GHG Methodology

Adoption of nitrogen stabilizers to transition to low-carbon agriculture

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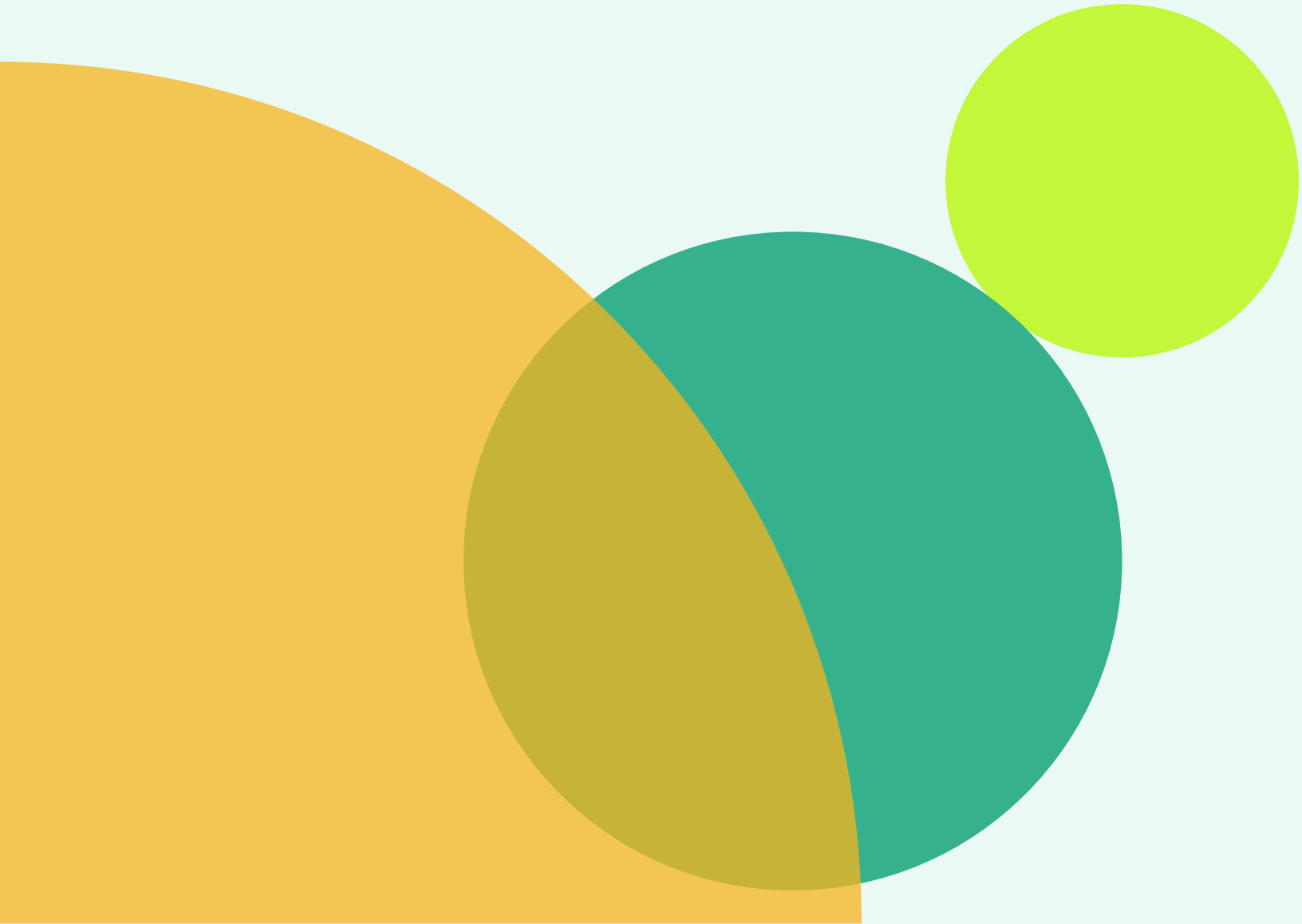
Version 1.0



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Methodology:

Adoption of nitrogen stabilizers to transition to low-carbon agriculture

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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. 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 CO_2, 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-6 assessment from UNFCCC[1].
Compound fertilizers	Fertilizer products composed of both stabilized and non-stabilized nitrogen components, such as bulk-blended formulations.
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

[1] https://ghgprotocol.org/sites/default/files/2024-08/Global-Warming-Potential-Values%20%28August%202024%29.pdf

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	excludes emissions from field application or any subsequent stages beyond the project's location.
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

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

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	GHG project is to convert the GHG impact into emission reduction certificates.
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 sustainable 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. This includes compound fertilizers in which only a portion of the nitrogen is stabilized (e.g., bulk-blended products combining stabilized and non-stabilized nitrogen forms).
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 among other metrics

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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

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

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	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 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.

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List of abbreviations

AR6	IPCC Sixth Assessment Report
AFOLU	Agriculture, Forestry, and Other Land Use
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

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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, which can reduce nitrate leaching and the production of nitrous oxide (N_2O), especially during the early and peak uptake stages of the crop[4].

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:

- Reduction in direct N_2O emissions: Nitrogen stabilizers reduce direct N_2O emissions by slowing processes like nitrification, minimizing N_2O formation in the soil.

[4] Nitrate leaching can still occur under certain conditions, such as after harvest if residual nitrate remains in the soil and is mobilized by precipitation

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- **Reduction in indirect N_2O emissions**: 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 improved 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[5] 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.
- Grassland and pasture systems are excluded due to the high variability in nutrient inputs from grazing and manure deposition, which makes it difficult to isolate the impact of nitrogen stabilizers. Additionally, there is limited scientific evidence on the stabilizers' effectiveness in these systems to support credible emission reduction claims.
- Partial substitution of conventional nitrogen fertilizer with nitrogen stabilizer-containing products is applicable, provided that the stabilizer component is clearly defined, the substitution is documented, and the corresponding emissions reductions are calculated only for the portion of nitrogen treated with the stabilizer.
- Project developers must ensure that the applicability, eligibility and additionality criteria presented in this methodology are fulfilled.
- 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

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

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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.
- Project developers must demonstrate that nitrogen inputs are applied at appropriate rates based on regional agronomic guidelines or best practices (e.g., nutrient recommendations from agricultural retailers, industry-supported agronomy platforms, etc.) supporting optimal nitrogen use efficiency (NUE). See Appendix D for different metrics for NUE. Where regional data is unavailable or unreliable, project developers may propose farm-level NUE benchmarks, provided they are supported by transparent historical records and justified environmental comparability. This ensures that baseline fertilization is not excessive and avoids rewarding projects that apply nitrogen beyond typical regional norms, which could otherwise inflate emission reductions linked to fertilizer substitution. Where regional baseline fertilization is excessive, project developers must clearly disclose this and structure their projects to support improved, agronomically appropriate nitrogen application rates. For this purpose, project developers must do a NUE Performance Test, as defined in section 3. Baseline scenario.
- 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[6], 2) a relevant meta-analysis, or 3) original scientific literature.

[6] The IFA Emission Factor Database for Nitrogen Stabilizers is currently under development

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    - 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 1 or 2 - type [7]), 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 agroecological zones must be supported by scientific evidence demonstrating the impact of nitrogen stabilizers on GHG emissions to be applicable under this methodology. In cases where such direct evidence is unavailable for a specific crop, project developers may propose the use of emission factors from agronomically and environmentally comparable crops. This approach is acceptable when supported by scientific evidence, demonstrating similar nitrogen use patterns, management practices, and environmental conditions. All assumptions and rationale must be transparently documented in the Project Overview Document (POD).
- 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)[8] **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 **synergistically** 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

[7] Explanation of the Tier approach can be seen in the appendix A.1 Tier definitions
[8] 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.

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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 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 nitrogen 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) [9].
- Other enhanced efficiency fertilizer products, such as control or slow-release fertilizers, biostimulants and bio-inhibitors (BI) are currently **excluded** from this methodology.

[9] By default only active ingredients for which there is solid scientific evidence are eligible as explained in the applicability section. In a next version of this methodology, guidance will be given on how to onboard new active ingredient products.

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- **Solid vs liquid forms:** 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.
- **Application method of stabilizer:** 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.
    - Compound fertilizers composed of both stabilized and non-stabilized nitrogen components, such as bulk-blended formulations. Eligibility in such cases applies to the stabilized portion of the product, provided that appropriate documentation is included in the POD, and emission reductions are proportionally assigned.
    - Post-application treatment: Nitrogen stabilizers applied separately after fertilization to control nitrogen transformations in the soil.

1.3.2 Regulatory compliance and application rates

Regulatory compliance:

For nitrogen stabilizer products to be eligible they must meet the regulatory requirements for use in the country or region of application. 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)[10], while NI falls under the jurisdiction of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)[11]. 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[12], which amends Regulation (EU) 2019/1009, establishes the requirements for compounds to be classified under Product Function Categories (PFCs) and

[10] http://www.aapfco.org/
[11] https://www.epa.gov/enforcement/federal-insecticide-fungicide-and-rodenticide-act-fifra-and-federal-facilities
[12] Regulation - 2019/1009 - EN - EUR-Lex

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comply with EU fertilizer regulations. Specifically PFC5[13] 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).
- 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)

Appropriate 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 POD demonstrating their efficacy under the specific conditions (of the project).

To further ensure consistency with scientifically validated performance levels, it is required that project-level application rates of nitrogen stabilizers (on a per hectare basis or per w/w ratio) remain within ±25% of the application rate reported in the supporting reference studies. If the supporting reference studies do not specify an application rate, the project developer must select an appropriate rate from another independent and credible source that aligns with their cropping system. This choice must be strongly justified. Particular attention should be paid to ensuring that the selected rate allows for the intended environmental benefits of the stabilized fertilizer to be achieved, without causing any adverse impacts (see Section 1.7 Risks). In such cases, the Validation and Verification Body (VVB) must carefully verify that the application rate was selected appropriately and in accordance with these criteria.

[13] This category includes stabilizers such as nitrification and urease inhibitors, and outlines composition and performance requirements to ensure both environmental safety and agronomic efficacy

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Effectiveness of products:

The effectiveness of nitrogen stabilizers can vary depending on environmental conditions such as temperature, soil texture, pH, and moisture. For instance, higher temperatures may accelerate the degradation of certain active ingredients of nitrification inhibitors (NI), reducing their inhibitory effectiveness in the soil.

Project developers must ensure that the selected stabilizer is suitable for the specific agroecological context of the project. If stabilizers are to be applied under such challenging conditions, the POD must include:

- Supporting evidence from peer-reviewed studies, manufacturer documentation, or regional field trials demonstrating consistent and effective performance under similar conditions; and
- Documented adjustments in application timing, formulation, or complementary agronomic practices (e.g., irrigation scheduling or carrier selection) that enhance stabilizer effectiveness.

Furthermore, the emission factors (EFs) selected for quantifying GHG reductions must accurately reflect the stabilizer's behavior under those conditions. This means that the EF must be supported by experimental data conducted under comparable environmental and management settings. Specific guidance on the required alignment between EF selection and project conditions is provided in Appendix A.2.

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.

Project developers are encouraged to use the *Proba Additionality Assessment Template* [14] to assess and demonstrate additionality, as defined in section 3.6 of the *Proba Standard*.

Alternatively, established tools and approaches can support project developers in assessing additionality, particularly for financial and common practice assessments. These include the UNFCCC's CDM Tool for the Demonstration and Assessment of Additionality (Version 07.0) [15] and

[14] https://proba.earth/hubfs/Project_Design/Proba_Additionality_Assessment_Template.pdf
[15] https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-01-v7.0.0.pdf

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the CDM Tool for Common Practice (Version 03.1) [16]. These tools offer structured guidance for conducting barrier analyses, determining financial attractiveness, and assessing market penetration levels of a given practice. While originally developed for offsetting contexts, they can be adapted for insetting projects when transparently applied and justified in the POD.

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 [17].
- 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. Proof that can be used for this assessment may be (but not limited)
    - A signed declaration by the farmer (or project participant) confirming that the use of nitrogen stabilizers is not standard practice on the farm and that carbon finance was a decisive factor in adopting the practice.

[16] https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-24-v1.pdf
[17] 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)

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    - A financial barrier analysis or cost-benefit model demonstrating that the stabilizer cost outweighs direct economic returns for the farmer, without the carbon revenue.

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 that carbon finance is positively affecting the adoption of nitrogen stabilizers within the company's sourcing region, crop system, or market segment.

Note: Additionality must be reassessed when renewing the crediting period to confirm that the project remains eligible under the Proba Standard. Project developers are responsible for monitoring regulatory changes, financial conditions, and market adoption that may affect the project's additionality. The use of a dynamic baseline is required to reflect these developments and ensure the continued credibility of the emission reductions being claimed, as seen in section 3. Baseline scenario.

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 re-validated, to ensure that additionality is still present, the baseline scenario is reassessed, and the project complies with the latest version of this methodology. If these requirements of the methodology are not fulfilled at the time of project re-validation then the crediting period can not be renewed.

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.

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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 POD, along with how the impact is achieved, measured (e.g., through KPIs[18]). 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[19].

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.

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

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- **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.

1.7 Risks

The project developer must conduct a comprehensive risk analysis outlining all potential risks associated with the GHG project, including environmental, social, and operational risks. This analysis must identify any possible negative impacts on local ecosystems or communities.

Based on this analysis, the project developer must develop and present in the POD appropriate mitigation measures and adaptive management strategies to address identified risks. These strategies must ensure that the project does not adversely affect its surroundings and continues to comply with safeguard principles throughout the project lifecycle.

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[20] (e.g., heavy thunder storms and hailstorms).

[20] 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).

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- The crop yield might be incorrectly measured or reported.
- 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.
- While stabilizer products are subject to regulatory approval and maximum residue levels (MRLs) in many jurisdictions, misapplication or excessive dosage could pose risks. To mitigate this, adherence to registered application rates, as outlined in section 1.3.2 Regulatory compliance and application rate, is required and must be documented in the POD.
- 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) must 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 refers to a net increase in GHG emissions outside the project boundary that is directly caused by project activities (IPCC, 2006). While projects are credited only for reductions within the project area, potential leakage must be assessed to ensure environmental integrity.

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For interventions in scope of this methodology there may be two main risks of leakage:

1. Leakage must be accounted for when fertilizer volumes no longer used in the project area are demonstrably sold and used by non-project actors [21]. Given the global nature of fertilizer markets, it is not feasible to monitor all potential displacement of conventional fertilizers at a global scale. However, project developers must take reasonable steps to assess and mitigate leakage risks within the project region. The project developer must provide reasonable evidence of how these volumes were managed. Evidence can include:
    - written confirmation from fertilizer supplier or distributor that production or delivery volumes were reduced;
    - project-level fertilizer application data showing reduction in conventional fertilizer use without corresponding increase elsewhere;
    - national or regional sales/trade data showing stable or decreasing conventional fertilizer volumes;
    - market analysis or reports indicating no increase in non-project sales.

    Where this cannot be confirmed, conservative deductions apply to account for potential leakage risk. These deductions can be adjusted retrospectively if new evidence is submitted. Specifically, after a period of 4 years, the project developer may submit evidence demonstrating that the project did not result in leakage elsewhere. If such evidence is accepted by the verification and validation body, the reserved emission reductions may be credited retroactively or released from a buffer pool. If sufficient evidence is not provided at that time, the deduction remains permanent.

Table 1: Market leakage deduction for different scenarios

Project scale[22]	Scenario	Traceability of the displacement	Deduction
<1.000 ha	A	Leakage risk is considered negligible.	0%
1,000 - 10,000 ha	B	Project shows displaced fertilizer was not used outside the project (e.g. supplier confirmation, farm data, or market data)	1%
	C	Fate of displaced fertilizer unknown or unconfirmed (no evidence)	5%

[21] This risk of leakage is not applied to nitrogen stabilizers/fertilizers mixtures and post-application treatments.
[22] The project scale classification is based on commonly observed thresholds in land-based GHG methodologies, where projects below 1,000 ha are typically considered small-scale with negligible market influence, while projects above 10,000 ha are likely to affect regional fertilizer supply chains. These thresholds reflect practical differences in traceability, monitoring capacity, and risk of market leakage, and are consistent with scale categories used in AFOLU methodologies under carbon standards.

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Project scale[22]	Scenario	Traceability of the displacement	Deduction
>10.000 ha	D	Project shows displaced fertilizer was not used outside the project (e.g. supplier confirmation, farm data, or market data).	2%
	E	Displaced fertilizer may have been used outside the project (uncertain or evidence of redirection). No evidence, or indications of redistribution in trade/sales data.	10%

2. The use of nitrogen stabilizers alongside the same quantity of fertilizer is expected (at least) to maintain the same crop yields. However, if there is a decrease in crop 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. 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[23] must be done to prevent leakage:

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

   - Demonstrate that the crop yield and NUE has not declined by more than 10% in the project scenario by:
     - comparing average within-project NUE (excluding years with extreme weather events) during the project period to the average baseline NUE during the historical period (farmer log based approach) [24], **OR**
     - comparing the ratio of average baseline crop yield and NUE to average regional crop yield during the historical period with the ratio of average within-project crop yield and NUE to average regional crop yield and NUE during the project period (market based approach) [25].

[23] The NUE can be measured/assessed using different metrics as described in the Appendix D (non-exhaustive list). The project developer is required to perform the NUE check with at least the PFP metric. Depending on their cropping system it is recommended to use further metrics, as presented in the Appendix, that make sense for their specific case.
[24] To reduce the impact of inter-annual variability, project developers may apply a weighted multi-year average NUE, excluding years with documented extreme weather. Additionally, yield-normalized NUE metrics (e.g., NUE per tonne of crop biomass) may be used where appropriate, provided they are transparently justified in the POD.
[25] 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.

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- 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.

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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 **synergistically** with other GHG methodologies or programs that target emissions reductions or removals in areas outside the scope of this methodology. For instance, it can be combined with approaches involving the introduction of controlled-release fertilizers (CRFs) or low-carbon fertilizers.

2.2 GHG sources

In this methodology, the impact of the stabilized fertilizer products starting from their production up until their application on the field is in scope. Specifically the activities (as seen in *Figure 1*) that result in GHG emissions and are in scope include:

1. Fertilizer production emissions (cradle-to-gate emissions of fertilizers). These 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.
2. Transportation of the fertilizers from the production location to the project location. Certain PCFs include these emissions already. If this is the case, then these must be updated to

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reflect the actual transportation emissions of the baseline and project and avoid potential double counting.

3. Field spreading of the fertilizers using machinery [26]. The use of stabilized fertilizer products may result in a different number of fertilizer applications compared to conventional practices, potentially leading to more or fewer tractor passes and associated fuel use. Any resulting change in fuel consumption must be accounted for if it is material. CO_2 emissions from this activity should be calculated using standardized emission factors (e.g., per liter of diesel or per hour of equipment operation), and must be supported by verifiable records such as machinery logs, fuel receipts, etc (see section 6.1 Monitoring). The project developer must be transparent in his choice to include or not the emissions from this activity. In addition, an intervention might include the switch to low-carbon fuel for the fertilizer spreading. This can be included in this activity. This activity can only be accounted for as a GHG benefit for LMU type of projects.
4. Application of fertilizers: The impact of both direct and indirect N_2O emissions resulting from the application of stabilized fertilizer products 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. Both direct and indirect N_2O emissions must be estimated using either a relevant peer-reviewed study (e.g., product-specific trials, scientific studies or meta-analyses) or IPCC[27] guidelines. If changes in organic fertilization (for example increased application of manure) happen as part of the intervention, which can affect the in-field emissions, then this needs to be accounted for as well. 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).

The activities in scope are presented in *Figure 1* below:

[26] It is acknowledged that there are various other activities related to farming that might lead to GHG emissions. However, for the purposes of this methodology we consider that field spreading of fertilizers is the one with the highest material impact.

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

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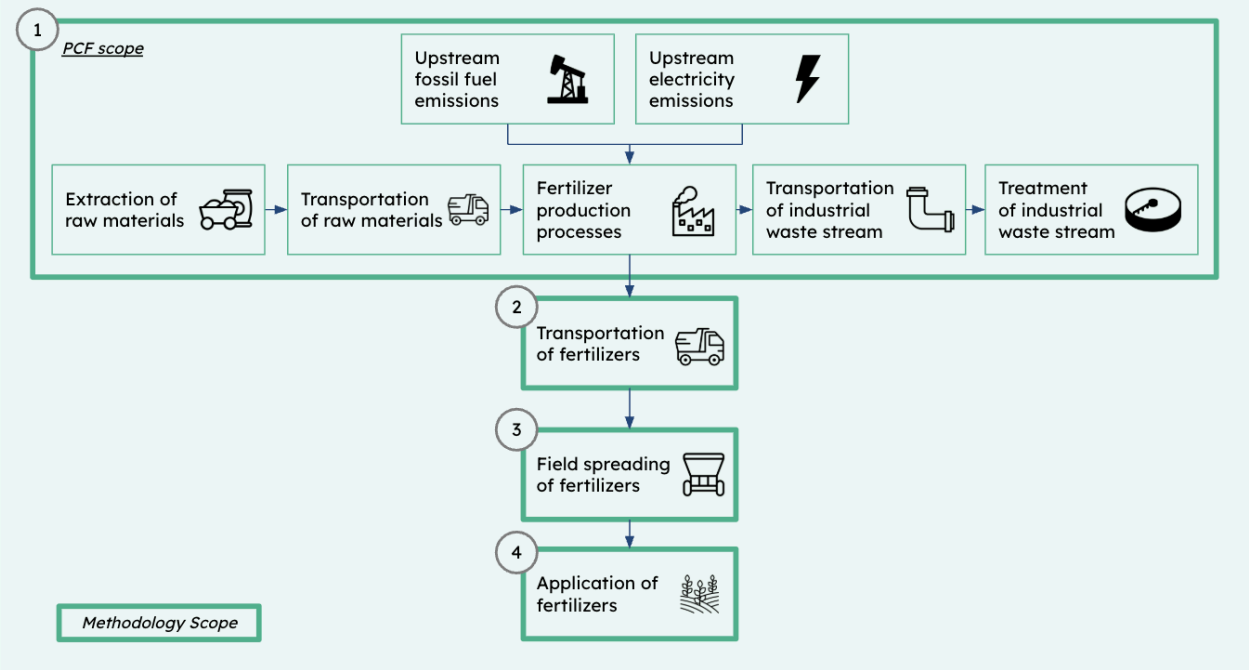
Figure 1: Activities in scope for the GHG sources calculations



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. However, methane (CH_4) emissions are only in scope for crop systems involving anaerobic conditions, such as flooded rice paddies. Project developers must assess and report CH_4 emissions in rice projects using relevant emission factors or direct measurements as described in section 4 Calculation of GHG emissions and Appendix A.2. For all other crop systems, CH_4 is excluded due to negligible impact.

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 2.

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Table 2: GHG sources in scope

Type	*Activity/Source*	*GHG*	*Included*	*Justification*
Baseline	(1) Production emissions of fertilizers used	CO_2e	Yes	Relevant to compare with the production emissions of the stabilized N fertilizer
	(2) Transportation of fertilizers	CO_2	Yes	Main emission from combustion of fuel
		CH_4	No	Typically not material
		N_2O	No	Typically not material
	(3) Field spreading of fertilizers	CO_2	Yes	Main emission from combustion of fuel
		CH_4	No	Typically not material
		N_2O	No	Typically not material
	(4a) Direct emissions resulting from the application of fertilizers	CO_2	No	Out of scope
		CH_4	Yes	Included, if the crop system involves anaerobic conditions (e.g., flooded rice).
		N_2O	Yes	N_2O is the major emitted GHG from the use of N fertilizer.
	(4b) Indirect emissions resulting from the application 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
Project	(1a) Cradle-to-gate emissions of fertilizers used	CO_2e	Yes	Relevant to compare with the production emissions of the stabilized N fertilizer
	(1b) 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
	(2) Transportation of	CO_2	Yes	Main emission from

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Type	*Activity/Source*	*GHG*	*Included*	*Justification*
	stabilized fertilizers			combustion of fuel
		CH_4	No	Typically not material
		N_2O	No	Typically not material
	(3) Field spreading of stabilized fertilizers	CO_2	Yes	Main emission from combustion of fuel
		CH_4	No	Typically not material
		N_2O	No	Typically not material
	(4a) Direct emissions resulting from the application of fertilizers in combination with nitrogen stabilizers	CO_2	No	Out of scope
		CH_4	Yes	Included, if the crop system involves anaerobic conditions (e.g., flooded rice)
		N_2O	Yes	N_2O is the major emitted GHG from the use of N fertilizer
	(4b) Indirect 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

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).[28]

[28] In principle, an increase in nitrogen uptake due to higher yields could reduce emissions, since more nitrogen is taken up by the plant and less is lost to the environment. However, in this methodology, emission reductions are quantified based on emission factors (EFs), not nitrogen mass balance equations (in other words the calculation is done ex-ante). The delta in emissions, and therefore the creditable reduction, is entirely derived from the difference in EFs between the baseline (no stabilizer) and the project intervention (with stabilizer), per unit of nitrogen applied. This means that there is no recalculation of emissions based on crop yield alone. While yield may improve NUE and potentially lower emissions, proper equipment (e.g. gas chambers) cannot be installed in every field to measure the actual fluxes, neither an extended samples lab analysis

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- 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 that impact 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[29]).
- **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

is feasible to measure the N uptake of the crop. In theory, the EFs already integrate the average response under specific conditions (including, in some cases, crop performance), and applying an additional yield-based adjustment would introduce double-counting or untraceable assumptions.

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

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Some distinctions between the two levels:

- 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.
- This methodology applies a **5% deduction to the net GHG emission reductions** when the sourcing region spatial boundary is used. This deduction is intended to further incentivize the adoption of LMU type of projects, again in alignment with the SBTi and GHG Protocol's guidance encouraging greater transparency and traceability through field-level interventions.

Project developers must justify their selection of spatial boundaries based on factors such as the access to farmer level data, homogeneity and level of insights.

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[30], 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 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.

[30] Environmental sensitivity refers to the vulnerability of ecosystems or regions to environmental impacts, such as water or air pollution, soil degradation, or biodiversity loss.

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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.
- The starting of the temporal boundaries is defined as the date of the first application of the fertilizer.
- The ending of the temporal boundaries is defined as the final harvest date of the target crop within the participating field [31] .
- 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[32], which provides crop calendar charts for various regions and major crops. However, it is critical to supplement these sources with local, region-specific 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**.

This temporal boundary is used because, at the sourcing region scale, fertilizer sales and corresponding N stabilizer use may span multiple cropping systems and planting seasons. Within one calendar year, it is possible to capture several crop cycles for short-duration or row crops (e.g., maize, wheat, vegetables), reflecting an accurate representation of nitrogen use and related emissions across a variety of cropping systems and management practices.

[31] 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.

[32] https://ipad.fas.usda.gov/ogamaps/cropcalendar.aspx

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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. Baseline N-rate

- 1.a 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.
- 1.b. Sourcing Region level approach
    - The baseline scenario is defined based on the total amount of stabilized N fertilizer sold within the defined sourcing region, with emissions calculated assuming the same nitrogen application rate but without the stabilizer. A key aspect of this approach is identifying and substantiating current common agricultural management practices in the region[33]. 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 3 years during the crediting period.

[33] 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.

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2. NUE performance test [34]

- 2.a Land Management Unit level approach:
    - 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)
        - Example equation of NUE

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

        - Different metrics for NUE assessment that can be used are presented in Appendix D)
    - NUE can vary from year to year due to weather patterns, pest diseases, or changes in soil conditions. Project developers are required to use multi-year historical data, such as a moving average (see Appendix C) of the last 3–5 growing seasons, to better represent typical practices. Single-year data may only be used in exceptional cases (e.g., newly established farms) and must be clearly justified.
    - If a field or region follows a crop rotation system (e.g., legumes in one year, cereals in the next), the baseline NUE must be specific to the focus crop in the rotation.
    - If the historical NUE was too low, and N was overapplied, then project intervention must include the reduction of N rate to be aligned with proper agricultural practices. In these cases, the baseline N rate is still defined as the project N rate. This ensures that the emission reduction is not overestimated, and

[34] The NUE can be measured/assessed using different metrics as described in the Appendix D (non-exhaustive list). The project developer is required to perform the NUE check with at least the PFP metric. Depending on their cropping system it is recommended to use further metrics, as presented in the appendix, that make sense for their specific case.

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that cropping systems that were overapplying are not rewarded more than they should.

- 2.b Sourcing Region level approach
    - 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. This requirement is intended solely for transparency purposes.

3. Baseline Fertilizer Type

- 3.a Land Management Unit level approach
    - This baseline reflects current agricultural management decisions. Each season, conventional fertilizer serves as the baseline, as it remains a viable and accessible alternative. This approach captures the additional emissions that would occur if a nitrogen stabilizer was 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. If available, historical farm-level data (such as fertilizer type, crop yield reports, and field management logs) can be used to help establish the baseline fertilizer type.
- 3.b Sourcing Region level approach
    - The baseline fertilizer type is determined using a regional-counterfactual approach. Specifically, the project developer must conduct a regional market analysis to identify the range of fertilizer products that could realistically be used in the context of the project's farming systems. This analysis should consider factors such as crop type, management practices, and input availability. The result is a baseline fertilizer mix, consisting of representative fertilizers and their respective proportions.
    - This baseline fertilizer mix reflects current agricultural management decisions as it serves as a viable and credible alternative to the stabilized fertilizers used in the project intervention, rather than relying on historical application records.

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4. Dynamic baseline

- Given that in many regions and markets regulatory changes and the industry standards are evolving rapidly and this can have a severe impact on baseline calculations, a dynamic baseline is required. Project developers must assess the regional baseline at least **every 3 years** during the crediting period. If the regional baseline has changed, then the project's baseline must be re-established based on the regional baseline. Moreover, updates which affect additionality (regulatory changes, subsidies, tax incentives, etc.) must be transparently presented in the verification report.

Where multiple options or data sources are available, conservative estimates must be used, to avoid overestimating the impact of the project interventions [35].

[35] 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.

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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:

$$E = \sum_{a=i}^{v} E_a \quad (2a)$$

If multiple interventions take place in the project, then:

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

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 for quantifying baseline and project emission factors are listed in Table 3. 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 3) 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).

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Table 3: 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
(1a) Fertilizer cradle-to-gate emissions $E_{1a} = EF_{IN} \cdot FIN \cdot A$		X		X
(1b) Stabilizer cradle-to-gate emissions $E_{1b} = EF_{ST} \cdot FST \cdot A$		X		X
(2) Transportation of fertilizers $E_2 = \sum_c \sum_x (EF_m \cdot Q_{x,c,m} \cdot D_{x,c,m})$		X		
(3) Field spreading of fertilizer products $E_3 = \sum_{cf} \sum_{mf} (EF_{mf} \cdot D_{cf,mf} \cdot N_f)$		X		
(4a) Direct N_2O emissions $E_{4a} = (FIN \cdot EF_{in,direct_N2O}) + (FON \cdot EF_{org,direct_N2O}) \cdot 44/28 \cdot A \cdot GWP_{N_2O}$	X	X	X	
(4b) Indirect ammonia volatilization $E_{4b} = (FIN \cdot NH_3\ volatilized_{in}) + (FON \cdot NH_3\ volatilized_{org}) \cdot EF_{.indirect_v} \cdot 44/28 \cdot A \cdot GWP_{N_2O}$	X	X	X	
(4c) Indirect leaching and runoff of N $E_{4c} = (FIN + FON) \cdot EF_{indirect_l} \cdot Nleaching \cdot 44/28 \cdot A \cdot GWP_{N_2O}$	X	X	X	

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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[36]. 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, GHG or national EF inventories

For the quantification of GHG emissions (direct and indirect N_2O emissions), EFs originating from available scientific literature (individual studies, meta analyses), GHG or national EF inventories[37] 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[38]. 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 or emission reduction percentages 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. Higher-tier emission factors (Tier 3 > Tier 2 > Tier 1) must be prioritized. If lower-tier EF are used,

[36] The *IFA Emission Factor Database for Nitrogen Stabilizers* is currently under development
[37] Many countries maintain national GHG emission factor inventories to support environmental reporting and policy. For example, the Netherlands provides detailed, annually updated emission data and country-specific emission factors through its Emission Registration system, available at: www.emissieregistratie.nl.
[38] 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

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the project developer must justify why higher-tier options were not feasible (see Appendix A.1.1 Prioritization of EF sources and Tiers).

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. Where exact alignment between the study conditions and the project characteristics is not available, project developers may use emission factors derived from studies that partially align with key parameters (e.g., soil type, climate type, fertilizer or stabilizer product type, etc.). In such cases, developers must select a conservative EF value from the available data (use of standard deviation ranges). The procedure of selecting an appropriate value is described in section 4.3. Uncertainty and must be properly justified and documented.
2. **Utilization of meta-analyses papers, GHG or national EF inventories:** These sources can be valuable when emission factors from individual studies are limited or when a broader evidence base is needed to support a representative value. Project developers may use data from these sources and use emission factors or emission reduction percentages, provided that a clear and well-documented selection process is followed. For example, in meta analyses, emission reduction results are typically presented across several subgroup factors (such as soil type, crop type, etc.), each with its own range of values. When multiple relevant subgroups apply, project developers can identify where these ranges overlap and select a conservative value from within that intersection (see section 4.3 Uncertainty).
3. **Experimental design (of studies/trials):** The experimental trials/scientific studies and meta analyses used to extract EFs or emission reduction percentages 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 95%. This means that the EF value chosen must fall within the range where there is greater than 95% certainty that it accurately represents the true emission factor under the specified conditions.

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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 gas 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 Quality criteria of 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. Special care must be given, to ensure that the PCF method between the baseline and the project products is at least consistent to make sure that we are comparing similar metrics.

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4.2 Equations of each activity

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.

(1a) Fertilizer cradle-to-gate emissions

$$E_{1a} = EF_{SN} \cdot FSN \cdot A \quad (8)$$

Where:

E_{1a}	=	Fertilizer cradle-to-gate emissions (kg CO_2eq)
FIN	=	Quantity of fertilizer applied (kg fertilizer / ha)
EF_{IN}	=	Emission factor for the cradle-to-gate of the fertilizer (kg CO_2eq / kg fertilizer)
A	=	Area of the intervention (ha)

(1b) Nitrogen stabilizer cradle-to-gate emissions

$$E_{1b} = FST \cdot EF_{ST} \cdot A \quad (76)$$

Where:

E_{1b}	=	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) • 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)

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A = Area of the intervention (ha)

(2) Transportation of fertilizers

The emissions are calculated for each product to be applied (x), based on the distance between the factory and the usage location (c), and the mode of transportation used (m).

$$E_2 = \sum_c \sum_x (EF_m \cdot Q_{x,c,m} \cdot D_{x,c,m}) \quad (9)$$

Where:

E_2 = Emissions of the transportation of the products (tCO_2eq)

EF_m = Emission factor of the mode of transportation m (tCO_2eq/tonne-km)

$Q_{x,c,m}$ = Quantity of product x sent to fertilizer usage location c via the mode of transportation m (tonne)

$D_{x,c,m}$ = Distance traveled of product x to the usage location c via the mode of transportation m (km). If the specific usage location is not known (for example for sourcing region type of projects), a conservative average distance can be assumed, provided that it is thoroughly justified in the POD.

(3) Field spreading of fertilizer products

These emissions include activities from the machinery used during the application process. The emissions are calculated based on the vehicle type or the field spreading machinery (mf) which apply the fertilizer on the field (cf), the distance traveled within the field ($D_{cf,mf}$), and the number of times the fertilizer is spread per the defined temporal boundaries (N_f).

$$E_3 = \sum_{cf} \sum_{mf} (EF_{mf} \cdot D_{cf,mf} \cdot N_f) \quad (6)$$

Where:

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E_3	=	Emissions of the application of fertilizers (tCO_2eq)
EF_{mf}	=	Emission factor of the vehicle type or application machinery m (tCO_2eq/tonne-km)
$D_{cf,mf}$	=	Distance traveled within the field cf via the vehicle type or application machinery mf for one spread (km)
N_f	=	Number of times the fertilizer is spread per defined temporal boundaries

(4a) Direct N_2O emissions

This approach is based on equations provided by the IPCC[39].

$$E_{4a} = (F_{in} \cdot EF_{in,direct_N2O}) + (F_{org} \cdot EF_{org,direct_N2O}) \cdot 44/28 \cdot A \cdot GWP_{N_2O} \quad (3a)$$

Where:

E_{4a}	=	Direct GHG emissions from managed soils due to fertilizer application (kg CO_2eq)
F_{in}	=	Quantity of inorganic N fertilizer applied (kg N / ha)
F_{org}	=	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]
$EF_{in,direct_N2O}$	=	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) [40]
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]

[39] https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch11_Soils_N2O_CO2.pdf
[40] 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.

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

$$E_{4a} = EF_{direct_N2O_c} \cdot A \cdot GWP_{N_2O} \quad (3b)$$

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)

(4b) Indirect emissions originated from ammonia volatilization

$$E_{4b} = (F_{in} \cdot EF_{in,\,indirect_NH3} \cdot NH_3\,volatilized_{in}) + (F_{org} \cdot EF_{org,\,indirect_NH3} \cdot NH_3\,volatilized_{org}) \cdot EF_{.indirect_v} \cdot 44/28 \cdot A \cdot GWP_{N_2O} \quad (4)$$

Where:

E_{4b} = Indirect volatilized NH_3 GHG emissions from managed soils due to fertilizer application (kg CO_2eq)

F_{in} = Quantity of inorganic N fertilizer applied (kg N / ha)

F_{org} = 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]

$EF_{in,\,indirect_NH3}$ = Emission factor for N_2O emissions from volatilized NH_3 originating form inorganic fertilizer (kg N_2O-N / kg NH_3-N volatilized)

$EF_{org,\,indirect_NH3}$ = Emission factor for N_2O emissions from volatilized NH_3 originating form iorganic fertilizer (kg N_2O-N / kg NH_3-N volatilized)

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

$NH_3\,volatilized_{org}$ = Fraction of organic N fertilizer N that volatilises as NH_3 (kg NH_3-N volatilized)

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$44/28$	=	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]

(4c) 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.

$$E_{4c} = (F_{in} \cdot EF_{in,\,indirect_l} \cdot N\,leaching_{in}) + (F_{org} \cdot EF_{org,\,indirect_l} \cdot N\,leaching_{org}) \cdot 44/28 \cdot A \cdot GWP_{N_2O} \quad (5)$$

Where:

E_{4c}	=	Indirect N leaching/runoff GHG emissions from managed soils due to fertilizer application (kg CO_2eq)
F_{in}	=	Quantity of inorganic N fertilizer applied (kg N / ha)
F_{org}	=	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]
$EF_{in,\,indirect_l}$	=	Emission factor for N_2O emissions from N leaching/runoff originating from inorganic fertilizer (kg N_2O-N/kg N leaching/runoff)
$EF_{org,\,indirect_l}$	=	Emission factor for N_2O emissions from N leaching/runoff originating from organic fertilizer (kg N_2O-N/kg N leaching/runoff)
$N\,leaching_{in}$	=	Fraction of inorganic N fertilizer that is lost through nitrate leaching and runoff (kg N leached/runoff)
$N\,leaching_{org}$	=	Fraction of organic N fertilizer that is lost through nitrate leaching and runoff (kg N leached/runoff)
$44/28$	=	Molar mass ratio of N_2O to N applied to convert N_2O-N emissions to N_2O emissions

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		[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]

4.3 Uncertainty

To ensure the credibility and conservativeness of emission reduction estimates, this methodology provides two approaches for addressing uncertainty, depending on the type of project and the tier of data used.

Option 1 - LMU type of projects with Tier 3 Data

For field-level (LMU) projects using Tier 3 data, the project developer must conduct a quantitative uncertainty assessment. To do that the tool 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, 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.

This approach allows for more precise project-specific estimates and may support higher claims when uncertainty is well-characterized and transparently reported.

Option 2 - LMU and sourcing region type of projects with Tier 1 or Tier 2 Data

For both LMU and sourcing region types of projects using Tier 1 or Tier 2 data, a simplified, conservative approach must be followed to ensure robustness of estimates, in cases where project-specific measurements are not feasible.:

- Conservative parameter selection: Project developers must select values from the conservative end of available ranges. While not necessarily the lowest value, selections should lean towards the lower half of the range to avoid overestimating emission reductions.

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- Meta-analysis and GHG inventories based factors: When using these sources to derive emission factors or emission reduction percentages, project developers should combine multiple context-specific variables, such as soil type, crop type, application rate, and product characteristics (if available), to ensure the selected EF (from the EF ranges) is both conservative and grounded in the most relevant evidence.
- Regional deduction: For sourcing region types of projects, a fixed 5% deduction (as explained in section 2.3 Spatial boundaries) must be applied to the estimated reductions to account for the higher uncertainty associated with aggregated data and absence of field-level monitoring.

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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 fertilizer, selected stabilizer, nitrogen application rate, etc.).

The GHG emission reduction is defined as the difference between the baseline emissions and the project emissions. To conservatively account for potential leakage, a (potentially reversible) leakage deduction factor is applied to the total net emission reductions. This factor reflects the assessed risk that the project activity may indirectly cause an increase in GHG emissions outside the project boundary, either through market displacement of conventional fertilizers or unintended yield impacts. The applicable leakage deduction is determined based on the classification described in section 1.8 Leakage & Permanence

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

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

Where:

ER	=	Net GHG emissions reduction (tCO_2e)
BE	=	Baseline emissions (tCO_2e)
PE	=	Project emissions (tCO_2e)
LP	=	Leakage penalty (%). If leakage is reversible, the credited emissions can be adjusted retroactively or the corresponding amount can be released from the buffer pool.
UP	=	Uncertainty penalty for sourcing region type of projects (%)

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.

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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 Project Developers must follow the monitoring, reporting and verification (MRV) procedures of the latest version of the Proba Standard.

The MRV 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 4).*
B. **Project design parameters:** Variables monitored and reported during each verification cycle to ensure compliance and accuracy (see *Table 5*). Those must be completed for each specific intervention that is outlined in the project scoping. As seen in *Table 5*, 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.

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Table 4: 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, on the LMU 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	

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Table 5: 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	Fertilizer PCF	Cradle-to-gate emissions	• Third party verified manufacturer's PCF report • Credible database e.g. National/regional PCF datasets	• Third party verified manufacturer's PCF report • Credible database e.g. National/regional PCF datasets	
		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 & method	Application rate of the fertilizer & method, timing, splitting	Farmer log or market based information	Farmer logs related to days of application	
B1.3	Nitrogen stabilizer	Nitrogen stabilizer PCF	Cradle-to-gate emissions	-	• Third party verified manufacturer's PCF report • Credible database e.g. National/regional PCF datasets	
		Type	Type of nitrogen stabilizer being applied	-	Proof of purchase (or sale from the distributor), product label & regulatory eligibility	

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Index	Category name	Subcategory name	Description	Evidence required for baseline	Evidence required for project	Frequency of reporting
		Application rate & method	Application rate of the nitrogen stabilizer & method, timing, splitting	-	• 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 • For compound fertilizers containing both stabilized and non-stabilized N components (e.g., bulk blends), project developers must report the application rate specific to the stabilized fraction, using manufacturer documentation, product composition data, and field-level application records.	
B1.4	Crop yield (Y)	-	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	Farmer log	Calculated based on the metrics presented in Appendix D	

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Index	Category name	Subcategory name	Description	Evidence required for baseline	Evidence required for project	Frequency of reporting
			verify that the baseline practices are following the region's guidelines.			
		Regional or historical NUE	Regional or historical NUE	Regional database (or similar) or farmer logs (for the historical NUE).	-	
B1.6	Transportation emissions	Distance	Average distance between the production location and the use location of the fertilizer	Data from distributor	Data from distributor	
		Vehicle type	Type of vehicle(s) used to transport the fertilizer	Data from distributor, industry reports	Data from distributor, industry reports	
B1.7	Field spreading emissions	Machinery type	Type of vehicle(s) used to spread the fertilizer	Farmer log	Farmer logs related to days of application	
		Distance traveled per field spread	Distance that the machinery (e.g. tractor) travels to spread the fertilizer	Farmer log	Farmer logs related to days of application	
		Number of field spreading events per cropping cycle	Based on the type of fertilizer, spreading method, etc. different number of field spreading events might happen.	Farmer log	Farmer logs related to days of application	
B1.8	(Optional) Additional management practices	-	Optional only if additional management practices are implemented, along with the nitrogen stabilizer introduction, which lead to	-	• Scientific evidence of the emission factor, that is related to this intervention • Proof that the additional	

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Index	Category name	Subcategory name	Description	Evidence required for baseline	Evidence required for project	Frequency of reporting
			an extra reduction of GHG emissions.		practice actually took place (remote sensing, video imagery, farmer log, or similar)	
B1.9	(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	
B1.10	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 6: 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	Fertilizer PCF	Cradle-to-gate emissions	• Third party verified manufacturer's PCF report • Credible	• Third party verified manufacturer's PCF report • Credible database	

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Index	Category name	Subcategory name	Description	Evidence required for baseline	Evidence required for project	Frequency of reporting
				database e.g. National/regional PCF datasets	e.g. National/regional PCF datasets	
		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	Nitrogen stabilizer PCF	Cradle-to-gate emissions	-	• Third party verified manufacturer's PCF report • Credible database e.g. National/regional PCF datasets	
		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	

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Index	Category name	Subcategory name	Description	Evidence required for baseline	Evidence required for project	Frequency of reporting
					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 of 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 the metrics presented in Appendix D	
B2.6	Transportation emissions	Distance	Average distance between the production location and the use location of the fertilizer	Market analysis or relevant industry reports on distance between production and use location of the products.	• A conservative average distance can be assumed, provided that it is thoroughly justified • Receipts of transport services if available	
		Vehicle type	Type of vehicle(s) used to transport the fertilizer	Market analysis or relevant industry reports presenting the typical vehicles	• Similar data as baseline • Receipts of transport services,	

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Index	Category name	Subcategory name	Description	Evidence required for baseline	Evidence required for project	Frequency of reporting
				used to transport these products.	if available	
B2.7	(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	
B2.8	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)		

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Table 7: 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		

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6.2 Reporting

Monitoring reports must include:

- A general description of the project, including:
    - For LMU type of projects: the location and outline of individual fields where nitrogen stabilizers would be applied and baseline emissions would have occurred.
    - For sourcing region type of projects: the defined regional boundary and the aggregate intervention area across the sourcing region.
- 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
    - For LMU type of projects: This includes field records, field investigations, farm implement measures, machinery receipts, delivery notes and/or invoices).
    - For sourcing region type of projects: This includes nitrogen stabilizers distribution data, regional sales volume, or aggregation reports from participating cooperatives or farming associations
- 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 temporal boundary (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 project's requirements are met, ensuring the accuracy of the calculated GHG reductions resulting from the use of nitrogen stabilizers. Information regarding the frequency of the verification process can be found in the Proba Standard. No additional requirements for site inspections are prescribed for this methodology. The project developer must define a proper site inspection plan in the POD.

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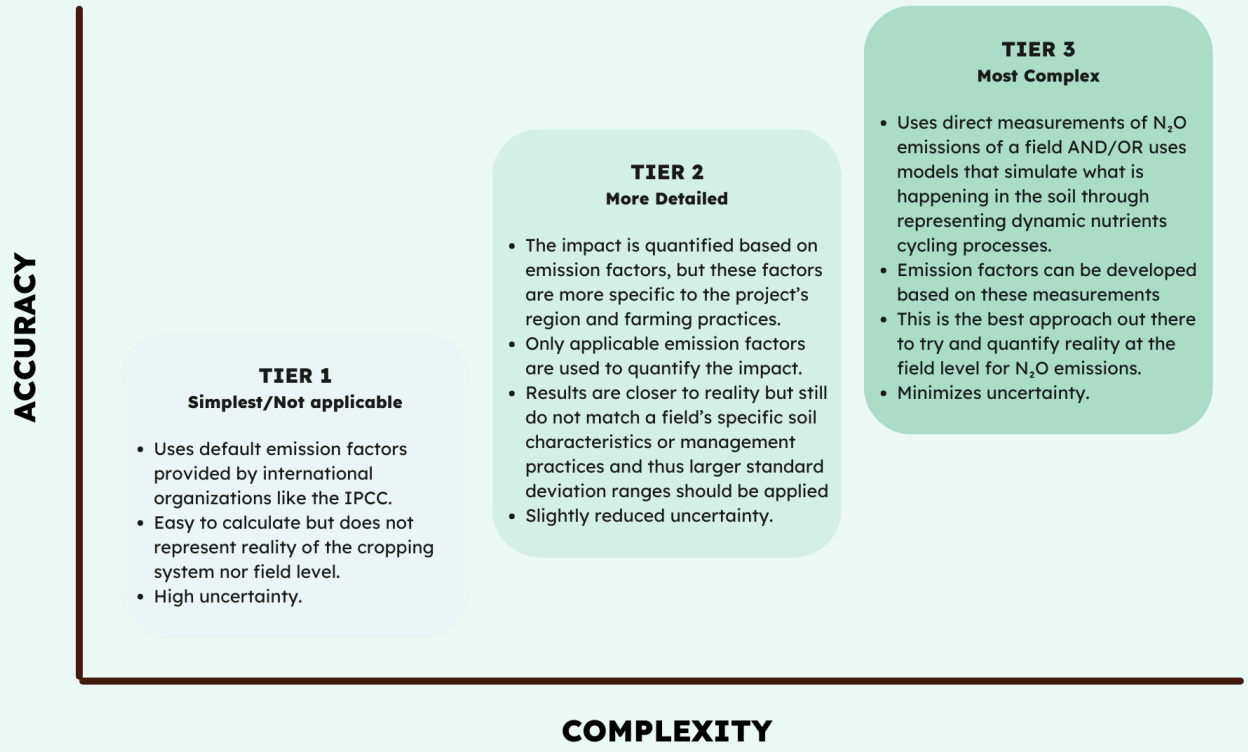
Appendix A: Emission factor description and usability

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 refinement tables). **Tier 1 is only applicable** in this methodology for estimating direct and indirect N_2O emissions in cases where **no project-specific or region-specific (Tier 2) data are available.**
- **Tier 2** EF can be derived from existing meta-analyses, systematic reviews, regional databases, scientific literature or the IFA-endorsed EF database (under development). This

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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[41] 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 type, soil moisture levels, 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.
- 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. In such cases, Tier 1 emission factors must be chosen based on the disaggregation options that are provided by IPCC and may be used to estimate the baseline emissions. For estimating the project's impact an emission reduction percentage which is derived from scientific literature or meta-analyses, or national EF inventory must be applied.

A.2 Emission factor selection criteria based on scientific studies

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

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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 most influential environmental variables should be prioritized, based on relevance (for instance as identified in the study of Fan et. al., (2022) "*Global evaluation of inhibitor impacts on ammonia and nitrous oxide emissions from agricultural soils: A meta-analysis*").
    - **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
    - If there is only partial alignment, project developers must adopt a conservative EF and document the rationale for its selection.
    - 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 as it is described in section 4.1 EF-data references approaches, 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

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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 and/or EF reduction %, 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. The use of the uncertainty ranges is described in Section 4.3. Uncertainty, where the methodology outlines how standard deviations or confidence intervals should be incorporated to ensure that emission reduction estimates remain credible and conservatively quantified, particularly when Tier 1 or Tier 2 data are used.

A.2.3 Quality criteria of 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:

- **Temporal coverage and measurement period:** Scientific studies often recommend a two-year temporal coverage 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. 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.

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- **Replication**: A minimum of three replicates per treatment is required (Abalos et al., 2014; Fan et al., 2022, Hutchings et al., 2024) 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 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 and equipment. 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 treatments groups) to ensure comparability. Differences in these conditions can misrepresent 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 (AI %)
    - Associated uncertainty ranges (e.g., standard error, standard deviation)
    - Environmental conditions (e.g., soil texture, rainfall, air and soil temperature, etc)
    - 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:

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- 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*.

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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.

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B.2 Uncertainty propagation of multi-source data

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

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

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

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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 8 the key metrics that can be applied are presented.

Table 8: 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

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	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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Appendix D: Different NUE metrics

Nitrogen Use Efficiency (NUE) is a crucial metric to evaluate how effectively nitrogen (N) inputs are converted into agricultural outputs. It plays a key role in both productivity and environmental sustainability, and forms a critical part of assessing the baseline conditions, potential leakage, and intervention effects in nitrogen stabilizer projects. While numerous definitions of NUE exist, this methodology adopts a practical approach by recognizing a core set of indicators, which can be used individually or in combination, depending on data availability and project context. These metrics have been adapted from the definitions and framework proposed by the Sustainable Plant Nutrition Responsible Practices Network (SPRPN) in their 2024 issue brief "Defining Nutrient Use Efficiency in Responsible Plant Nutrition[42]

NUE indicator	*Description*	*Calculation*	*Unit*	*Practicality*
Partial Factor Productivity (PFP)	Yield of crop harvested per unit of fertilizer nitrogen applied.	$PFP = Y/N$ Where: $Y = reported\ crop\ yield$ $N = N\ application\ rate$	kg crop/kg N	[Must be measured and must be reported in every project] Highly practical, easy to calculate from standard or reported crop yield and N rate application data.
NUE based on Outputs/Inputs (NUEpb)	Ratio of total N output (harvested) to total N input. Indicates system-level nitrogen use	$NUEpb = R/(N + M + B + D)$ Where: $R = Total\ nitrogen\ removed\ in\ harvested\ crop\ biomass$ $N = N\ application\ rate$ $M = N\ from\ manure\ or\ organic\ amendments$	Fraction or %	Comprehensive but data-intensive. It is related to a more detailed analysis at research or institutional level.

[42] https://qvg.yiu.mybluehost.me/wp-content/uploads/2023/08/SPRPN-Issue-Brief-Defining-Nutrient-Use-Efficiency.pdf

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	efficiency.	$B = N\ from\ biological\ fixation$ $D = Atmospheric\ deposition\ of\ reactive\ nitrogen$		
N Balance (NUEfg)	Difference between N inputs and N outputs. Indicates potential for environmental losses.	$NUEfg = U/(N + M + B + D)$ Where: $U = N\ uptake\ in\ crops$ $N = N\ application\ rate$ $M = N\ from\ manure\ or\ organic\ amendments$ $B = N\ from\ biological\ fixation$ $D = Atmospheric\ deposition\ of\ reactive\ nitrogen$	kg N/ha	Requires full N input/output accounting. It is challenging for most farmers but useful for environmental assessments.
Agronomic Efficiency (AE)	Increase in crop yield per unit of N applied compared to untreated control. Reflects crop gain efficiency from fertilizer.	$AE = (Y - Yo)/N$ Where: $Y = reported\ crop\ yield$ $Yo = crop\ yield\ from\ unfertilized\ plot$ $N = N\ application\ rate$	kg crop/kg N	Less practical, it requires untreated control plots, which may be hard to implement widely.
Recovery Efficiency (RE)	Proportion of applied N that is taken up by the crop. Indicates the effectiveness of N uptake.	$RE = (U - Uo)/N$ Where: $Uo = N\ uptake\ in\ crop\ from\ unfertilized\ plot$ $U = N\ uptake\ in\ crop\ from\ fertilized\ plot$ $N = N\ application\ rate$	Fraction or %	Less practical, it requires plant N uptake data or lab analysis and control plots, which may be hard to implement widely.

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