crediting period based on the best available data at the time of the validation of the POD.
The issuance of the emission reduction certificates is done on a yearly basis, after updating the project design parameters (see section 6.1 Monitoring), and verifying the GHG emission reduction by a VVB. In other words, the *project emissions* and therefore the *net reduction of GHG emissions* are *dynamic* as they can change from year to year, depending on the management practices on the field (e.g., crop cultivated, selected inorganic fertilizer, selected stabilizer, nitrogen application rate, etc.).

The GHG emission reduction is defined as the difference between the baseline emissions and the project emissions.

An Uncertainty Factor (UF) is applied to the calculations to avoid overestimating the benefits of a project. This UF includes the potential variability in the emission factors, input data, measurements and assumptions used in the project. To calculate the Uncertainty Factor, the tool [30] developed by the GHG Protocol Initiative can be used. This Excel-based tool automates the aggregation steps for developing a basic uncertainty assessment for GHG inventory data, following the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National GHG Inventories. The tool is supplemented by a guidance document [31], which describes the functionality of the tool and gives a better understanding of how to prepare, interpret, and utilize uncertainty assessments. In the Appendix B, the equations to calculate the propagation of uncertainty for single and multi source data are presented.

The project developer must quantify and document all uncertainties concerning assumptions, data measured and tooling involved. Moreover, the project developer must ensure to use conservative standard data and document the choice for the data used.

To calculate the net GHG emissions reduction, the following equation can be used:

$$ER = (BE - PE) \cdot (1 - UF) \quad (8)$$

Where:

ER	=	Net GHG emissions reduction (tCO_2e)

[30] https://ghgprotocol.org/calculation-tools-and-guidance
[31] https://ghgprotocol.org/sites/default/files/2023-03/ghg-uncertainty.pdf

BE	=	Baseline emissions (tCO_2e)
PE	=	Project emissions (tCO_2e)
UF	=	Uncertainty Factor (%)

The *net GHG emissions reduction* for the entire project is a key metric, representing the total annual reduction in emissions, expressed in tonnes of CO_2e. However, it is equally important to present the impact of the intervention using different metrics that can be used by various stakeholders. Examples of these metrics are presented in Appendix C.

6 Monitoring, reporting, and verification (MRV)

The MRV process is a structured approach to quantifying, tracking, reporting, and verifying greenhouse gas (GHG) emissions and reductions achieved through the application of nitrogen stabilizers (alongside organic or inorganic fertilizers) or stabilized N fertilizers. The goal of the MRV approach is to ensure accurate, consistent, and credible measurement and reporting of emissions over time, enabling the issuance of high-quality emission reduction certificates.

The monitoring plan includes:

- The type of information that needs to be collected
- The evidence for each datapoint
- The frequency of reporting

6.1 Monitoring

For this methodology, the monitoring focuses on collecting three key types of data:

A. **Project scoping:** Key project details defined before the project start, submitted once during the POD validation phase (see *Table 3).*

B. **Project design parameters:** Variables monitored and reported during each verification cycle to ensure compliance and accuracy (see *Table 4*). Those must be completed for each specific intervention that is outlined in the project scoping. As seen in *Table 4*, the evidence required for these design parameters primarily rely on traditional methods such as farmer logs and market-based assessments. Where feasible, it is recommended to integrate for advanced approaches such as satellite monitoring, IoT sensors, and blockchain-based recordkeeping in regional approaches, to enhance efficiency, accuracy, and transparency.

C. **Project impact:** Outcomes calculated during each verification cycle, based on the monitored project design parameters. Again, the impact must be calculated and presented separately for each intervention in scope.

Table 3: Project scoping

Index	***Name***	***Description***	***Background from this methodology***	***Evidence required***	***Frequency of reporting***
A1	Scope of activities	Present list of interventions that are in scope of the project, for each field within the entire farm or on the Sourcing Region level	Section 2.1	N/A	Once during POD validation or update during verification if they change during the crediting period
A2	GHG sources	Explain which GHG sources are in scope of the intervention	Section 2.2	N/A	
A3	Spatial boundary and size (hectares or similar)	Present coordinates delineating the: • locations of the field (for Land Management Unit level boundary) • boundaries of the region (for Sourcing Region level boundary)	Section 2.3	Satellite imagery, coordinates	
A4	Temporal boundary (for monitoring)	Define the temporary boundary for the project	Section 2.4	N/A	

Table 4: Project design parameters for Land Management Unit level intervention

Index	Category name	Subcategory name	Description	Evidence required for baseline	Evidence required for project	Frequency of reporting
B1.1	Crop type	-	Type of crop being cultivated	Farmer log or market based information	Farmer log	Reconfirmed or updated for every verification
B1.2	Fertilizer	Type	Type of fertilizer being applied	Farmer log or market based information	Proof of purchase and product label	
		N rate	Nitrogen rate in each fertilizer, % total N, %urea-N, % ammonium-N	Farmer log or market based information	Fertilizer product description (f.i. label or safety data sheet)	
		Application rate	Application rate of the fertilizer	Farmer log or market based information	Farmer logs related to days of application	
B1.3	Nitrogen stabilizer	Type	Type of nitrogen stabilizer being applied	-	Proof of purchase (or sale from the distributor), product label & regulatory eligibility	
		Application rate	Application rate of the nitrogen stabilizer	-	• For stabilized N fertilizer: fertilizer application rate based on, product label and farmer logs • For stabilizer/fertilizer mixtures: the product label, instructions/ recommendation from the manufacturer and farmer log	

Index	Category name	Subcategory name	Description	Evidence required for baseline	Evidence required for project	Frequency of reporting
B1.4	Crop yield	-	Amount of crops harvested	Farmer log or market based information	Proof of crop yield productivity (e.g., Crop insurance reporting records)	Reconfirmed or updated for every verification
B1.5	NUE	Project NUE	Nitrogen use efficiency, which must be compared to historical or regional benchmark NUE values to verify that the baseline practices are following the region's guidelines.	Farmer log	Calculated based on crop yield and N rate	
		Regional or historical NUE	Regional or historical NUE	Regional database (or similar) or farmer logs (for the historical NUE).	-	
B1.6	(Optional) Additional management practices	-	Optional only if additional management practices are implemented, along with the nitrogen stabilizer introduction, which lead to an extra reduction of GHG emissions.	-	• Scientific evidence of the emission factor, that is related to this intervention • Proof that the additional practice actually took place (remote sensing, video imagery, farmer log, or similar)	
B1.7	(Optional) Additional data for more detailed EF	Influential environmental and/or management practices	Optional. In case more detailed EF are selected, then additional information are required	Farmer log or market based information	For each additional data point, sufficient evidence is required	
B1.8	Emission factors	-	List of EFs selected for each activity in scope	Relevant evidence depending on the approach selected (see section 4.1 EF-data reference approaches)		

Table 5: Project design parameters for Sourcing Region level intervention

Index	Category name	Subcategory name	Description	Evidence required for baseline	Evidence required for project	Frequency of reporting
B2.1	Crop types	-	The types of crops grown in the region, allowing emissions to be weighted based on the proportion of total cultivated hectares for each specific crop	Regional databases / sources	Regional databases / sources	Reconfirmed or updated for every verification
B2.2	Fertilizer	Types	Type of fertilizer being applied on the region	Regional databases / sources	Proof of sale (or purchase) of fertilizer	
		N rate	Nitrogen rate in each fertilizer, % total N, %urea-N, % ammonium-N	Regional databases / sources	Proof of sale (or purchase) of fertilizer	
		Application rate	Average application rates of the fertilizer	Regional databases / sources	Regional databases / sources	
B2.3	Nitrogen stabilizers	Type	Type of nitrogen stabilizer being applied	-	Proof of sale (or purchase) of stabilized N fertilizer / fertilizer-stabilizer mixture	
		Application rate	Application rate of the nitrogen stabilizer	-	• For stabilized N fertilizer: fertilizer application rate based on, product label and regional fertilizer	

					application rate • For stabilizer-fertilizer mixtures: the product label, instructions/ recommendation from the manufacturer	
B2.4	Crop yield	-	Average crop yields, to showcase the impact of the intervention per tonne of crop produced	Regional databases / sources	Farmer log or sale proof from a representative sample of farmers	
B2.5	NUE	Nitrogen use efficiency or the region	For transparency purposes it is recommended to present the relevant (to the project interventions) NUE of the region	Regional databases / sources	Calculated based on crop yield and average application rates	
B2.6	(Optional) Additional data for more detailed EF	Influential environmental and/or management practices	In case more detailed EFs are selected, then additional information are required	Regional databases / sources	Regional databases / sources	
B2.7	Emission factors	-	List of EFs selected for each activity in scope	Relevant proof depending on the approach selected (see section 4.1 EF-data reference approaches)		

Table 6: Project impact (for LMU or Sourcing Region level intervention)

Index	Category name	Subcategory name	Calculation method	Frequency of reporting
C1.	Net reduction of GHG emissions	-	Section 5	Updated every verification
C2.	Different metrics of GHG emissions	Per unit of land area	Appendix C	
		Per unit of crop produced		
		Per unit of nitrogen containing fertilizer applied		

6.2 Reporting

Monitoring reports must include:

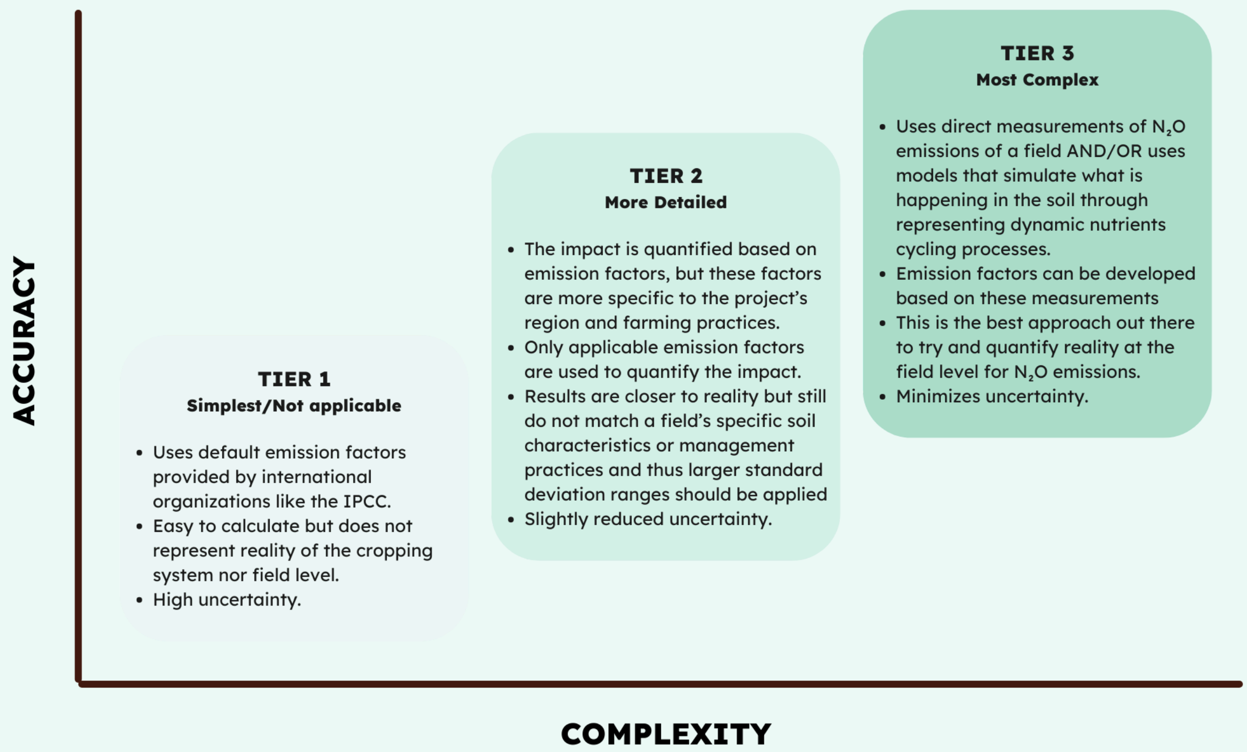
- A general description of the project, including the location of the fields where baseline emissions would occur and nitrogen stabilizers will be applied.
- A description of the data collection process, frequency of monitoring, and procedures for archiving data, as presented in section 6.1 Monitoring.
- A recordkeeping plan to maintain accurate documentation that shows when and where nitrogen stabilizers application has occurred (e.g., field records, field investigations, farm implement measures, machinery receipts, delivery notes and/or invoices).
- The roles of individuals involved in monitoring and data collection (e.g., responsibilities).
- The monitoring time period must be documented in every report.
- Monitoring reports must be submitted once per crop season (see 2.4 Temporal Boundaries).
- All monitoring reports must be accessible at the demand of the *Validation, Verification Bodies* (VVB) for validation and verification procedures.

6.3 Verification

An approved Validation and Verification Body (VVB) must be selected to execute the verification process based on the monitoring plan and reports to confirm that the program's requirements are met, ensuring the accuracy of the calculated GHG reductions resulting from the use of nitrogen stabilizers.

Appendix A: Emission factor description and usability

A.1 Tier definitions



Tiers 1, 2, and 3 represent progressively detailed approaches for quantifying emissions related to fertilizer use (baseline) and during the application of nitrogen stabilizers, suitable for different levels of data availability and analysis precision:

- **Tier 1** is the most generic approach, utilizing global default EF for generalized estimates. It relies on broad quantification with minimal data requirements (e.g., IPCC 2019 tables). However, Tier 1 **is not applicable in this methodology**, as it does not provide the specificity needed to accurately quantify direct N_2O emissions from nitrogen fertilizer inputs (baseline) or nitrogen stabilizer interventions. Nevertheless, due to the limited availability of scientific data (Tier 2 EF) on indirect emissions, **Tier 1 EFs may be used to estimate indirect N_2O emissions**.

- **Tier 2** EF can be derived from existing meta-analyses, systematic reviews, databases, scientific literature or the IFA-endorsed EF database (under development). This approach allows for more accurate quantification of emissions associated with both the baseline fertilizer application and the intervention using nitrogen stabilizers. Empirical equations are used, with contextualized EF reflecting to the highest potential possible the agricultural practices, soil types, and environmental/climatic conditions of a particular area. Detailed procedures and guidelines of how to select appropriate EF is discussed below.
- **Tier 3** represents the most detailed and accurate approach, relying on either advanced biogeochemical process-based modeling[32] or site-specific data collection through field measurements during the project implementation. This tier quantifies emissions related to baseline fertilizer use and nitrogen stabilizer application by incorporating site-specific data, such as soil properties, actual site precipitation and temperature data, timing of specific practices (e.g., planting, fertilization, irrigation, harvesting), and crop yield.

Field-based data collection, including direct N_2O measurements (e.g., via static chambers), fertilizer/nitrogen stabilizer inputs, crop yield outputs, and associated environmental variables such as soil moisture, temperature, and pH, can provide high accuracy and credibility to the reduction claims.

A.1.1. Prioritization of EF sources and Tiers

- Priority should be given to Tier 3 (site-specific data or field measurements) whenever such data is available. If a project developer does not use this tier, they must explain why a more granular approach was not feasible. As such, EF Approaches 3 then 2 are preferable (see section 4.1 EF-data reference approaches).
- Tier 2 should be used when Tier 3 data is unavailable, and the available literature or scientific data provides sufficient relevance to estimate emissions accurately (see section A.2.1 Alignment with the key environmental factors and management practices). As such, EF Approaches 1 and 2 then 4 are the next best options.
- Tier 1 can be used when neither Tier 2 nor Tier 3 data is available, but only for estimating indirect emissions or for Sourcing Region level in regions with significant data gaps.
- If there is a lack of scientific literature or data related to the intervention or region, the project cannot make a claim about emission reductions, as this methodology is based on a science-driven approach.

[32] Note: The use of process-based models for deriving the Emission Factors is not eligible in this version of the methodology.

A.2 Emission factor selection criteria based on scientific studies

A.2.1 Alignment with the key environmental factors and management practices

- Scientific studies used for deriving EFs must align with the project's geographical and agricultural context. This ensures that the baseline and project emissions reflect realistic and applicable conditions. Key criteria must include:
  - **Environmental factors:** The study must be conducted in a location with environmental conditions similar to the project area. The environmental conditions that should be similar are these with the highest relevance based on the Fan et. al. (2022) explanatory variables.

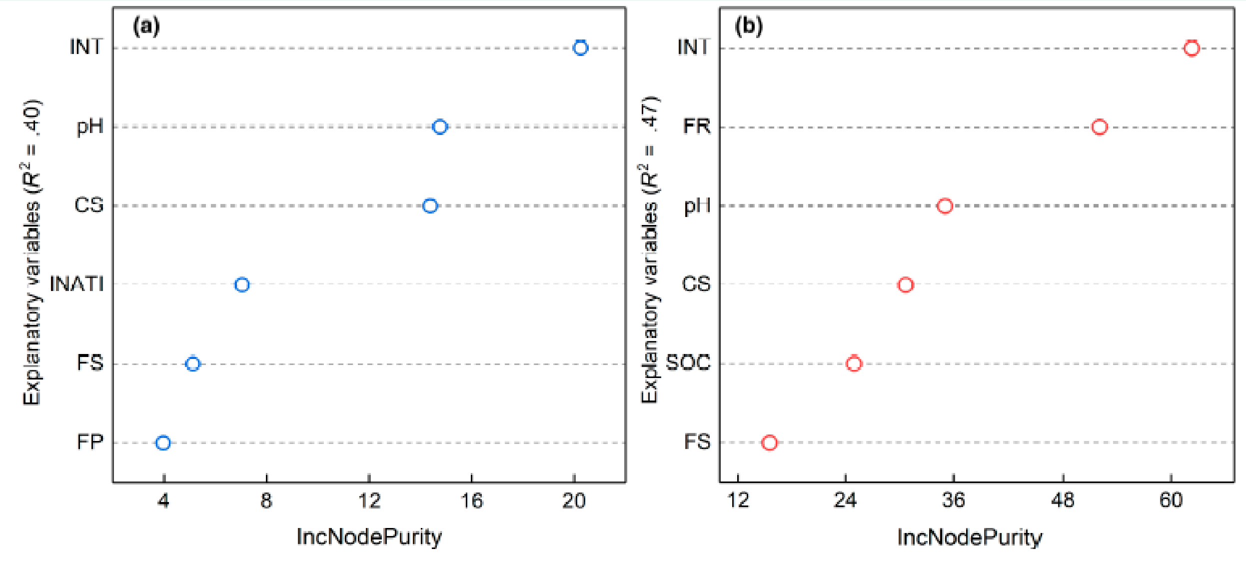


FIGURE 7 Relative importance of different explanatory variables for the NH_3 (a) and N_2O (b) models. CS, cropping system; FP, fertilizer placement; FR, fertilizer application rate; FS, fertilizer source; INATI, inhibitor application timing; IncNodePurity, total decrease in node impurity; INT, inhibitor type; pH, soil pH; SOC, soil organic carbon. [Colour figure can be viewed at wileyonlinelibrary.com]

  - **Management practices:** The study must involve management practices that match the baseline and project interventions, such as:
    - Fertilizer type and application rates
    - Use of the same category of nitrogen stabilizers (e.g., urease, nitrification inhibitors, or their combination)
    - Crop type
  - The fertilizers and nitrogen stabilizers used in the study must follow the criteria mentioned in section 1.3 Eligible products, be commercially available and have the same N stabilizer category to those applied during the project implementation.

- Temporal relevance: The studies that EF are retrieved from should be recent enough to reflect current climatic conditions, agricultural technologies and practices. A common practice is to utilize studies published within the last 30 years, provided there have been no significant changes in agricultural practices, technologies or climatic conditions (due to climate change) in the region. If such changes have occurred, more recent studies (e.g., within the past 10 years) should be considered, in order to accurately reflect the current conditions.

A.2.2 Utilization of meta-analyses papers

Meta-analyses papers can serve as valuable sources for EF extraction, provided they meet specific quality criteria:

- **Representation of diversity**: The meta-analysis must include studies with diverse environmental and management conditions. It should provide distinctions based on factors such as regions, soil types, or other relevant characteristics that can be correlated to the project's specific conditions.
- **Study alignment**: Each individual study within the meta-analysis must adhere to the project's regional, temporal, and management relevance criteria. The meta-analysis should offer a clear breakdown of data categorized by region, soil type, or other variables to enable alignment with the project's characteristics.
- **Data extraction**: When a meta-analysis provides average EFs, in order to use them project developers must ensure that these averages align with their project's specific characteristics, including environmental factors and management practices as mentioned in section A.2.1. If the provided averages do not sufficiently match the project's conditions, wherever feasible, project developers should extract raw data from the meta-analysis and create new averages that better reflect the project's specific context. In such cases, detailed documentation of the procedure must be provided to ensure transparency and traceability.
- **Uncertainty consideration**: Each average EF must be accompanied by its reported average standard deviation. Meta-analyses must report standard deviations (SDs) or confidence intervals for derived average EFs. An additional uncertainty penalty must be applied if raw data is unavailable or if inclusion criteria for individual studies are unclear.

A.2.3 Experimental design (of studies/trials)

The robustness of the experimental design is critical to ensure that the EF values derived are reliable and reproducible. To achieve this, the following criteria must be met:

- **Measurement period and temporal coverage:** Scientific studies often recommend a three-year monitoring period to account for year-to-year variability in environmental conditions. However, due to practical limitations, a one-year experiment is also acceptable, provided that more plot-level replications (e.g., multiple experimental units under different conditions) are included to strengthen reliability and improve data robustness.
- **Replication**: A minimum of three replicates per treatment is required (Abalos et al., 2014; Fan et al., 2022) to account for variability in environmental and management conditions. A lack of replication may undermine the reliability of the results.
- **Controls**: The experiment must include treatment without nitrogen stabilizers (baseline) and if possible a control without nitrogen fertilizer application , to isolate the effect of the stabilizers accurately.
- **Measurement period**: The measurement duration should align with the crop cycle and seasonal variations to ensure comprehensive data. Emissions should be measured over a period that captures all significant nitrogen loss events, including heavy rainfall, drought, or temperature fluctuations, if they occurred.
- **Standardized measurements**: Emissions must be quantified using scientifically recognized methods. For instance, chamber-based measurements for direct N_2O emissions or isotopic techniques for tracking nitrogen transformations.
- **Consistency across treatments**: Environmental and management conditions (e.g., fertilizer application rates, irrigation) must be consistent across treatments (control and intervention) to ensure comparability. Differences in these conditions can skew results and reduce the validity of derived EFs.
- **Data reporting**: Studies must clearly present key information, including:
    - Mean cumulative N_2O emissions (direct and/or indirect) for control and treatment groups
    - EF for each treatment
    - Stabilizer type, application rate
    - Associated uncertainty ranges (e.g., standard error)
    - Environmental conditions (e.g., soil texture, rainfall, air or soil temperature)
    - Number of replicates

- **Field-based measurements**: Measurements must be conducted under field conditions. Measurements reported from laboratory experiments are not considered applicable for this methodology.

For on-field measurements, project developers must adhere to the relevant guidelines to ensure that field measurements are conducted rigorously and provide data that meet the quality standards required to provide emissions from the field and eventually Tier 3 EF to be developed. Some examples include:

- Hutchings et al. (2024), *Preconditions for Including the Effects of Urease and Nitrification Inhibitors in Emission Inventories*,
- Lyons et al., (2024b) *Field Trial Guidelines for Evaluating Enhanced Efficiency Fertilizers*.

Appendix B: Uncertainty Factor calculation

The uncertainty factor of the data depends on the source and quality of the data, which leads to different calculation methods for data collected from different sources.

B.1 Uncertainty propagation for single-source data

The overall uncertainty in the net GHG emission reduction can be derived by combining the uncertainties from both the baseline and project emissions. This can be done using the following propagation of uncertainty formula:

$$UF = \sqrt{(\sigma_{BE})^2 + (\sigma_{PE})^2 - 2\cdot\ \sigma_{BE\ PE}} \quad (8)$$

Where:

UF_i	=	Uncertainty of source i (source i can refer to literature i /field plot i, etc.)
σ_{BE}	=	uncertainty in the baseline emissions (%)
σ_{PE}	=	uncertainty in the project emissions (%)
$\sigma_{BE\ PE}$	=	covariance between the uncertainties of the two values (if they are correlated). Since the baseline and project emissions are independent (no correlation between them), the covariance is typically considered zero.

B.2 Uncertainty propagation of multi-source data

When combining EF from multiple sources into one, the following equation can be used:

$$UF = UF_{avg} = \frac{\sqrt{\sum_{i=1}^{n} UF_i^2}}{n} \qquad (9)$$

Where:

$UF = UF_{avg}$	=	will be the Uncertainty Factor (%) used in calculating the actual GHG emissions reduction, which is the average of the uncertainties in the relevant data from all the from 1 to n sources
UF_i	=	Single-Source Uncertainty Factor of source i
n	=	number of independent Single-Sources that have similar conditions to the actual project being implemented

Appendix C: Different metrics of GHG emissions

A commodity-based approach for quantifying the impact is particularly relevant for downstream stakeholders. For example, a food company may want to use this data for their Product Carbon Footprint (PCF) reports or Life Cycle Assessments (LCAs), where the GHG emissions per tonne of crop is crucial. For a fertilizer producer, the focus may be on the GHG emissions per tonne of fertilizer or nitrogen stabilizer applied (again for the cradle-to-grave PCF/LCA), while for a farmer, the GHG emissions per hectare might be more relevant. In Table 7 the key metrics that can be applied are presented.

Table 7: Metrics that can be used for the project GHG emissions

Metric	***Description***	***Example***	***Unit***
Per unit of crop produced **[PCF of crop]**	This metric correlates emissions reductions to crop yield, making it valuable for assessing GHG emissions throughout the food supply chain. By expressing emissions reductions relative to the amount of crop produced, it helps food companies track improvements in sustainability while lowering their carbon footprint. This approach directly links emission reductions with crop yield.	Companies within the food industry (such as food producers) can use this metric to demonstrate that the production of their crops are associated with lower emissions	tCO_2e / ton of crop
Per unit of nitrogen containing fertilizer applied **[PCF of fertilizer]**	This metric demonstrates the emissions reductions achieved per ton of nitrogen fertilizer applied, providing insight into the efficiency of nitrogen use. It directly quantifies the impact of improved fertilizer management strategies, such as the use of nitrogen stabilizers, and demonstrates how much N_2O emissions are saved for every kilogram of fertilizer used.	Fertilizer companies looking to show progress in nitrogen use efficiency and claim reduction in their Scope 3 emissions.	tCO_2e / ton of fertilizer
Per unit of land area	This metric provides clear insights into GHG emissions reductions on a field level. By quantifying emissions	Companies within the food industry (such as food producers) can use this metric to	tCO_2e / ha

	reductions per hectare, this metric allows for direct comparison between different fields or farms, making it critical for broader environmental claims.	demonstrate that the production of their crops are associated with lower emissions	

To showcase the impact of the project intervention, these metrics can be compared against the metrics for each of two baseline approaches (see section 3 Baseline scenario).

The quantification of the field emissions (direct and indirect N_2O) derived from this methodology, can be directly used by supply chain participants as an input for the Product Carbon Footprints (PCFs) of the crops.

When calculating the **impact per tonne of crop produced** (for the PCF of the crop), it is essential to account for variations in annual crop yield, which can be heavily influenced by external factors such as weather patterns, pests, or regional events. These fluctuations may not accurately reflect the impact of the intervention itself but instead represent broader external trends. To address this, a normalization process is recommended, such as using a moving average for the crop yield.

A **moving average** is a statistical method used to smooth out short-term fluctuations and highlight longer-term trends by creating a series of averages from subsets of data points. Mathematically, it is a type of convolution, where the crop yield data is combined with a filter function—in this case, a simple averaging filter (sometimes referred to as a "boxcar filter"). For a moving average, this filter computes the mean of crop yields within a fixed window size (e.g., 3–5 years). For crop rotation scenarios, only the years with the same type of crop are relevant for each moving average. The window shifts forward through the data series, excluding the oldest value and including the next, producing a smoothed trend line.

This approach effectively reduces the noise caused by year-to-year variability, allowing for a clearer understanding of the intervention's impact. By comparing the normalized yields with the farmer log and regional baseline scenario, stakeholders, such as (downstream) reporting companies, can better distinguish the intervention's true contribution to emission reductions from region-wide external factors. Additionally, reporting **both** the raw and smoothed yield data provides transparency and ensures that all stakeholders involved understand the normalization process.

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