Avoided Emissions *in the Agriculture & Food Sector*

World Business Council *for Sustainable Development*

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Executive Summary

Establishing the need for sectoral guidance

In 2025, we published our updated *Guidance on Avoided Emissions* to help businesses in making credible, consistent and transparent avoided emissions (AE) assessments and claims, and to incorporate AE into their decision-making.
AE are defined as “the estimated difference in full life cycle greenhouse gas (GHG) emissions that results from a scenario with a solution in place, compared to a reference scenario without the solution. When the solution scenario emissions are lower than the reference scenario emissions, emissions have been avoided.” AE are a key part of our efforts in decarbonizing the planet, offering a way to accelerate decarbonization through the development of products and services. Companies that can reliably measure AE are better able to scale impactful climate solutions, leverage them for competitive and commercial advantage, and demonstrate how their innovations contribute to reducing (future) emissions compared to most likely alternative solutions.

Recognizing that different industries face unique methodological choices when applying AE methodologies, we work with our member companies to develop complementary, sector-specific guidance for the Agriculture & Food sector. This document therefore provides tailored methodologies to address sector- and solution-specific AE assessments, including defining accurate system boundaries, setting an appropriate timescale, choosing data, and developing representative reference scenarios. Our intention is to harmonize methodological approaches on solution-level, and to help companies address questions or issues that come up during an assessment.

Showcasing AE assessments through case studies

This document provides five illustrative case studies spanning the entire agriculture and food value chain. We chose these case studies through a multi-stakeholder process, based on solutions’ system-wide potential for AE, expertise among WBCSD member companies, technical maturity, data availability, and alignment with eligibility criteria. The inclusion or exclusion of a solution as a case study does not imply a general judgment on its relevance or decarbonizing potential as this is often context-specific. There are many valid, eligible, and high-potential solutions that are needed to transform the agriculture & food sector beyond the examples showcased in this guidance. The use cases help illustrate the key principles of AE assessment in practice and cover all key factors necessary for a thorough and credible evaluation.

The five case studies included are:

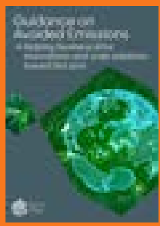
1. **Feed additive for livestock: Avoiding GHG emissions from dairy cows.**
2. **Crop input innovation: Bio-stimulants to increase crop yield.**
3. **Fertilizer use efficiency: Precision agriculture using variable rate technology (VRT).**
4. **Improved packaging system: Reducing food loss and waste at retail.**
5. **Diet shifts to plant-based products: Plant-based cream cheese.**

Each case study details the methodological approach to assess the AE of a specific solution in line with the WBCSD Guidance on Avoided Emissions, but all assessment goals, markets, and data are illustrative. The intention is to inform analysis of comparable solutions or solution groups in the sector, rather than prescribe a single approach.

Enabling companies to incorporate AE into their business

We intend this guidance for use by sustainability teams who will lead AE assessments, as well as managers in key business functions such as R&D, finance, sales and marketing, investor relations, and communications with the aim to harmonize methodologies and support companies in making AE claims that are transparent, consistent, and credible.

Ultimately, this document empowers companies in the agriculture and food sector to integrate AE thinking into strategy, product development, and disclosure practices, strengthening their contribution to global decarbonization and aligning business objectives with broader climate goals.



How to use this guidance document

Agrifood companies should use this document alongside the WBCSD Guidance on Avoided Emissions, which provides a detailed framework and step-by-step methodology to assess, disclose, and leverage AE, applicable across all sectors.

Introduction

01.

01. Introduction

Assessing and reporting AE supports global decarbonization efforts. It does this by quantifying how products and services reduce GHG emissions, demonstrating the business case, and communicating value to customers. It also gives companies a holistic view and a consistent basis for tracking performance, making decisions, and achieving mitigation goals.

Climate mitigation is especially relevant in the Agriculture & Food sector. Food systems are responsible for 18-20 Gt CO_2 eq. of GHG emissions annually, roughly one-third of total anthropogenic emissions.[1] There are many opportunities for AE solutions across the agrifood value chain, such as the development of new technologies like precision agriculture and new products like alternative proteins. Agrifood AE solutions may also span sectoral boundaries, such as the upcycling of agriculture and food products into feedstocks for other industries (e.g., bio-fuels and bio-materials).

Assessing AE can be complex, and conclusions can differ based on key assumptions, data quality and methodological approaches. AE assessments risk being meaningless if not developed using methods that are consistent across stakeholders and across solutions within the same company.

To address this, the WBCSD Guidance on Avoided Emissions provides a framework for companies in all sectors to assess and communicate AE in a consistent and robust manner.[2]

However, given the breadth of potential solutions and distinct methodological challenges, there is a need for guidance tailored to specific sectors. We have therefore designed this Guidance to complement the WBCSD Guidance on Avoided Emissions, by offering case studies (see Section 5) that take a step-by-step approach to AE assessment in the Agriculture & Food sector.

Figure 1 shows where there is potential for emissions reduction in the agrifood sector. The case study solutions in Section 5 correspond to these areas and illustrate where assessing AE can help solution providers demonstrate their contribution to systemic emissions reductions compared to a baseline.This also supports the identification of solutions that may be the most effective in delivering required reductions across the value chain.

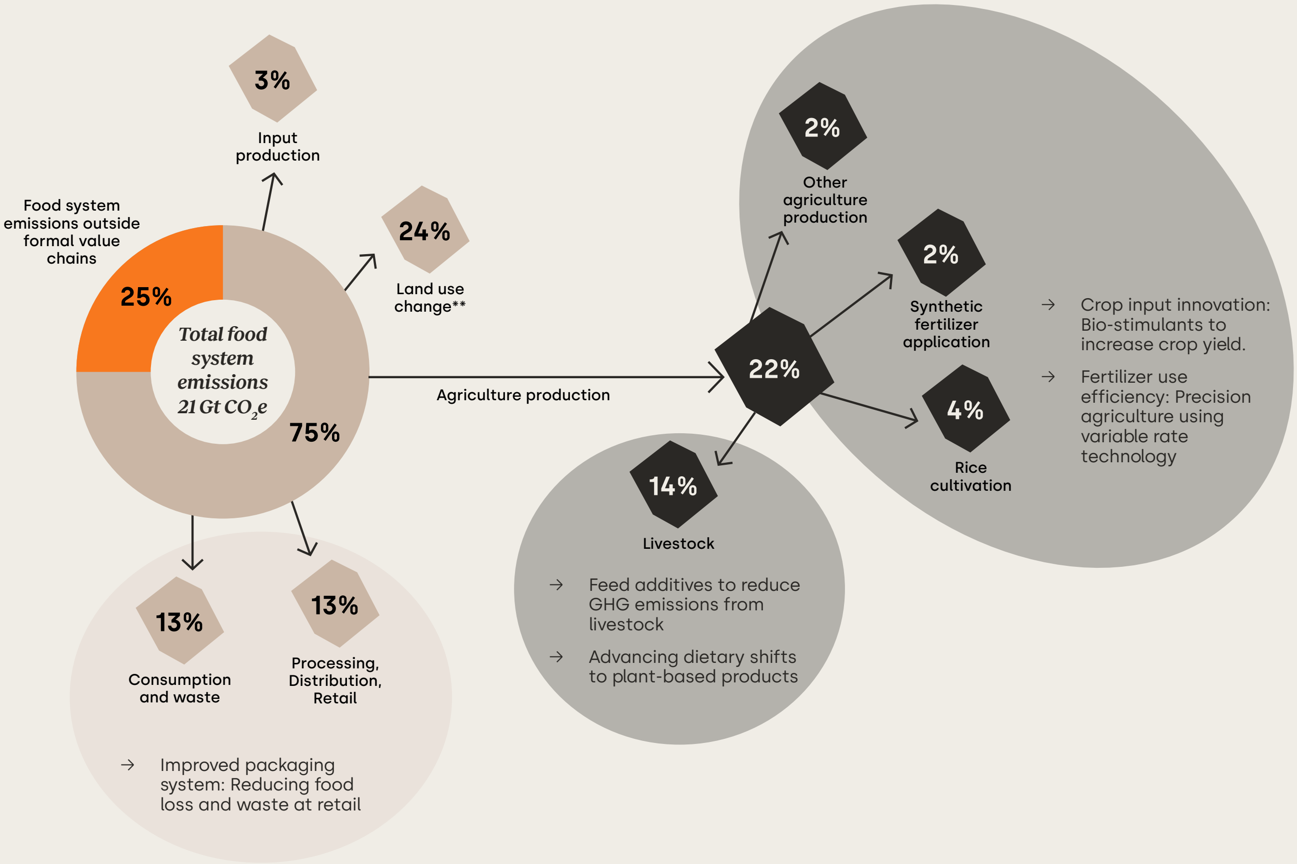
In Section 2, we define and scope AE solutions and determine eligibility for reporting AE. In Section 3, we share information on the assessment process. Section 4 provides insights into assessing rebound effects, negative side effects and co-benefits, while Section 5 presents a series of in-depth case studies including step-by-step guidance for AE assessment and reporting. Section 6 describes how AE assessments can be leveraged for competitiveness and in corporate decision-making. All sections focus on relevant content for the Agriculture & Food sector in particular.

Use cases selection and inclusion:

Use cases were selected based on their system-wide potential for avoided emissions, maturity, relevance to stakeholders, data availability for modeling, applicability across the value chain, and alignment with WBCSD's AE eligibility criteria. Topics like regeneration, circularity, rebound & side effects have been considered in the implementation context (see Section 4 and 5), even if they where not core factors in the methodological approach and decision-making.

Note that the inclusion, exclusion, or order of the case studies does not imply endorsement or reflect any assessment of its relevance or potential to support decarbonization. Many other credible, eligible, and impactful solutions exist beyond those highlighted in this guidance.

Figure 1: Emissions from agriculture and food (estimates for 2030) and select solutions featured in use cases in this guidance



→ Case-Study Solutions in the Guidance

*Note that the solutions are shown here in the value chain stages where most of the avoided emissions occur. Also, the circle sizes do not indicate the relative contribution of individual components to the carbon emissions.

**Land use change emissions refer to the release of carbon dioxide and methane from carbon stored in forest and peat lands etc. into the atmosphere as a result of the conversion of crop lands to produce animal feed or food for direct human consumption.

Source: Total emissions and percentage breakouts, reflecting estimates for 2030, are from Figure 1 of FOLU (2024)

Avoided emissions solutions *and claim eligibility*

02.

02. Defining and scoping avoided emissions solutions *and validating claim eligibility*

2.1. Definition and scoping of avoided emissions solutions

All AE assessments should begin with an assessment of the scope of the solution as outlined in the *WBCSD Guidance on Avoided Emissions*. This involves defining the goal of the assessment, the type of solution (end-use solution or intermediary solution) and the solution system to be evaluated, including the functional unit, system boundary, and reference scenario. We recommend reading Section 2.3 of the WBCSD Guidance on Avoided Emissions before reading the following section of this document.

An important distinction during the defining and scoping phase is between end-use solutions and intermediary solutions.

- → **End-use solutions** are products and services consumed by the end user in their current form, without further processing, transformation or inclusion in another solution. In the agrifood sector, this typically includes, for example, plant-based products and feed additive for livestock.
- → **Intermediary solutions** are inputs in the production of other products or services that require further processing, transformation or inclusion in another solution before use by the end user. In the agrifood sector, this includes technologies and agronomic knowledge to optimize nitrogen management in the field, for example.

All case studies included in Section 5 are end-use solutions. However, it is not uncommon that food products can be considered both an end-use solution, and an intermediary solution. For example, a plant-based cream cheese (as shown in Case Study 5) can be consumed in its current form by the consumer (end-use), but can also be an ingredient in other end-use products such as a plant-based pudding (intermediary solution).

See Section 3.3 of this document for guidance on how to define the functional unit, system boundary, and reference scenario in an agrifood context.

2.2 Assessment of solution eligibility

There are three eligibility criteria (or "gates") that any climate solution should meet before a company calculates AE (see Section 3 of the WBCSD Guidance on Avoided Emissions for a detailed overview).

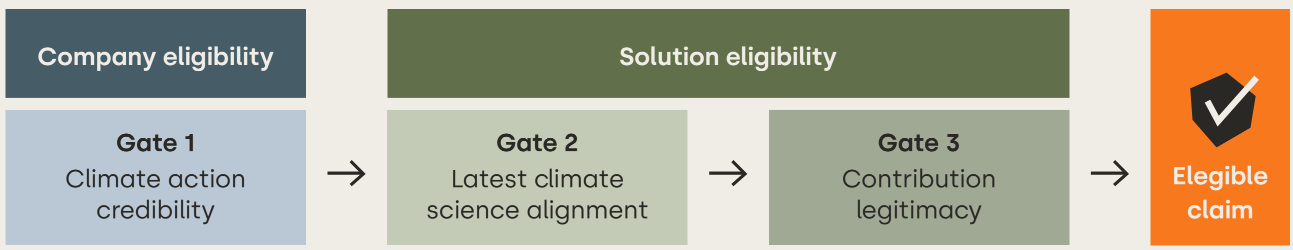
2.2.1 Gate 1: Climate action credibility

The Gate 1 requirements ensure companies claiming AE are assessing and verifying their GHG emissions inventory, and practice regular monitoring and reporting. Full requirements for monitoring, target setting, and reporting can vary depending on the age and size of the company (see Section 3.1 of the WBCSD Guidance on Avoided Emissions).

In the agrifood sector, target-setting, transition plans, and reporting on Scope 3 emissions can be especially challenging. Allocating GHG emissions across multiple supply chains for farm inputs and products is complex, even when data are available on farmers' use of nutrient management, cover cropping, precision agriculture, or other practices.[3]

Where applicable, agrifood business should follow sector-specific guidance to calculate emissions, in addition to the Corporate Accounting and Reporting Standard and Corporate Value Chain (Scope 3) Standard. Sector specific guidance should include (but is not limited to) the GHG Protocol Agriculture Guidance and the GHG Protocol Land Sector and Removals Guidance (currently in revision, anticipated Q4 2025 release).

Figure 2: Eligibility gates for AE assessments



For target setting in line with the latest climate science, relevant sector-specific guidance may include the Science Based Targets Initiative (SBTi) Forest, Land and Agriculture (FLAG) Guidance or SBTi's planned Chemicals Sector Guidance (when considering chemical inputs, such as fertilizers).[4]

For climate transition plans and reporting, agrifood companies should consult the Transition Plan Taskforce (TPT) Food & Beverage Sector Guidance and the WBCSD Guide to Transition Planning for Food, Agriculture, and Forest Products.[5]

2.2.2 Gate 2: Latest climate science alignment

To pass Gate 2, the solution must have mitigation potential according to the latest climate science and recognized sources. Fossil-derived efficiency solutions are not excluded by default, but additional requirements apply (see Section 3.2 of the WBCSD Guidance on Avoided Emissions). See Section 3.2.1 of the WBCSD Guidance on Avoided Emissions for recognized sources. Businesses in the Agriculture & Food sector should refer in particular to the EU Taxonomy and the IPCC Sixth Assessment Report (AR6), especially Chapter 7 of the IPCC AR6 Working Group 3 Report, which describes mitigation opportunities within agriculture, forestry, and other land-uses sectors. Another recognized source is Project Drawdown.[6]

Companies with solutions relying on fossil-based inputs must justify their use, increase impact monitoring and traceability, and explain how fossil lock-in will be avoided as part of a transition plan or public report (see Section 5.2.2 of the WBCSD Guidance on Avoided Emissions for more details). If no scalable low-emission alternative exists, such claims may still be eligible. However, we strongly encourage using renewable and biological feedstocks and/or renewable energy for production, to avoid carbon lock-in associated with intensification of agricultural production and the food value chain.

2.2.3 Gate 3: Contribution legitimacy

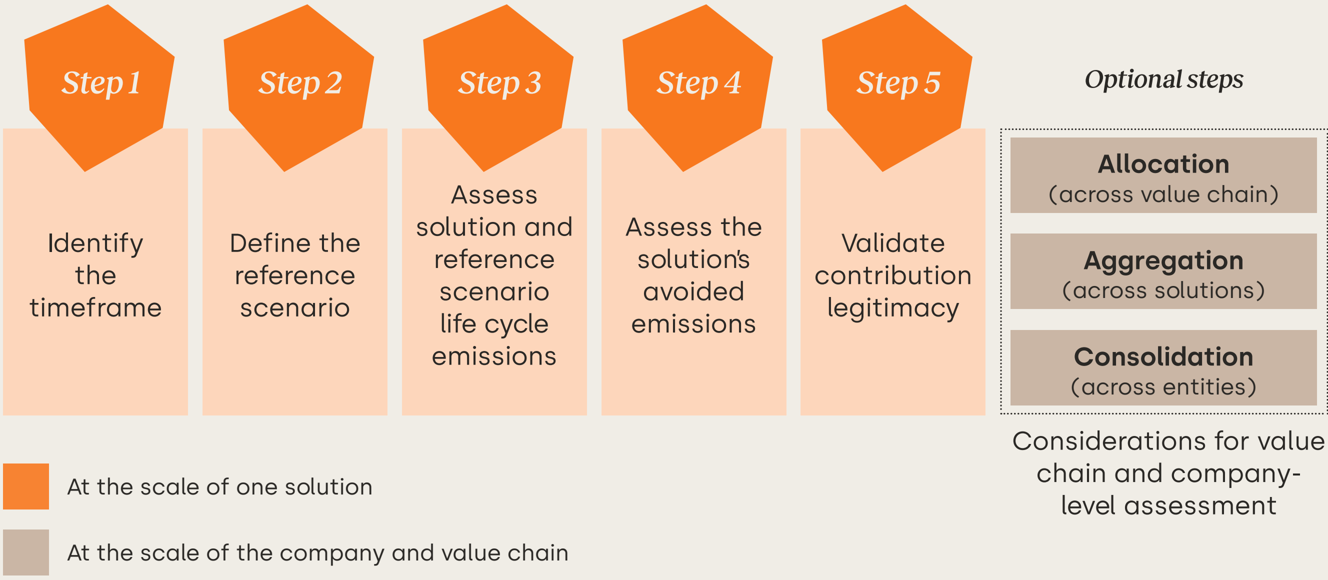
To pass Gate 3, the solution must achieve measurable GHG emissions reductions compared to a reference scenario and these reductions must be significant ("significant decarbonization impact") and demonstrably attributable to the solution ("substantiated impact"), as described in Section 3.3 of the WBCSD Guidance on Avoided Emissions. The case studies in Section 5 of this document provide examples of how to assess contribution legitimacy in an agrifood context.

Assessing *avoided emissions*

03.

For a detailed breakdown of the process for assessing AE, including full methodological requirements, refer to Section 4 of the WBCSD Guidance on Avoided Emissions. The information below is intended as supplementary guidance specific to the Agriculture & Food sector.

Figure 3: The five-step approach to calculating AE



3.1. Step 1: Identify the timeframe of the AE assessment

Many solutions in this sector have a useful life of one year or less, therefore a year-on-year timeframe is the most appropriate for assessment. Where the lifetime of the solution exceeds one year, choose a timeframe in line with the considerations indicated in the WBCSD Guidance on Avoided Emissions.

3.2 Step 2: Define the reference scenario

Choosing the reference scenario and the functional unit (FU) for comparison may not be straightforward where solutions replace or improve existing products but have different attributes or performance characteristics, or where the solution impacts multiple functions or co-products in different ways (see Case Study 1b and Case Study 5).

Factors that affect agricultural systems also vary significantly by location and climate. It is therefore essential that the reference scenario should consistently reflect the same conditions as the solution scenario (see Section 3.3.).

3.3 Step 3: Assess the life cycle emissions of the solution and the reference scenario

3.3.1 Definition of scope and system boundaries

We recommend including all life cycle stages and processes that contribute to the GHG emissions of the solution or reference scenarios. This is important, as it can provide further insights into the main drivers of GHG emissions and help to contextualize the magnitude of the AE. This is particularly relevant when assessing AE on an intensity basis, such as in cases of yield increases from agricultural systems (see Case Studies 1b, 2 and 3 in Section 5). In such cases, only a complete life cycle assessment can accurately reflect changes in emissions intensity.

Within an assessed life cycle stage there may be minor contributors to the total GHG emissions, such as R&D activities. These can be excluded using cut-off rules, as long as they are transparently reported and deemed immaterial. Product category rules (PCRs) that are applicable to the AE assessment can provide relevant rules.

Sometimes, processes are present in the solution but absent from the reference scenario. Where this is the case, companies should use cut-off criteria to assess whether these represent a potentially significant additional source of GHG emissions. They should evaluate the AE impact of any exclusions and show that they are immaterial relative to total AE (see Table 20 in Case Study 3).

The case studies in Section 5 provide examples of determining scope and system boundaries for agricultural inputs as well as post-farm-gate solutions.

3.3.2. Functional unit

The FU is a measure that defines the function a solution fulfils, making it possible to compare the solution to a reference scenario. It is defined by:

- Product outputs from the system (e.g., mass of crop, packaged unit of food, etc.).
- Performance characteristics of the system product outputs (e.g., nutrient content of food, or other physical properties that determine their function).

The FU must be the same for the solution and reference scenarios to ensure functional equivalence and consistency.

Agriculture and food systems may have multiple functions or performance characteristics. For example, livestock farms can provide multiple products (e.g., milk, meat), and foods provide multiple nutrients (e.g., protein, energy, fiber) representing specific performance characteristics. To maintain consistency and support a transparent analysis, companies should clearly define the performance characteristics of the FU (e.g., moisture content for arable crops, nutrient content of foods), especially where the choice of solution could impact these. The solution must provide at least the same function(s) as the reference scenario. If the solution does not have an equivalent function, there are two options:

- Drawing the system boundary to create equivalence – for example, including additional processes and products in either the solution or reference scenario (also known as system expansion).
- Scaling the amount of system product outputs and associated inputs in the reference scenario to achieve the same function as the solution scenario.

Bear in mind that an AE assessment looks at the change in GHG emissions within the system boundary as a result of the solution, rather than establishing the GHG emissions of a specific product. In some cases, a solution may change the amount or type of products produced, or change the performance characteristics of a process or product outputs. In these cases, consider using system expansion (i.e., extending of the boundaries of the system under investigation to include additional processes and functions). Doing so means that only a single FU need be considered, as shown in Case Study 1b. Alternatively, multiple FUs may be considered, for example where a solution changes the output of all co-products (e.g. feed additive that reduce GHG emissions from cows that produce both meat and dairy).

Where a solution provides an alternative to an existing product (like plant-based cream cheese as an alternative to dairy cream cheese in Case Study 5) it will likely have different performance characteristics, such as nutrient content. If the performance characteristics are very similar and consumers view the products as direct substitutes, it is reasonable to assume a 1:1 replacement. But if there are significant differences in performance characteristics – despite consumers seeing them as substitutes – it may be necessary to adjust how much of the amount of reference scenario product is considered equal to the solution. These adjustments, or scaling factors, can be based on consumer behavior surveys or on physical comparisons, such as fat, energy, or protein content. Whether they use a 1:1 or a proportional scaling factor, companies should justify this choice and investigate the impact of these differences using sensitivity analysis and considering rebound effects (see Case Study 5).

If the solution is an agricultural input or a service that helps produce agricultural or food products, the FU is usually the mass or volume of output of the same product (e.g., one kilogram of hard red winter wheat). This is the standard FU for intermediary solutions as it allows flexibility when assessing end-use solutions. If the solution improves production efficiency or reduces food loss and waste while still producing the same product, the FU would be the mass or volume of the product.

The choice of FU depends on the goal of the assessment and the product's place in the value chain. For example, in Case Study 4, we assessed AE from the reduction of food waste per kilogram of beef sold, rather than per kilogram of beef produced. Companies may choose other FUs, as long as they can show that the comparison between the solution and reference scenarios is relevant and consistent.

3.3.3. Attributional and consequential approaches

Section 4.2.3 of the WBCSD Guidance on Avoided Emissions describes the attributional and consequential approaches. Companies can adopt either or both approaches, and they should state the reasoning behind the choice in their AE assessment.

If a solution increases supply, for example an increase in crop yield (see Case Study 2 and 3 in Section 5) or other outputs (see Case Study 1b), a consequential approach may be required to aggregate AE at a company level (see Section 3.6). This is because an increase in yield or output that reduces GHG emissions per unit of output may not actively avoid emissions in the cultivated area where the solution is in use. For instance, in Case Study 2, a bio-stimulant increases carrot crop yields but all other inputs are unchanged – resulting in no reduction in GHG emissions per hectare cultivated. There is likely to be a benefit from the increase in yield, but it is unclear what the most likely alternative would have been. The growth in output may displace production of the same or different crops elsewhere, prevent the conversion of forest into cropland (see Section 3.3.4), or have no market and therefore create a waste product.

3.3.4 GHG emissions from land use and land use change (LUC)

The Agriculture & Food sector is closely connected to land use. This means that GHG emissions from either direct land use change (dLUC) or indirect land use change (iLUC) are likely to be relevant. Where a solution may either induce or avoid dLUC or iLUC, companies should use the assessment methods outlined in the forthcoming GHG Protocol Land Sector and Removals Guidance.[7]

Note that, although the agrifood sector's provision of carbon sinks is important for global decarbonization efforts, AE assessments do not include carbon sequestration or removals (refer to WBCSD Guidance on Avoided Emissions for more information). Any overlaps in claims or assessments should be addressed separately and communicated with transparency.

3.3.5 Data principles and sources for calculating AE

See Section 4.2.3 of the WBCSD Guidance on Avoided Emissions for a summary of general data types, sources, collection, quality, and management. The below is supplementary information specific to the Agriculture & Food sector.

Data types and data gaps

The main data types identified in the WBCSD Guidance on Avoided Emissions are primary data and secondary data, with primary data taking priority whenever possible. Sources for primary data include utility meters, invoices, bills of materials, crop production records, field records of crop operations or livestock movements, and nutrient management plans. To fill data gaps, it may be necessary to use modeled or calculated data based on secondary data sources.[8]

Potential sources of secondary data are PCRs (see Table 1), other published secondary sources (e.g., product life cycle assessments, life cycle inventory [LCI] databases, field trials), or from modeling approaches. The UN Food and Agriculture Organization Livestock Environmental Assessment Performance (LEAP) Partnership Guidance outlines how to address data gaps and select proxy data.[9]

Table 1 provides non-exhaustive guidance on relevant PCR sources for the agrifood sector. These are the most relevant sources at the time of publication of this Guidance; we advise consulting the most up to date PCRs at the time of calculation.

Table 1: Example sources of PCRs

Guidance	*Product categories / life cycle stages*	*Additional comments*
UN Food and Agriculture Organization (FAO) and Livestock Environmental Assessment and Performance Partnership (LEAP, 2016 - 2020)	Field crops (cradle to farm gate), animal feed and feed additives (cradle to grave), livestock – large ruminants, small ruminants, pigs and poultry (cradle to trader).	Globally applicable.
International Dairy Federation (IDF, 2015)	Dairy (cradle to retail).	Global focus but developed from data for intensive systems in developed countries (e.g., OECD).
PCRs managed by International Environmental Product Declaration (EPD) System[10]	Food and beverage products (cradle to grave), including arable and vegetable crops, meat from poultry, fish and fish products.	Overarching food and beverage PCR was released on July 2025
Product environmental footprint (EC, 2021) and PCRs[11]	General guidance covers all products (cradle to grave) with specific PCRs under revision (feed for food producing animals, dairy products, beer, and pasta).	General guidance draws on LEAP and IDF for agricultural products.

Variability in crop production cycles

In any year, crop cultivation is dependent on temperature, rainfall, humidity, pest prevalence, and other factors. This can result in significant variation between production cycles in yields and inputs, even if some key inputs (e.g., fertilizers) remain the same.

Year to year variations in inputs and yields make it difficult to compare a solution to a reference scenario in a limited geographic area, because any emissions differences between the two scenarios may not be isolated to the solution itself. To address this, data should represent a long enough time-period for an average assessment of inputs and outputs that accounts for seasonal differences and other variations.

The UN FAO LEAP Partnership Guidance recommends that the data used should cover a three-year rolling average for annual and perennial crops.[12] Where this is too difficult, the guidance states that shorter time periods may be used. Other approaches can include:

- → Gathering data from a wider geographic area for similar farms growing the same crop, to assess an area average.[13]
- → Using field trials to measure the benefit of the solution compared to a reference point.
- → Using empirical models to assess a counterfactual yield under the same growing conditions but without the solution.

Field trial data

Field trials provide important data on the efficacy of new products or processes related to crop cultivation and livestock. Companies can use this data to evaluate changes in input and output when it is not possible to consistently measure outside a controlled setting. The European and Mediterranean Plant Protection Organization (EPPO) provides further guidance on standards for field trials.[14] Instructions for assessing field trial data and the efficacy of GHG mitigation technologies are under development for the dairy sector[15] and for nitrogen stabilizers.[16]

When using field trial data to estimate AE, it is important to prioritize high-quality and context-relevant sources. The FAO recommends using peer-reviewed publications in reputable journals. A single study provides only limited substantiation; a more suitable level of evidence is at least three independent studies.[17] Be sure to carefully evaluate the quality, design, and limitations of all field trials.

To ensure robust and appropriate use of field trial data, it is necessary to:

- → Select a representative value for GHG emissions calculations, typically an average or a value derived from a function of the parameter assessed, accounting for outliers and data quality.

- Recognize the inherent uncertainty when applying field trial results to different contexts. To minimize this:
  - Use trials involving the same crop or animal type.
  - Only use data from trials conducted under similar climates, management practices, and conditions, spanning multiple locations and years.
  - Clearly report the conditions of the original field trial (e.g., climate, location, management) and specify any extrapolations or deviations in your application.

Due to the limitations associated with field trial applications, companies should always use conservative values when estimating AE. These limitations may include:

- **Publication bias**: Published field trials are more likely to represent positive and statistically significant results.
- **Site-specific outcomes**: Results often reflect the unique conditions of the trial site, including soil, weather, and management practice at the time the field trial was undertaken.
- **Non-representative application**: The way tested products are used in the field trial (e.g., input amounts) may not reflect how the average customer uses them.

Modeling

In the agriculture and food sector, modeling is often used to assess complex natural processes that are difficult to measure directly (e.g. enteric methane from ruminants, manure management emissions, decomposition of crop residues or fertilizers in soil).

The IPCC provides widely used methodologies for such assessments, structured into three tiers of increasing complexity and data specificity:[18] Tier 1 relies on default emission factors, Tier 2 incorporates country-specific data, and Tier 3 uses advanced, often localized models. Tier 1 and 2 approaches are commonly embedded in farm- and field-level tools that offer consistency for GHG assessments and may be used in avoided emissions evaluations.[19] However, these tools often lack flexibility to modify inputs or modeling assumptions, which can limit their ability to align with the specific scope and system boundaries of an AE assessment. Tier 3 approaches allow for more detailed, context-specific modeling—such as field-level or sub-national assessments—but require rigorous validation to ensure accuracy and representativeness.

Secondary data

Companies can access secondary data through published life cycle inventory (LCI) databases (see Table 2). These offer a source of emission factors data that can fill data gaps in foreground data (see Section 3.3.5.1). Other sources of secondary data include peer-reviewed LCAs or EPDs, industry association and government reports, and emission factor databases.

Selected secondary data should, as far as possible, align with the methodologies used (e.g., allocation method, cut-off levels), as well as the technology and geography it is representing. Companies should assess the data quality and prioritize the highest quality data.

Table 2: Example secondary data sources

Name	*Type*	*Geographies represented*	*Source / current versions*
AgriBalyse	LCI database	France	https://doc.agribalyse.fr/documentation-en
Agri-footprint	LCI database	Global	https://blonksustainability.nl/tools-and-databases/agri-footprint
ecoinvent	LCI database	Global	https://ecoinvent.org/
Global Feed LCA Institute (GFLI)	LCI database	Global	https://globalfeedlca.org/gfli-database/
Sphera	LCI database	Global	https://lcadatabase.sphera.com/
United States Department of Agriculture (USDA) LCA Commons	Database	USA	https://www.lcacommons.gov/
World Food LCA database	LCI database	Global	https://quantis.com/who-we-guide/our-impact/sustainability-initiatives/wfldb-food/

Data quality and uncertainty

High quality emissions data can be difficult to collect in the agrifood sector, because factors such as climate and location create significant data variability, and emissions from complex biological and chemical interactions in plant and animal systems can be difficult to measure or model accurately. Section 4.2.3 of the WBCSD Guidance on Avoided Emissions provides an overview of good practice recommendations for data quality assessment and management.

Data quality and uncertainties can have a major influence on the calculated AE. Companies should therefore communicate a quantitative estimate or qualitative description of the uncertainty of the results, listing key assumptions and limitations for both solution and reference scenarios (see Section 5 for examples of qualitative descriptions).

3.4 Step 4: Assess AE

AE are assessed by calculating the difference in emissions between the reference scenario and the solution, taking the solution's entire life cycle into consideration, as defined in the FU.

AE (kg CO_2 eq.) = reference scenario (kg CO_2 eq.) – solution scenario (kg CO_2 eq.)

In most cases, it is necessary to multiply the GHG emissions per FU (e.g., one kilogram of milk) in each scenario by the total production considered.

However, in some situations the solution leads to an increase in yield (e.g., kilogram of crop per hectare or kilogram of milk per cow). In these cases, whilst the AE can be assessed as an intensity (i.e., the avoided emissions per unit of output), there may not be a reduction in absolute GHG emissions between the solution and reference scenarios. This is shown in Case Study 2 in Section 5, where a bio-stimulant increases the yield of carrots but all other inputs remain the same. There are no avoided GHG emissions for one hectare of production (as there has been no reduction in inputs); but the additional yield results in a decreased intensity of GHG emissions per tonne of carrots. Absolute AE could occur if the farmer were to cultivate a smaller area to produce the same amount of crop as would be produced under the reference scenario, but this would not be a typical response by the farmer looking to maximize yield or profit from their land.

Another consideration is that the additional yield produced by the solution could displace production with a higher GHG emission intensity elsewhere, or prevent the conversion of forest into cropland. However, there is often significant uncertainty about the extent to which the additional yield will displace existing production (e.g., how demand for output may change as a result of the solution). A consequential LCA or hybrid consequential approaches (i.e., assessment of market mediated effects) could assess this, but uncertainty about the effects on production in other locations will remain. The case studies in Section 5 therefore focus on using attributional approaches to illustrate the general methodology and highlight relevant issues.

Often agricultural processes produce multiple products (co-products), such as milk and meat in some dairy farms, as described in Case Study 1b. It may be necessary to allocate GHG emissions between these co-products. If the solution changes the output (yield) of any of the co-products then all co-products should be considered in the AE calculation, not just the product that is the main focus of the assessment. This is because the change in yield can change the allocation of the GHG emissions between co-products.

3.5 Step 5: Validate contribution legitimacy

Using the results from Step 4, a company should (re-)confirm Gate 3 eligibility for its solution by quantitatively validating the contribution legitimacy, as described in Section 4.2.5 of the WBCSD Guidance on Avoided Emissions.

3.6 Considerations for value chain and company level assessments (optional)

AE at the company-level are the aggregate of all solutions provided by the company. Section 4.3 of the WBCSD Guidance on Avoided Emissions outlines archetype conditions for when companies can aggregate separate end-use solutions and intermediary solutions. It also addresses good practice approaches for value chain allocation and entity consolidation of AE.

Rebound and *side effects*

04.

04. Rebound and *side effects*

4.1. Rebound effects

Rebound effects are defined as "the increased use of a solution as a consequence of its lower GHG emissions impact, which partly or fully cancels out the initial emissions savings intended by the solution". For instance when a farmer switches from synthetic fertilizers to organic fertilizers and, in the process, chooses to apply more organic fertilizers in a way that increases nitrous oxide emissions. Other examples in the Agriculture & food sector include:

→ Additional consumption of a solution or alternative products compared to the reference scenario due to characteristics that are lacking in the solution (see Case Study 5).

→ Unintended consequences from the enhanced efficiency or efficacy of a solution. For instance, an improved seed variety that increases farming profitability could lead to more land being used for farming, causing deforestation. Mitigations could include advocating for public policy that favors land and resource use planning, conservation incentives, or regulations to prevent adverse environmental impacts.

Companies should describe any potential rebound effects and actions undertaken to mitigate them. Consequential LCA or aspects of the consequential LCA approach may be useful in these assessments, as this takes into account the effects of increased production and changes in price or demand. However, the consequential LCA approach may require assumptions about biophysical factors, supply and demand, or other aspects, depending on the specific setting and solution.

4.2. Co-benefits and negative side effects

Companies should assess and disclose any additional environmental side effects or co-benefits of the solution and describe actions to mitigate negative impacts. They may use an environmental LCA or other methods for economic and social assessment.

The Agriculture & Food sector is closely linked to land use, so key areas for assessing negative side effects and co-benefits include water scarcity/stewardship and biodiversity. Useful assessment methodologies and tools include the WRI Aqueduct tool for water risks and the WWF water and biodiversity risk filter tools.[20, 21] Any relevant impacts of food changes on human health are also particularly relevant to monitor and disclose.

Case *studies*

05.

05. Case *studies*

The following case studies illustrate how the AE assessment can apply to specific solutions / solution groups in the Agriculture & Food sector.

All markets, and data calculations presented in these case studies are purely illustrative. For each assessments, assumptions were made about the claimant's goals (e.g. annual ESG reporting, R&D/innovation strategy, investor engagement/ financing, go-to-market), the target market, and the solution's implementation—aiming to reflect the typical context practitioners face when conducting such evaluations. Users of this guidance can adapt these approaches to their own solutions by following the step-by-step process outlined in WBCSD's AE Guidance.

Note on case study use and interpretation

- → The inclusion, exclusion or order of solutions in these case studies does not imply endorsement or prioritization.
- → Although each case study focuses on a specific solution, goal and market, the underlying approach is applicable to a broader set of products or services, including those in other contexts and regions. See Table 3 for related examples.
- → All calculations are illustrative only, serving to demonstrate the application of the AE assessment framework.

Table 3: Summary of case studies, including other solutions where a similar assessment approach can be used (non-exhaustive)

Solution provider	*Solution user*	*Description - Impact compared to reference scenario*	*Other relevant solutions*
Case study - 1) Feed additive for livestock: Reducing GHG emissions from dairy cows			
Feed additive producer	Dairy farm operator	a. Methane reduction case: Feed additive leads to reduced enteric methane emission from cattle. b. Yield increase case: Feed additive increases milk yield.	→ Solutions related to livestock feed or meat production. → Solutions used in agricultural systems with multiple co-products.
Case study - 2) Crop input innovation: Bio-stimulant to increase crop yield			
Bio-stimulant producer	Farm operator	The bio-stimulant enables the plant to use other inputs more efficiently, resulting in a greater yield.	→ Farm input solutions (e.g., bio-based fertilizers or formulants, changing from petrochemical base to bio-based feedstock) → Solutions to improve the efficiency of inputs and increase crop yields.
Case study - 3) Fertilizer use efficiency: Precision agriculture using variable rate technology (VRT)			
Precision agriculture system provider	Farm operator	VRT precision agriculture optimizes nitrogen use efficiency by applying fertilizers at the right rate, time, and place based on field data, reducing emissions per tonne of crop produced.	→ Solutions to improve nitrogen use efficiency (e.g., slow-release fertilizers or nitrification / urease inhibitors). → Efficiency improvement technology on farms or other agricultural contexts.
Case study - 4) Improved packaging system: Reducing food loss and waste at retail			
Packaging producer	Food retailer	Packaging extends the product's shelf-life, reducing spoilage at the retail stage. This lowers GHG emissions associated with beef that may otherwise be discarded.	→ Food packaging. → Solutions which reduce or valorize waste. → Retail efficiency solutions.
Case study - 5) Diet shifts to plant-based products: Plant-based cream cheese			
Plant-based cream cheese producer	Consumer	A plant-based product reduces reliance on animal-based ingredients, and the substitution lowers GHG emissions by avoiding emissions from dairy production and land use.	→ Plant-based products where animal products are (fully or partially) displaced. → Food products with lower carbon footprint than likely alternatives.

5. 1 Case Study 1: Feed additive for livestock - Reducing GHG emissions from dairy cows

5.1.1 Solution scoping, eligibility, and first steps of the assessment

GHG emissions from livestock account for approximately 14% of the total for the food and agriculture sector, and are increasing with the affordability and consumption of meat and dairy globally.[22] The primary emissions from cattle result from enteric fermentation (methane), and manure management (methane and nitrous oxide).[23] Feed production and land use change are also significant contributors to the GHG emissions from livestock production.

Farmers have long used feed additives to optimize animals' health. More recently, scientists have developed feed additives that directly reduce GHG emissions. This case study assesses two examples of feed additives for dairy cows:

→ **The 'Methane Reduction case' (1a)**, in which feed additives (e.g., 3-nitrooxypropanol) reduce enteric methane emissions from the cows' digestive system.

→ The '**Yield Increase case' (1b)**, in which feed additives increase milk production in dairy cows by enhancing animal health and increasing the efficiency of feed conversion, such as the enzyme amylase and rumen protected amino acids. Also note that rumen-protected lysine, which enables amino acids to bypass the first stomach (rumen) and be absorbed in the small intestine, can provide additional benefits, including reductions in greenhouse gas (GHG) emissions, by improving protein utilization efficiency, such as reducing the amount of protein required in the feed and decreasing nitrogen excretion in manure.

Note: Rumen protected amino acids may also amplify enteric methane reduction when applied in combination with 3-nitrooxypropanol by optimizing microorganism composition in the rumen. However, we have not assessed these effects in this case study. Any synergistic effects identified are not additive, so data for the combined effects of different additives is always required unless the effects are clearly shown to be independent of each other.

This study focuses on dairy systems, however these systems may also produce meat. Therefore, assessing the product carbon footprint for milk may need to include allocation of total emissions between produced milk and meat (see Table 6).

Table 4 (Methane Reduction case) and Table 5 (Yield Increase case) outline the assessment approach and first steps for each case. Table 6 summarizes key data sources and assumptions.

Case Study 1a: Methane Reduction case

Table 4: Scoping and eligibility assessment - Case Study 1a

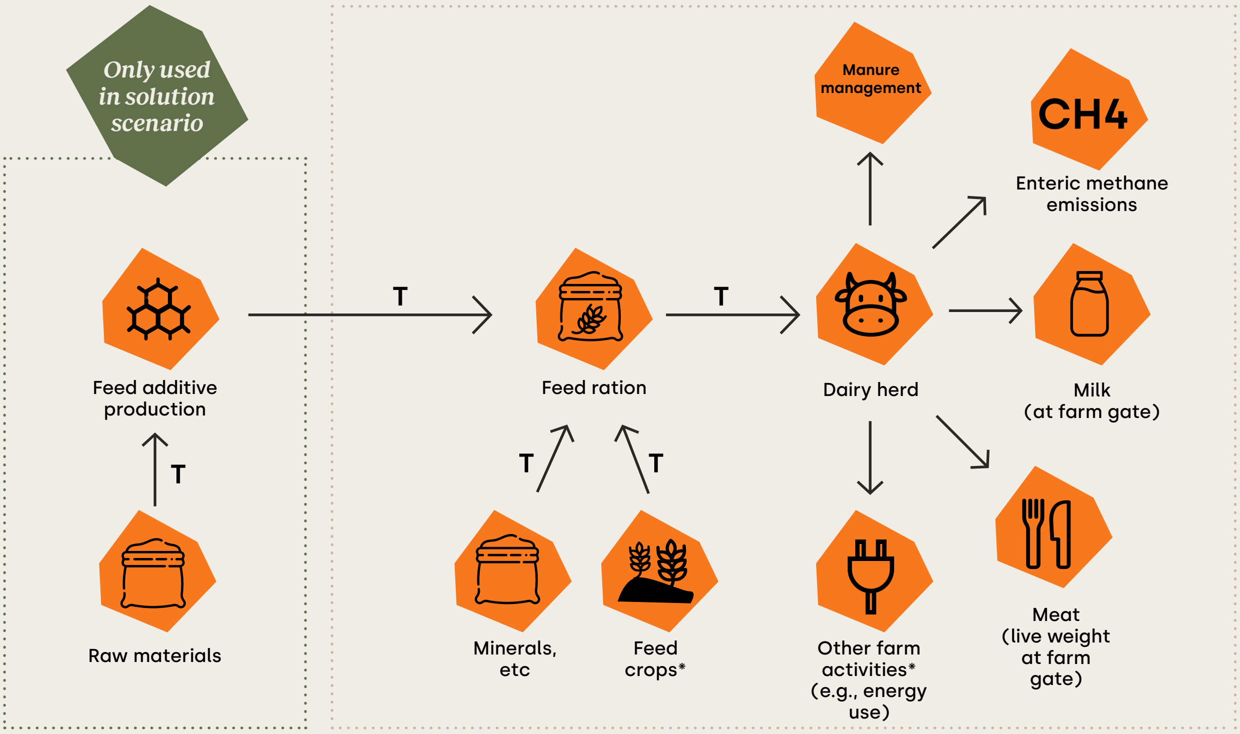
Criteria	*Description*
Feed additive (3-nitrooxypropanol) inhibits the process by which methane forms in a cows' digestive system when digesting feed and fibers, resulting in a reduction in methane emissions.	
Who is claiming the AE?	The feed additive supplier.
Type of solution	End-use solution: Cows consume the feed additive in its current form.
Market assessed	→ Housed dairy system market (farmers of dairy cows kept indoors all or most of the time). → US market (where significant numbers of dairy producers use similar technology). → Other markets could also be considered, where dairy producers use similar technology in a similar climate to the countries where field trials have been completed.
How is the solution implemented?	→ The additive is mixed in to the feed product before the feed is shipped to farms. → Farmers give the supplemented feed to housed dairy cows with mixed rations (required to achieve the reductions seen in field trials).
Functional unit	→ 1 kg fat-and-protein-corrected milk (FPCM).[24] → Correction for fat and protein content enables comparison between milk produced on different farms with different feeds.
System boundary	→ Cradle to farm gate (see Figure 4 below). → This does not consider downstream use of milk products (assumed same for solution and reference scenarios).
Reference scenario	The farm operates with cows consuming the same feed but without the feed additive. Reference scenario definition: → Existing demand – improvement: Use of the feed additives considered improves the current system by reducing enteric methane emissions. Could be considered a replacement If a different feed additive was previously used to provide a similar function. → Use of methane reducing feed additives is low and new to most farmers.
Timeframe	→ Year-on-year: The useful life of the product is less than one year; assessment is based on collected data.
Eligibility gates	
Gate 1: Climate action credibility	→ Yes (for the purposes of this illustrative case study, the hypothetical company fulfils Gate 1 criteria).
Gate 2: Latest climate science alignment	→ Reducing enteric methane emissions is included in the latest IPCC AR6 Working Group III Report.[25] → The solution is not directly involved in the extraction, production, or sale of fossil fuels.
Gate 3: Contribution legitimacy	→ Significant decarbonization: Yes. Peer-reviewed field studies and meta-analysis (based on field trials across a range of countries) have shown that a feed additive (3-nitrooxypropanol) can reduce average methane emissions in dairy cows by approximately 10-60%, with no evident effect on milk or meat production, animal health, feed intake, or manure emissions.[26] → Substantiated impact: Yes. Feed additive directly leads to reductions in methane emissions.

Case Study 1b: Yield Increase case

Table 5: Scoping and eligibility assessment - Case Study 1b

Criteria	*Description*
The feed additive is an amino acid balanced feed with rumen-protected lysine supplement, which increases overall protein intake and milk yields.	
Who is claiming the AE?	The feed additive supplier.
Type of solution	End-use solution: Cows consume the feed additive in its current form.
Market assessed	→ Housed dairy system market (farmers of dairy cows kept indoors all or most of the time). → US market (where significant numbers of dairy producers use similar technology). → Other markets could also be considered, where dairy producers use similar technology in a similar climate to the countries where field trials have been completed.
How is the solution implemented?	→ The additive is mixed in to the feed product before the feed is shipped to farms. → Farmers give the supplemented feed to housed dairy cows with mixed rations (required to achieve the reductions seen in field trials).
Functional unit	→ 1 kg fat-and-protein-corrected milk (FPCM) (see Table 4 for more details). → If the yield of milk and meat were both increased by the solution, then it may be necessary to assess two FUs (milk and meat) in order to accurately represent the system by allocating GHG emissions between co-products.
System boundary	→ Cradle to farm gate (see Figure 4 below). → This does not consider downstream use of milk products (assumed same for solution and reference scenarios)
Reference scenario	The farm operates with cows consuming the same feed but without the feed additive. Reference scenario definition: → Existing demand – improvement: Improves the current system by increasing milk yields. Could be considered a replacement If a different feed additive was previously used to provide a similar function → The farmer has reported that that they were not previously using the feed additive.
Timeframe	→ Year-on-year: The useful life of the product is less than one year; assessment is based on collected data.
Eligibility gates	
Gate 1: Climate action credibility	→ Yes (for the purposes of this illustrative case study, the hypothetical company fulfils Gate 1 criteria).
Gate 2: Latest climate science alignment	→ The latest IPCC AR6 Working Group III Report includes 'sustainable intensification' of agriculture (i.e., increasing yields without causing additional impacts)'.[27] → The solution is not directly involved in the extraction, production, or sale of fossil fuels.
Gate 3: Contribution legitimacy	→ Significant decarbonization: Yes. Multiple field studies conducted by the solution provider have shown that a feed additive can increase milk yields by up to 20%. → Substantiated impact: Yes. The feed additive directly leads to increases in milk yields by increasing the availability of protein from feed.

Figure 4: System boundary for solution and reference scenario - Case Study 1



* = Energy/ raw material inputs and waste included
T = Transport

Key impacts of the solution:		
Both cases	*Methane Reduction case*	*Yield Increase case*
↑ **Production of feed additive:** GHG emissions from production and transport of feed additive.	↓ **Decrease in methane emissions:** Feed additive reduces methane emissions by approx. 20%.	↓ Increase in milk yield: Decrease in feed input and direct emissions per kg milk produced thus lower the GHG emission intensity. However, this does not represent decrease in absolute GHG emissions unless the number of dairy cows is reduced or wider market effects are assessed.

Table 6: Key data and assumptions for assessment - Case Study 1

<table>
<tr><th>Life cycle stage / process</th><th>Reference scenario</th><th>Solution scenario</th></tr>
<tr><td colspan="3">Case Study 1a: Methane Reduction case</td></tr>
<tr><td>Feed additive production</td><td>N/A</td><td>→ Primary data on amount of feed additive used.
→ The feed additive cradle to gate system emissions incl. transport.[28]</td></tr>
<tr><td>Feed ration</td><td colspan="2">→ The amount and composition of the feed ration and the distance that feed is transported to farms.
→ Primary data for the amount and composition of feed rations is required, to calculate the enteric methane and manure management emissions.
→ Market average data on the source of feed components to evaluate GHG emissions, – unless supplier specific data are available.</td></tr>
<tr><td>Enteric methane emissions</td><td>Modeled based on feed ration amount and composition (to provide energy content and digestibility parameters) and dairy cows' characteristics (e.g., breed and location).[29]</td><td>Using primary and field trial data, and the same modelling approach as in the reference scenario. Including a parameter to scale enteric methane emissions to reduce by up to 20%. This is below the average reduction for dairy cows assessed in the region.[30]</td></tr>
<tr><td>Manure management</td><td colspan="2" rowspan="2">→ The solution's implementation does not affect manure management processes and other farm activities, thus primary data are not required (i.e. proxy data or assumptions may be used) or the stage may be excluded.
→ Assuming same values for the solution and reference scenarios.</td></tr>
<tr><td>Other farm activities (e.g., energy use)</td></tr>
<tr><td>Dairy herd</td><td colspan="2">→ Assuming same number and type of cows (i.e., only producing cows, not heifers) and same amount of milk produced in each scenario. The amount of milk is required to normalize results to the FU based on the average production for the herd size in the market.
→ We have excluded culled dairy cows and calves produced by dairy cows (sold for meat as co-products) from the assessment as the yield of milk or meat is not impacted by the feed additive, therefore all GHG emissions can be allocated to the milk. Though, note that the GHG emissions intensity for the AE calculation would not represent the product carbon footprint for milk production as assessed using the IDF guidance.[31]</td></tr>
<tr><td colspan="3">Case Study 1b: Yield Increase case
(the same data sources and assumptions apply as for Case Study 1a above, unless otherwise specified)</td></tr>
<tr><td>Feed ration</td><td colspan="2">→ Market average:
– Primary data on the amount and composition of feed (e.g., roughage, grains, protein) and transportation logistics (distance, method).
– Primary data for the feed amount (kg/head/day) and composition, comparing the reference scenario with the solution scenario. We established a profile using data for nutrient digestibility and feed efficiency.
– The source of feed components, to evaluate GHG emissions including direct land use change in value chain (where relevant).</td></tr>
<tr><td>Enteric methane emissions</td><td colspan="2">→ See Methane Reduction case.</td></tr>
<tr><td>Manure management</td><td>→ Average US market manure management methods and amounts from USDA statistics.
→ Modeled based on the feed ration amount and composition, and dairy cows' characteristics (e.g., breed and location) based on the market average.
→ IDF (2015) requires the use of at least a tier 2 IPCC calculation approach.</td><td>→ The same modeling approach and assumptions as the reference scenario.
→ It is likely that there is some reduction in the nitrogen content of manure due to the use of feed additive and increased milk yield. However, these changes are relatively small and the manure management route is uncertain (e.g., does a nitrogen reduction in manure require additional synthetic nitrogen fertilizer?). Bespoke tier 3 calculation method could be developed to calculate change in N2O emissions as a result of change, if robust data for the effect and disposal methods for manure are available
→ However, evidence for methane emissions reductions from field trials is limited. We have therefore assumed that methane emissions are the same in each scenario.</td></tr>
<tr><td>Milk yield</td><td>→ Market average value for milk yield for the average dairy farm.</td><td>→ Peer reviewed field trials have shown 5-20% increase in milk yield as a result of using the feed additive. We have assumed a 5% increase as a conservative assessment.</td></tr>
<tr><td>Meat yield</td><td colspan="2">→ Based on expected live weight for the average herd at a dairy farm.
→ Because meat output doesn't change, the impact allocated to meat needs to be removed by assuming the GHG impact for meat is the same in both scenarios.</td></tr>
</table>

5.1.2 Next steps: Assessing AE and validating significance

The following data calculations illustrate how to complete steps 4 and 5 in the WBCSD Guidance on Avoided Emissions.

AE assessment for Case Study 1a: Methane Reduction case

Table 7: Example data for calculation - Case Study 1a

Life cycle stage / process	*Unit*	*Reference scenario*	*Solution scenario*	*Comment*
Milk production	kg FPCM	100,000	100,000	
Feed additive	kg CO_2 eq.	0	165	Feed additive results in a small increase in production emissions.
Feed ration production	kg CO_2 eq.	18,000	18,000	
Raw materials transport	kg CO_2 eq.	900	935	A small increase due to the mass of the feed additive.
Dairy farm activities (energy)	kg CO_2 eq.	2,100	2,100	
Enteric methane emissions	kg CO_2 eq.	51,000	40,800	20% lower in the solution scenario (average)
Manure emissions (methane)	kg CO_2 eq.	27,000	27,000	
Manure emissions (N_2O)	kg CO_2 eq.	34,000	34,000	
Total GHG emissions (for life cycle stages shown in table)		**133,000**	**123,000**	
GHG emissions per kg milk (for life cycle stages shown in table)		**1.33**	**1.23**	
AE per kg of FPCM milk		**1.33 – 1.23 = 0.1 kg CO_2 eq.**		**7.5% lower GHG in the solution scenario.**

The calculations show that the GHG emissions in the solution scenario are 7.5% lower than in the reference scenario. This represents substantial AE, both as a percentage reduction and in the absolute decrease in emissions when used at scale. However, as the modeling is based on field trial data, there will be variability. This should be assessed through sensitivity analysis (see Table 10).

If life cycle stages and processes have been omitted, the company cannot claim AE as a percentage reduction. To do so requires calculation of the full set of life cycle stages and processes.

If absolute AE are to be reported for a market or aggregated for a company, the AE should be calculated as follows:

For 100,000 kg FPC milk = (100,000 x 1.33) – (100,000 x 1.23) = 10,000 kg CO_2 eq.

AE assessment for Case Study 1b: Yield Increase case

Table 8: Example data for calculation - Case Study 1b

Life cycle stage / process	*Unit*	*Reference scenario*	*Solution scenario*	*Comment*
Milk production	kg FPCM	100,000	105,000	There is a 5% higher milk yield in the solution scenario.
Meat (calves and cows sent for culling)	kg LW	2,000	2,000	
Feed additive	kg CO_2 eq.	0	315	The feed additive is only used in the solution scenario.
Feed ration production	kg CO_2 eq.	18,000	18,000	
Raw materials transport	kg CO_2 eq.	900	935	
Dairy farm activities (energy)	kg CO_2 eq.	2,100	2,100	
Enteric methane emissions	kg CO_2 eq.	51,000	51,000	
Manure emissions (methane)	kg CO_2 eq.	27,000	27,000	
Manure emissions (N_2O)	kg CO_2 eq.	34,000	34,000	
Total GHG emissions (for life cycle stages shown in table)		133,000	**133,350**	
GHG emissions per kg live weight animal for meat		**8.5[a]**	**8.5**	
GHG emissions per kg FPC milk		**1.16[a]**	**= (133,500 – (8.5 x 2,000[b]) / 105,000 = (133,500 – 17,000) / 105,000 = 1.11**	
AE per kg of FPCM milk		**1.16 – 1.11 = 0.05 kg CO_2 eq.**		**4.3% lower GHG emissions per kg milk in the solution scenario.**

Notes:

a: As the solution impacts more than one type of yield, it is necessary to consider the co-products in the emissions – in this case, milk and meat'. We have assumed GHG intensity for meat to be the same as in the reference scenario, and these emissions are deducted in order to compare only the GHG intensity of milk production.

Table 8 above shows example results for the AE calculations. The use of the feed additive leads to an increase in milk yield, which reduces the GHG emissions intensity to produce 1 kg of milk by 4.3%. However, this does not indicate a reduction in the dairy farm's absolute GHG emissions unless fewer cows produce the same output as the reference scenario. Also, as modeling of the effect is based on field trial data, there will be variability. This can be assessed through sensitivity analysis (see Table 10).

A consequential LCA or hybrid consequential approaches could give a more detailed assessment that takes into account the change in demand for milk due to the increased yield (i.e., an assessment of market mediated effects).

5.1.3 Identify rebound effects side effects

Most solutions will have an impact beyond that which was intended – both positive and negative. See Table 9 for a summary of these effects in relation to the Methane Reduction case and Yield Increase case.

Table 9: Rebound and side effects - Case Study 1

Type of effect	*Potential effect*	*Proposed mitigation / assessment methods*
For Case Study 1a (Methane Reduction case) and 1b (Yield Increase case)		
Rebound effects	→ Higher consumption of dairy products resulting in higher overall GHG emissions.	→ Conduct market research on customer preferences. If demand is unaffected, prioritize continued emission intensity reduction in production.
Rebound effects (yield increase case only)	→ Yield Increase case: Increased milk yield may lead to increased milk wastage with risk of oversupply.	→ More reliable yield forecasting and market research or fixed contracts for milk
Negative side effects	→ Farmer profitability may be reduced, e.g. in case of lack of adherence to feed protocol, volatility in downstream/milk prices, lack of response in targeted feedstock. → Increasing disincentivizing of smaller, non-industrual farms to compete on an environmental impact basis.	→ Compare the incremental net cost of the feed additive. → Pursue supportive public policy (e.g., subsidies for early adopters). → Identify if financiers or product buyers could provide financial support to reduce their Scope 3 GHG emissions. → Support farmers to apply the proper feed protocols to avoid the risk of profit loss.
Co-benefits	→ Additional farmer income through, e.g. achieving low-carbon premiums (1a or 1b) or allowing replacement of more expensive high-protein feed (e.g., soybean meal) with lower-cost feed by enhancing protein utilization efficiency (1b). → More conscious consumer choices due to promoted sustainability benefits.	→ Engage with farmers to support commercial uptake and ensure continued competitiveness

5.1.4 Uncertainty

We encourage companies to internally track and communicate quantitative estimates or qualitative descriptions of the uncertainty of the results, and list key assumptions and limitations. See Table 10 for key uncertainties relating to both the Methane Reduction case and Yield Increase case.

Table 10: Uncertainty assessment - Case Study 1

Life cycle stage / process	*Uncertainty*	*Potential assessment methods*
Field trial data (Methane Reduction case)	Field trial data showed there can be significant variability (10-60% reductions) in the effects.	→ Use (empiric) sensitivity analysis or Monte Carlo analysis incl. standard deviations from field trials to develop and transparently communicate range of results → Undertake additional ground truthing studies to verify and monitor the additive's effectiveness over time
Enteric emissions modeling	Enteric emissions calculations are based on modeled data (IPCC tier 2 country specific model), and there is uncertainty related to the input parameters required for modeling.	→ Use sensitivity analysis scenarios to assess the range of values for key parameters for modeling the emissions. → Assess impact using other models. → For greater accuracy, use more detailed modeling approaches (tier 3) specific to the relevant farm technology.
Manure emissions modeling	Manure emissions calculations are based on modeled data (IPCC tier 2 methods).	
Feed additive used at dose required	Estimated emissions reductions are based on the amount and type of feed sold. Actual feeding practices may vary (e.g., if farmers also use feed without the additive).	→ Conduct sensitivity analysis to quantify the impact of sub-optimal additive feeding. → Support farms and value chain partners in applying and tracking the additive at the correct rate.

5.2 Case Study 2: Crop input innovations - Bio-stimulant to increase crop yield

5.2.1 Solution scoping, eligibility, and first steps of the assessment

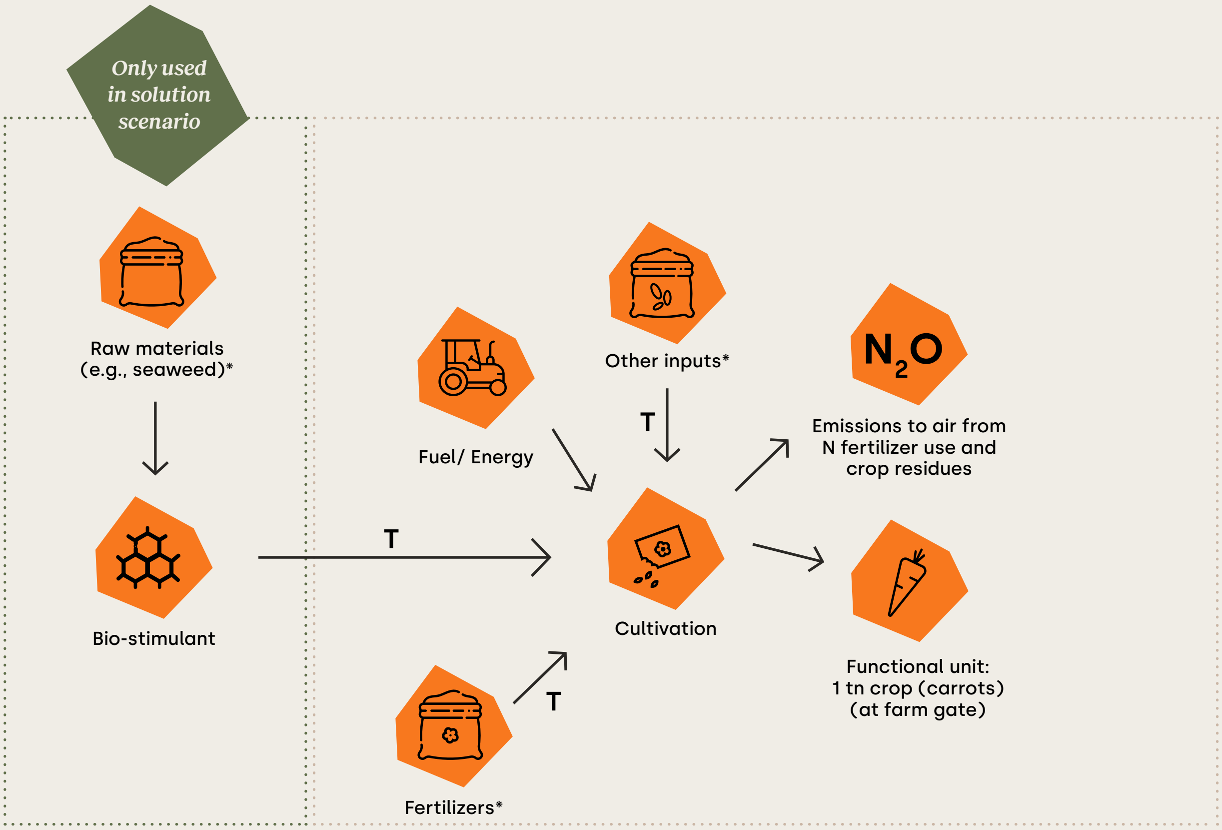
Decades of innovation in crop inputs (e.g., improved seed varieties, nutrients, crop protection products, water retention polymers) have improved productivity and enabled agricultural production in challenging environments.[32] This case study concerns the innovative crop input of bio-stimulants, which the European Commission defines as a "product stimulating plant nutrition processes independently of the product's nutrient content with the sole aim of improving one or more of the following characteristics of the plant or the plant rhizosphere: nutrient use efficiency, tolerance to abiotic stress, quality traits, or the availability of confined nutrients in soil or rhizosphere". Bio-stimulants which enable crops to more efficiently absorb nutrients can reduce the emissions from crop production per area of land. [33, 34]

Table 11 outlines the first steps of the assessment and Figure 5 illustrates the solution. Table 12 lists key data sources and assumptions.

Table 11: Scoping and eligibility assessment - Case Study 2

Criteria	*Description*
A bio-stimulant made from seaweed extract is applied to a vegetable crop (carrot). To achieve yield increases of 10-20%, as the crop is able to more efficiently absorb nutrients and water resulting in improved yield per unit area of land. This reduces the environmental footprint of crop production for a given yield.	
Who is claiming the AE?	The bio-stimulant producer.
Type of solution	End-use solution: Farmers use the bio-stimulant in its current form.
Market assessed	→ Conventional farms in Northern Poland
How is the solution implemented?	→ The non-microbial bio-stimulant is made from seaweed extract, and applied to carrot crops.
Functional unit	→ 1 tonne of carrots (88% moisture content). → Carrots produced in the solution and reference scenarios are assumed to be of the same quality and nutritional characteristics.
System boundary	→ Cradle to farm gate (see Figure 5). → Does not consider downstream use (assumed to be the same for the solution and reference scenario).
Reference scenario	Cultivation of carrots without using bio-stimulants. Reference scenario definition: → Existing demand – improvement: Bio-stimulant enhances nutrient use efficiency leading to increased yields and reductions in nutrient losses. If the farmer previously used a different bio-stimulant to provide a similar function, this could be considered a replacement. → The solution provider collects data from farm operators (location, amount purchased, intended use of products). Use of bio-stimulant products in the region is very low (<5%). → Solution required by regulation: No.
Timeframe	→ Year-on-year: The bio-stimulant's lifetime is less than one year – farmers apply it during the growing season of an annual crop.
Eligibility gates	
Gate 1: Climate action credibility	→ Yes (for the purposes of this illustrative case study, the hypothetical company fulfils Gate 1 criteria).
Gate 2: Latest climate science alignment	→ IPCC AR6 Working Group III Report includes 'sustainable intensification' (i.e., increasing crop yields without causing additional impacts) and 'nutrient management'.[50] → The solution is not directly involved in the extraction, production, or sale of fossil fuels.
Gate 3: Contribution legitimacy	→ Significant decarbonization: Yes. Peer-reviewed field trials in Poland have identified yield increases of 10-20%. The bio-stimulant can improve nutrient use efficiency, resulting in an improved yield per unit area of land. This reduces the environmental footprint of crop production for a given yield compared to the reference scenario. → Substantiated impact: Yes. Field trails have shown that the bio-stimulant can increase the nutrient use efficiency of the crop, resulting in increased yields.

Figure 5: System boundary for solution and reference scenario - Case Study 2



Market: Conventional farms in Northern Poland
AE claimant: Bio-stimulant producer (solution provider) USA

*= Energy/ raw material inputs and wastes included
T = Transport

Key impacts of the solution:	
Bio-stimulant:	***Increase in yield:***
↑ Production and transport increase GHG emissions.	↓ Whilst there is no change in the amount of other inputs per hectare, the increased yield results in a decrease in all inputs per kilogram of crop produced, thus lowering the GHG emission intensity of the crop.

Table 12: Key data and assumptions for assessment – Case study 2

Life cycle stage / process	*Reference scenario*	*Solution scenario*
Bio-stimulant	N/A	→ The amount of bio-stimulant recommended for this crop in this region. → Primary data on the bio-stimulant's cradle to gate emissions for the solution provider.
Synthetic fertilizers and manure	Secondary data on average fertilizer application rates for carrot production in Poland (from government reports and peer-reviewed studies).	Assuming the same rates as the reference scenario.
Other inputs (e.g., seeds and crop protection products)		
Fuel use (e.g., farm equipment)	Based on secondary data for assumed required field activities for each scenario.	
Transportation of inputs to farm	No additional inputs	Additional transport is required for the bio-stimulant. Transport distances for the other inputs are unchanged.
Direct N_2O emissions from fertilizer use	IPCC tier 2 approaches based on the type and amount of nitrogen fertilizers used.	
Crop residues (N_2O emissions)	Crop residues and their management assumed to be similar per kg of carrot crop produced.	
Net CO_2 emissions from changes in soil organic carbon (SOC)	No significant difference in changes of SOC and soil net CO_2 emissions. Field trials did not show net CO_2 emissions changes. These changes typically occur over longer periods. We have not considered the potential for increase in SOC, as this would represent carbon removals that are outside the scope of the AE assessment.	
Crop yield	Three-year average for carrot production in Poland (from government statistics).	10% yield increase assumed (peer-reviewed studies find a 10-20% yield increase).

5.2.2 Next steps: Assessing AE and validating significance

Table 13: Example data for calculation - Case Study 2

Process	*Unit*	*Reference scenario*	*Solution*	*Comment*
Bio-stimulant production	kg CO_2 eq.	-	35	Emissions are higher in the solution scenario as this is the only scenario in which the bio-stimulant is used.
Nitrogen fertilizer (inorganic)	kg CO_2 eq.	500	500	There is no difference in fertilizer use.
Phosphate fertilizer (inorganic)	kg CO_2 eq.	75	75	
Manure (0.6% N, 0.32% P_2O_5)	kg CO_2 eq.	0	0	There are no embodied GHG emissions, as manure is a residual by-product.
Crop protection products	kg CO_2 eq	165	165	
Raw materials transport [c]	kg CO_2 eq.	3	4	Emissions are higher in the solution scenario due to transport of the bio-stimulant.
Diesel	kg CO_2 eq.	435	450	Additional fuel is required in the solution scenario for applying the bio-stimulant and irrigation water.
N_2O emissions from fertilizer application	kg CO_2 eq.	850	850	
Carrot yield	tonnes	60	66	10% higher yield in the solution scenario.
Total GHG emissions per ha		**2,028**	**2,079**	
GHG emissions per tonne of carrots		**33.8**	**31.5**	
AE per tonne of carrots		**33.8 – 31.5 = 2.3 kg CO_2q. / tonne**		**6.8% lower emissions in the solution scenario.**

The use of the bio-stimulant increases the crop yield with the same inputs, reducing the GHG emissions intensity to produce one tonne of crop. However, the absolute GHG emissions per hectare of carrots produced remain the same, as the only change is the additional application of bio-stimulant.

The calculations show that the GHG emissions intensity in the solution scenario is 6.8% lower (2.3 kg CO_2 eq. per tonne of carrots) than in the reference scenario. This represents the potential for substantial AE. However, as the modeling is based on secondary data and field trial data, more detailed engagement with growers is required to provide robust assessment for public reporting. There is also variability within the field trial and production data used, which a sensitivity analysis could assess (see Table 15).

Increased crop yields have the potential to avoid GHG emissions in absolute terms by reducing the area cultivated, displacing production crops with higher GHG emissions, or reducing the need to expand cropland into forests, grasslands, or other land with high carbon storage (see Section 3.4). However, to assess and report these AE in absolute terms would require the use of suitable consequential LCA or hybrid consequential approaches.

5.2.3 Identify rebound effects, negative side effects, and co-benefits

Most solutions will have an impact beyond that which was intended – both positive and negative. See Table 14 for a summary of these effects in relation to the bio-stimulants application and how to mitigate them where needed.

Table 14: Rebound and side effects - Case Study 2

Type of effect	*Potential effect*	*Proposed mitigation / assessment methods*
Rebound effects	→ Yield increases may lower crop prices, which could increase demand and lead to cropland expansion into forests or other land types.	→ Conduct consequential analysis of market response. → Support regulatory levers to restrict expansion of croplands or find alternative sources
Negative side effects	→ Optimized yields from biostimulant use may lead (in practice) to farmers applying the product increasing water withdrawals for irrigation to support enhanced growth. → There is a risk of additional cost without additional yield if farmers do not apply bio-stimulants at the right dose or at the right time.	→ If indicated by LCA analysis, work with farmers to help implement water-efficient irrigation methods. → Engage with farmers to provide support and training on how to use the solution.
Co-benefits	→ Decreased nutrient runoff and improved local water quality. → Increased plant resilience to extreme weather events and environmental stress (e.g., drought and extreme heat).	→ Conduct controlled field trials to evaluate the environmental effects of the product. → Collect long-term data to measure the impact of extreme events when the solution is used compared to the reference scenario.

5.2.4 Uncertainty

We encourage companies to internally track and communicate quantitative estimates or qualitative descriptions of the uncertainty of the results, and list key assumptions and limitations. Table 15 outlines the uncertainties for this case study and potential methods to assess them.

Table 15: Uncertainty assessment - Case Study 2

Life cycle stage / process	*Uncertainty*	*Potential assessment methods*
Agricultural inputs and yields for average market	Significant variation across the region.	→ Conduct sensitivity analysis to assess how GHG emissions vary across the range of inputs and yields. → Create subsets of cultivation areas with inputs and yields matching their characteristics, to provide more granular assessment – supported by field trials organized in a similar way, if possible.
Multi-season management practices	Use of cover crops and crop rotations can affect the availability of nutrients for a crop in subsequent years.	→ Allocate GHG emissions from the implementation of different management practices using appropriate methods (see Section 11.2 of FAO 2016). → Complete a GHG emissions assessment every year across the management cycle (e.g., crop rotation) and compare the multi-year average of the solution to the reference scenario average.
Yield effect from field trials	The yield effect seen in field trials is not representative of all conditions, practices, and effects of the bio-stimulants across the region.	→ Conduct sensitivity analysis to consider a range of effect levels. → Increase the number of trials completed across a wider range of conditions, and apply findings on a stratified basis to reflect different conditions in the region assessed.
Field emissions (N_2O emissions from fertilizer use)	N_2O emissions calculations are based only on modeled data.	→ Conduct Monte Carlo or sensitivity analysis to assess the range of fertilizer inputs in the reference scenario. → Assess the impact of using other models or calculations for N_2O emissions.

5.3 Case Study 3: Fertilizer use efficiency - Precision agriculture using variable rate technology

5.3.1 Solution scoping, eligibility, and first steps of the assessment

The production and use of fertilizers are a major source of GHG emissions from agriculture. For instance, less than 50% of nitrogen applied to fields is absorbed by crops, with the remainder lost to the environment.[36] There is potential for nitrogen to be used more efficiently, which would make it possible to increase crop production to meet demand for food and other crops without significantly increasing GHG emissions. Research is ongoing to use crop residues and other waste products as feedstock for bio-plastics and bio-based chemicals, but this technology remains nascent and even when better developed, competition with primary crop output seems likely.

The best management practices for fertilizer application aim to match the nutrients supplied with the crop's requirements. This optimizes yields and farm profits, while minimizing nutrient losses to the environment. A science-based framework, commonly referred to as the 5 Rs (Right source, Right rate, Right time, Right place, Right water)[37] guides the efficient and effective management of fertilizer use in the field.

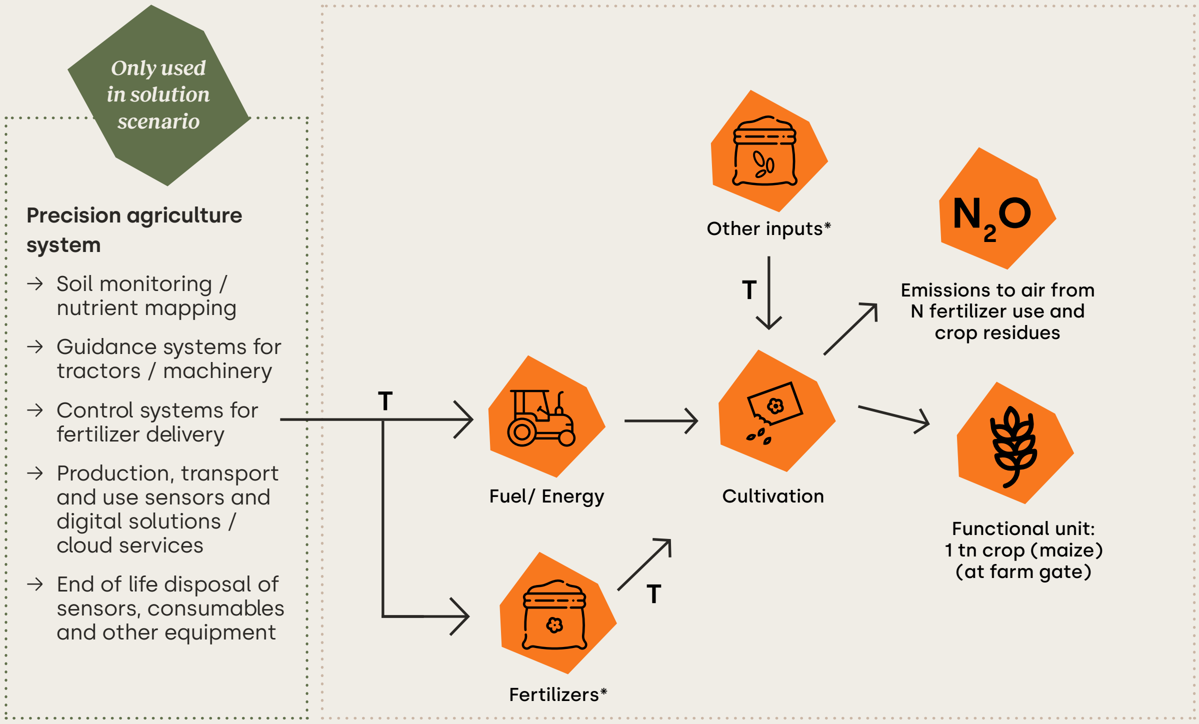
Precision agriculture (PA) is an integrated system using sensors, software, guidance systems, and reacting systems to optimize farm inputs and activities based on spatial and temporal variability. Variable rate technology (VRT) is a method within PA in which farmers apply fertilizer, crop protection products, and water at different rates across a field based on survey data of field conditions or prior yield. This increases the amount of fertilizer delivered at the Right rate, Right time and Right place and reduce losses from the field.

Table 16 and Figure 6 outline details of the solution and the first steps of the assessment. This example focuses on PA to improve nitrogen use efficiency, however the same principles are relevant to other solutions that improve nitrogen use efficiency and increase crop yields.

Table 16: Scoping and eligibility assessment - Case Study 3

Criteria	*Description*
VRT to improve nitrogen use efficiency during crop growth. By applying fertilizers at the right rate, time, and place based on field data, VRT makes it possible for the crop to use nutrients more efficiently. This improves yields while reducing excess fertilizer use, so that inputs and direct emissions are lower per tonne of crop produced.	
Who is claiming the AE?	The solution provider. The farm contracts the solution provider to guide fertilizer application and improve production, and the farm operator invests in the farm equipment required to implement the solution.
Type of solution	End-use solution: The VRT is used in its current form by the farmer. The system relies on various interdependent components from different suppliers.
Market assessed	Large scale farms producing maize in the state of Iowa, USA.
How is the solution implemented?	The solution provider collects field data to develop a prescription map for fertilizer application rates across different zones of the field: → Field/soil surveys and sensors on farm equipment provide data to inform soil and yield mapping. → Specialized software produces a map of yield potential in the field and prescribes the optimal inputs at fine spatial resolution. → A remote guidance system on the fertilizer spreaders determine the application rate based on the prescription map.
Functional unit	→ 1 tonne of maize crop produced. → Maize with 15% moisture content, assumed to have the same quality and nutritional characteristics in reference and solution scenarios.
System boundary	→ Cradle to farm gate (see Figure 6). → Does not include downstream use of the maize (assumed to be the same for both the solution and reference scenario).
Reference scenario	Maize is produced at the same farm where the solution was implemented, but without the PA system (situation before the solution was implemented). Reference scenario definition: → Existing demand – improvement: Improves yields and nitrogen use efficiency → Required by regulation: No. However, regulations for type, amount and timing of applications of nitrogen fertilizers or other farm inputs may be in place.
Timeframe	→ Year-on-year: Inputs and outputs are usually consumed and produced over a short time period (<1 year) and the assessment is based on recorded data for the solution.
Eligibility gates	
Gate 1: Climate action credibility	→ Yes (for the purposes of this illustrative case study, the hypothetical company fulfils Gate 1 criteria).
Gate 2: Latest climate science alignment	→ The latest IPCC AR6 Working Group III Report includes 'improved cropland management' and 'sustainable intensification'[38] → The solution is not directly involved in the extraction, production, or sale of fossil fuels.
Gate 3: Contribution legitimacy	→ Significant decarbonization: Yes. VRT has shown a 5-60% decrease in fertilizer usage, and up to 30% increase in yield through improved nitrogen use efficiency.[39] This can result in absolute reductions in N_2O emissions and reductions in GHG emissions per unit output. → Substantiated impact: Yes. The use of VRT is directly responsible for the change in fertilizer applications and any associated reductions in GHG emissions.

Figure 6: System boundary for solution and reference scenario – Case study 3



Market: Large scale intensive farm, Iowa, USA
AE claimant: PA system producer (solution provider) USA

*= Energy/ raw material inputs and wastes included
T = Transport

Key impacts of the solution:		
Operation of PA system:	***Decrease in fertilizer use:***	***Increase in yield:***
↑ Increase in emissions due to energy use and additional equipment.	↓ Reduction in fertilizer production and transport. Reduction in direct N_2O emissions.	↓ Increased yield leads to a decrease in all inputs per kilogram of crop produced. This lowers the GHG emission intensity of the crop.

Table 17: Key data and assumptions for assessment - Case Study 3

Process	*Reference scenario*	*Solution scenario*
Precision agriculture survey	N/A	→ Energy use for undertaking soil nutrient mapping. → Use of software, cloud-based services, manufacture of sensors, consumables, and other equipment with short lifetime (e.g., <3 years) to assess annualized GHG emissions based on estimated cost of equipment using Environmentally Extended Input-Output (EEIO) data. → This may require a scoping assessment. Exclusion may be justified based on the findings of previous similar assessments.
Synthetic and organic fertilizers	→ Three-year average fertilizer use for crop type from the same farm. → This assumes the type and source of fertilizers are the same in both scenarios.	Crop-specific primary data from the farm for the year assessed, ideally representing multiple years to account for variability.
Other inputs (e.g., seeds and crop protection products)	Amount same as in the solution scenario, because application rates are not affected by the VRT system.	
Fuel use (e.g., diesel for tractor / farm equipment)	Fuel use estimates for each farm activity (e.g., spraying) are calculated based on farm-specific data or, if this is unavailable, secondary data.	
Farm equipment (e.g., tractors)	Infrastructure is typically excluded from the assessment as annualized GHG emissions are typically de minimis (i.e., <1% of total GHG emissions).	
	N/A	If additional equipment used by the VRT system has a significant annualized impact, this should be included. This can be assessed using EEIO or other assessments.
Direct N_2O emissions from fertilizer use	→ N_2O emissions are calculated using IPCC tier 2 approaches based on the type and amount of fertilizer used. → If available and verified, use tier 3 models to assess the use of a specific fertilizer type in a specific region.	
Crop residues (N_2O emissions)	Assuming crop residues and management will be similar per kilogram of maize crop produced.	
Net CO_2 emissions from changes to SOC	We have assumed that there are no significant differences in changes of SOC and net CO_2 emissions from the soil as there is little evidence for immediate differences.	
Crop yield (maize)	Three-year average for crop type from the same farm.	Crop-specific primary data from the farm for the year assessed, ideally representing multiple years to account for variability.
PA equipment end of life	N/A	Disposal of sensors / consumables and other equipment with a short lifetime (e.g., <3 years) to assess annualized GHG emissions. This may require a scoping assessment, using EEIO or other assessments.

5.3.2 Next steps: Assessing AE and validating significance

Table 18: Example data for calculation - Case Study 3

Process	Unit	Reference scenario	Solution scenario	Comment
Sensors, software, and hardware for mapping	kg CO_2 eq.	-	3.1	Estimated based on annualized cost. Has only a small impact, relevant only to the solution scenario.
Nitrogen fertilizer (inorganic)	kg CO_2 eq.	578	561	2.9% lower in solution scenario.
Phosphate fertilizer (inorganic)	kg CO_2 eq.	69	69	
Manure (0.6% N, 0.32% P_2O_5)	kg CO_2 eq.	-	-	There are no embodied GHG emissions because manure is a residual by-product.
Pesticides	kg CO_2 eq.	40	40	
Raw materials transport	kg CO_2 eq.	7.0	6.9	
Diesel	kg CO_2 eq.	219	211	Lower in solution scenario due to efficiencies from guidance systems.
Electricity (farm use and mapping survey)	kg CO_2 eq.	70	84	Higher in solution scenario due to PA survey.
N_2O emissions from fertilizer application	kg CO_2 eq.	991	961	Lower in solution scenario because less fertilizer is used.
Maize yield	tonnes	10.5	11	4.8% higher yield in the solution scenario.
Total GHG emissions per ha		1,974	1,936	-
AE per ha		1,974 – 1,936 = 38 kg CO_2 eq. / ha		-
GHG emissions per tonne of maize		188	176	-
AE per tonne of maize		188 – 176 = 12 kg CO_2 eq. / tonne		**6.4% lower GHG emission intensity in the solution scenario**

The example calculation in Table 18 shows:

- Absolute AE of 38 kg CO_2 eq. / ha (1.9% decrease) in the solution scenario, due to a reduction in nitrogen fertilizers use.
- A decrease in GHG intensity of 12 kg CO_2 eq. / tonne (6.4% decrease), due to a reduction in nitrogen fertilizer use and an increase in yield.

The AE due to the reduction in fertilizer use are significant, because uniform application involves little variation in application rates between years, so application rates are unlikely to ever drop as low as those seen in the solution scenario. However, as noted in Section 3.3.5, there can be variation in crop yields over time due to changes in farm practices and external factors like weather and pests. Assessing the solution based on the average increase in yield across multiple years of applying the solution can provide greater confidence that the increase is a result of the solution and not other factors (see Table 20).

As outlined in Section 3.4, it is not possible to calculate absolute AE resulting from increased crop yields solely using attributional methods. Increases in crop yields have the potential to avoid GHG emissions in absolute terms by reducing the area cultivated, displacing the production crops with higher GHG emissions, or reducing the need to expand cropland into forests, grasslands, and other land with high carbon storage. However, to assess and report these AE in absolute terms requires suitable consequential LCA or hybrid consequential approaches.

That said, where the solution results in absolute AE (e.g., a reduction in fertilizer use per hectare) then a company may report absolute AE for a market or aggregated for the company. For example, if 100 hectares of maize is grown using the solution:

$$\textbf{Total AE (kg } CO_2 \textbf{ eq.) = 100 ha x 38 kg } CO_2 \textbf{ eq. / ha = 3,800 kg } CO_2 \textbf{ eq.}$$

5.3.3 Identify rebound effects, co-benefits, and negative side effects

Most solutions will have an impact beyond that which was intended – both positive and negative. See Table 19 for a summary of these effects related the VRT solution and how to mitigate them where needed.

Table 19: Rebound and side effects - Case Study 3

Type of effect	*Potential effect*	*Proposed mitigation*
Rebound effects	→ Yield increases may lower crop prices, potentially driving up demand (e.g., for bio-fuels) and leading to cropland expansion into forests or other land types. → A change in fertilizer use may reduce the residual availability of nutrients in the soil for subsequent crops. → The skills required to operate the system may be too much for a farmer to manage long-term, so efficiency gains may be lost while incurring additional emissions and operation costs.	→ Support policies to restrict the expansion of croplands and/or manage the production of bio-fuels and other new bio-based products (e.g., chemicals). → Conduct ongoing monitoring of fertilizer application rates and AE on fields where the VRT system is applied. The impact should diminish with continued monitoring and optimal nutrient application. The benefits of reduced emissions likely outweigh any negative impacts. → Ensure that farmers receive adequate training and offer ongoing support.
Negative side effects	→ The automation system could reduce the availability of jobs, particularly for lower skilled workers. → The increased yield may result in greater water requirements and loss through evapotranspiration.	→ Provide training opportunities in local communities to offer more highly skilled jobs – this could create co-benefits. → A PA approach can result in more efficient water use. Support water stewardship and management at catchment level.
Co-benefits	→ A reduction in nitrate run-off, reducing the risk of pollution and eutrophication of waterways. → Where farmers use irrigation, PA systems can also improve water use efficiency. → A reduction in inputs per unit of output can reduce costs and increase profits for farmers. However, this should be balanced against the initial and running costs of PA systems. → By identifying areas with lower yield potential there is the opportunity to focus cultivation on land with higher yield potential and use other land areas to support wildlife or carbon sequestration (e.g. trees).	

5.3.3.1 Uncertainty

We encourage companies to internally track and communicate quantitative estimates or qualitative descriptions of uncertainty of the results, and list key assumptions and limitations. Table 20 outlines the uncertainties for this case study and potential methods to assess them.

Table 20: Uncertainty assessment - Case Study 3

Life cycle stage / process	*Uncertainty*	*Potential assessment methods*
Maize yield for reference scenario	Factors like weather, pests, and diseases affect yields. The average yield in the reference scenario may be significantly different from the yield that would have been achieved under the same conditions as the solution scenario.	→ Conduct sensitivity analysis to assess how GHG emissions vary across the range of yields seen in previous years and in a year with similar conditions. → Use empirical models or other modeling approaches to establish what the reference scenario yield would have been under same conditions. → Complete a GHG emissions assessment every year and compare the multi-year solution average to the reference scenario average.
Multi-season management practices	Use of cover crops and crop rotations can affect the availability of nutrients for a crop in subsequent years.	→ Allocate GHG emissions from the implementation of management practices using appropriate methods (see Section 11.2 of FAO 2016). → Complete a GHG emissions assessment every year across the management cycle (e.g., crop rotation) and compare the multi-year average of the solution to the reference scenario average.
Field emissions: N_2O emissions from fertilizer use	N_2O emissions are the largest contributor to the GHG emissions in this context, and are based on modeled data (IPCC tier 2 country specific model).	→ Conduct Monte Carlo or sensitivity analysis to assess the range of fertilizer inputs in the reference scenario. → Assess the impact using other models to calculate N_2O emissions.

5.4 Case Study 4: Improved packaging system - Reducing food loss and waste at retail

5.4.1 Solution scoping, eligibility, and first steps of the assessment

According to the UN Food and Agriculture Organization (FAO), around one-third of all food produced is lost or wasted each year.[40, 41] Food loss and waste creates emissions from waste management (e.g., landfill methane) as well as embodied emissions from the wasted product – i.e., all emissions from the cultivation of a crop, and the processing, transportation and retail of the food product. It is possible to avoid food loss and waste emissions through prevention (e.g., use of fungicides, bio-based waxes, improved cold storage, and more efficient food processing systems) or by valorization of by-products and waste (e.g., soy okara and brewer's spent grain). Both mechanisms can provide benefits across the value chain.

Industry innovations like lightweight packaging, reuse of wholesale and consumer packaging, and shifting to bio-based alternatives, including bio-polymers can improve the carbon and material efficiency in the packaging industry.

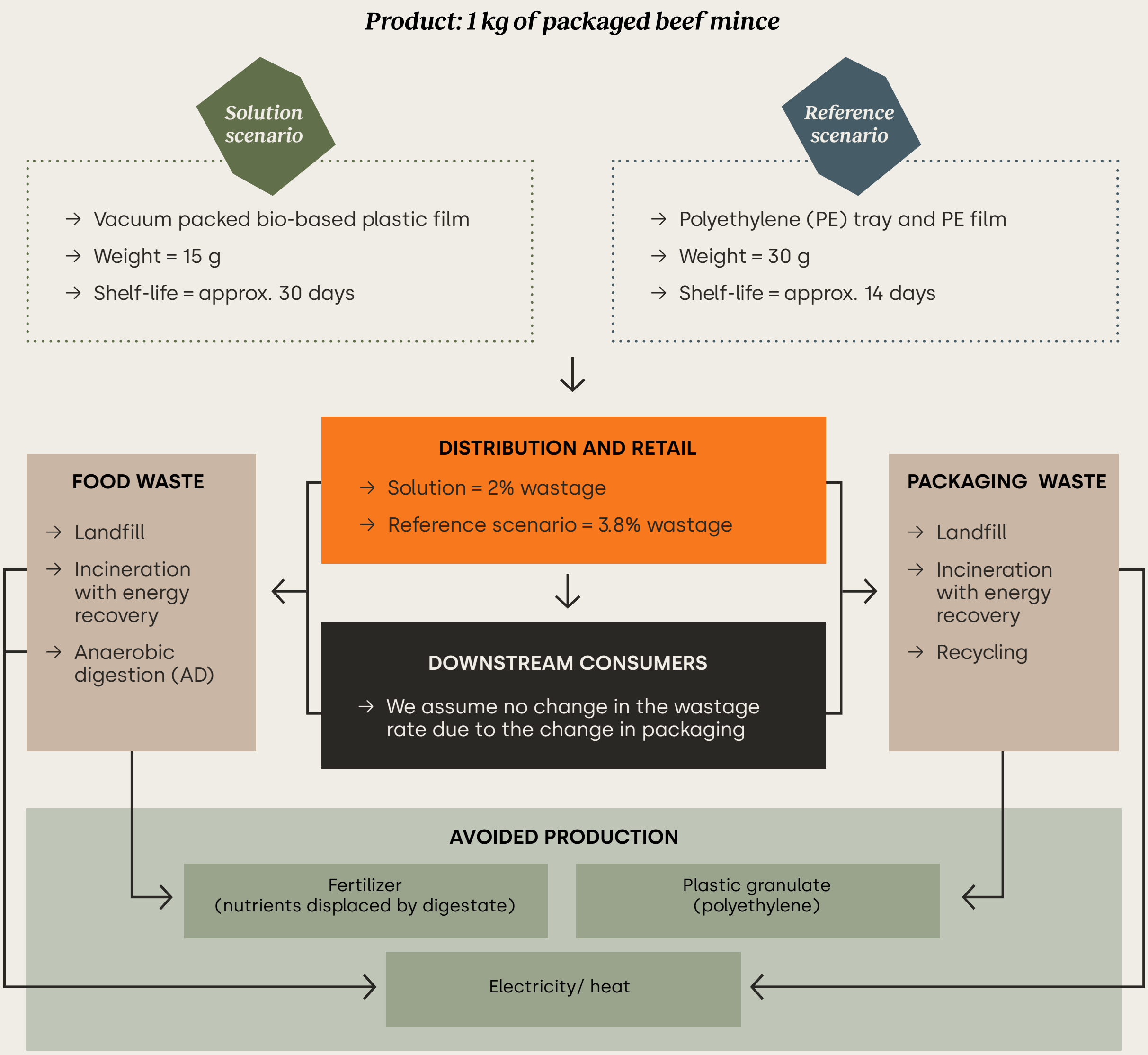
This case study focuses on a bio-based packaging solution that extends food's shelf-life to reduce spoilage. It is applicable to all sectors where food is sold (specifically, where it will be stored before sale/consumption). Improved packaging reduces GHG emissions from production and disposal of food waste, but a full analysis must incorporate potential additional impacts from production and disposal of the packaging itself.

Table 21 and Figure 7 outline details of the solution and the first steps of the assessment. Table 22 shows key data sources and assumptions for the assessment.

Table 21: Scoping and eligibility assessment - Case Study 4

Criteria	*Description*
Vacuum-packed bio-based plastic for packaging beef mince sold by retailers. The bio-based packaging extends the product's shelf-life from approximately 14 days to 30 days, when compared to existing polyethylene tray and film. This reduces spoilage at retail stage. Preventing food waste lowers GHG emissions associated with the production, processing, and distribution of beef that would otherwise be discarded.	
Who is claiming the AE?	The packaging producer.
Type of solution	End-use solution: The packaging solution does not require further processing.
Market assessed	The UK market.
How is the solution implemented?	→ Beef mince is packaged in a flexible bio-based plastic vacuum skin packaging. The plastic is a multi-layer biopolymer with ethylene-vinyl alcohol co-polymer (EVOH) layer, sustainably produced from biogenic feedstock. It is not biodegradable or recyclable. → The packaging weight is lower than plastic trays in film wrap and prolongs the beef's shelf-life by removing all oxygen from the product. This is because EVOH provides an effective gas barrier, compared to the current packaging format of a polyethylene (PE) tray and PE film cover. → Extending the beef's shelf-life reduces both loss (pre-consumer) and waste (household, foodservice, or other end users).
Functional unit	→ 1 kg of packaged beef mince consumed. → This accounts for additional products that must be produced to provide the function to the consumer. It does not include the mass of food waste from spoilage.
System boundary	→ Cradle to grave (see Figure 7). → Includes end of life disposal processes for food and packaging relevant to each scenario, including product waste at retail. However, we have excluded consumers' wastage (post-purchase) due to a lack of accurate data on how extended shelf-life affects consumer product wastage. → We have selected a closed-loop approach to assess the use of recycled material, recovery, and recycling of waste material. This allows more granular assessment of a key element of this example: changes to waste quantity and management (see Appendix 1 for other main methods). If the solution led to varying the use of recycled content in packaging, it would be more appropriate to use a hybrid approach between the 'closed-loop' and 'recycled content' approaches (e.g., '50/50 approach' or 'circular footprint formula').
Reference scenario	A polyethylene tray with polyethylene film. Reference scenario definition: → Existing demand – improvement: Replacement of the current packaging format improves the quality of the whole product, not just the packaging. → The solution provider collects data from retailers on existing packaging solutions for beef to develop assumptions for what the most likely alternative packaging would have been. → Required by regulation: No.
Timeframe	Year-on-year: The useful product lifetime is less than one year.
Eligibility gates	
Gate 1: Climate action credibility	→ Yes (for the purposes of this illustrative case study, the hypothetical company fulfils Gate 1 criteria).
Gate 2: Latest climate science alignment	→ The IPCC AR6 Working Group III Report includes 'reduction in food waste' and 'decarbonization of feedstocks' (e.g., replacing fossil fuels with a biological alternative)[42] → The solution is not directly involved in the extraction, production, or sale of fossil fuels.
Gate 3: Contribution legitimacy	→ Significant decarbonization: Yes. Food wastage in stores is a potentially significant contributor to GHG emissions from retail. The solution reduces the amount of food waste through increased shelf-life and potential to reduce GHG emissions from packaging disposal. → Substantiated impact: Yes. Product tests have shown that the vacuum packaging results in a longer shelf-life for beef mince, and this can help to avoid food waste.

Figure 7: System boundary for solution and reference scenario - Case Study 4



Key impacts of the solution:	
Decrease in product waste	***Use of bio-based polymer film***
↓ Less beef required (GHG emissions from beef production are the main driver of AE).	↓ Decrease in production emissions due to reduced weight of material required.
↓ Net decrease in emissions from waste management despite reduction in avoided products.	↓ No fossil carbon released during incineration, as the material is bio-based.
	↑ Difficult to recycle, unlike like PE tray used in reference scenario.

Table 22: Key data and assumptions for assessment - Case Study 4

<table>
<tr><th>Process</th><th>Reference scenario</th><th>Solution scenario</th></tr>
<tr><td colspan="3">Production</td></tr>
<tr><td>Beef mince production</td><td colspan="2">→ We have back-calculated the total mass required based on wastage rates.
→ We have used the country average impact factor, in the absence of more accurate data (e.g., retailers and their suppliers have completed an assessment).
→ Allocation between meat and other carcass co-products (e.g., based on economic allocation as described in Section 4.5.1.6 of EC PEF 2021).</td></tr>
<tr><td>Packaging production</td><td>Modeling is based on industry average secondary data relevant to the market (e.g., LCI databases for relevant geography) unless supplier specific GHG assessment is available.</td><td>Modeling is based on primary data from the solution provider, including an assessment of whether the feedstock for bio-plastic is from a sustainable source. This should include direct land use change if relevant for bio-based feedstock.</td></tr>
<tr><td colspan="3">Distribution and retail</td></tr>
<tr><td>Transport</td><td colspan="2">We have assumed transport distances and mode of transport are the same for both scenarios.</td></tr>
<tr><td>Storage</td><td colspan="2">Average days for storage in distribution and retail and energy requirements are based on information provided by retailers and / or standard market assumptions (e.g., PEF methodology[1] or other product category rules (PCRs)). We have assumed the same time in storage for both scenarios.</td></tr>
<tr><td>Wastage rate</td><td colspan="2">We have used data from retailers. Industry-wide surveys may also provide data if no specific retailer data are available. If retailer data are unavailable, then it could be modeled based on a change in shelf-life, if a suitable relationship can be established (e.g., linear relationship or regression analysis based on conservative assumptions).</td></tr>
<tr><td colspan="3">Downstream consumers</td></tr>
<tr><td>Storage</td><td colspan="2">This is excluded from the assessment as we have assumed it to be the same in both scenarios.

If it varies, then data for average days in storage based on survey data from retailers or wider market analysis could be used. It is possible to use energy requirements for refrigeration assessed using standard market assumptions from PCRs (e.g., EC PEF 2021).[43]</td></tr>
<tr><td>Wastage rate</td><td colspan="2">For this example, we have assumed no difference in wastage rate between scenarios. We have therefore excluded food waste from customers from the assessment. It would be possible to assess wastage rate data using survey data or wider market analysis. Assumptions about the impact of increased shelf-life on customer wastage could be made by adjusting the reference scenario value based on a change in shelf-life (e.g., a linear relationship or regression analysis based on conservative assumptions).</td></tr>
<tr><td colspan="3">Waste management</td></tr>
<tr><td>Food waste</td><td colspan="2">We have assumed that the proportion of waste to each disposal route (i.e., to anaerobic digestion, incineration, or landfill) is the same in both scenarios, based on actual data for retail, consumer surveys, and national statistics.

Emission factors for each waste disposal route are appropriate for the methodological choice (i.e. closed-loop method). Ideally factors should be supplier or country specific. It is possible to use models for developing country specific factors or proxies (e.g., USEPA WARM tool).[44]</td></tr>
<tr><td rowspan="2">Packaging disposal</td><td colspan="2">Packaging waste disposal routes from retail are based on actual data from retailers, industry surveys, and national statistics.

We have developed emission factors using similar data sources as food waste.</td></tr>
<tr><td>A proportion of rigid PE tray is recycled (35%) with the remainder sent to landfill (25%) or incineration with energy recovery (75%).</td><td>We have assumed landfill (25%) or incineration with energy recovery (75%), as the bio-polymer packaging is not recyclable and open incineration is forbidden in the UK. In other contexts, open incineration may still be common practice and should be regarded in the assessment.</td></tr>
<tr><td>Avoided production</td><td colspan="2">For materials that are recycled, or from which energy is recovered, the system boundary is expanded to include the reduction in the need to use virgin materials to produce new products (e.g., petrochemicals for plastic production), and the fuel use that is avoided when energy is recovered. We have applied this to the calculation as a negative GHG emission. It is known as the closed-loop approach for allocation at end of life.</td></tr>
</table>

5.4.2 Next steps: Assessing AE and validating significance

Table 23 shows the calculation. This includes negative emissions, which represent the displaced production of energy or materials as a result of their recovery from the waste management process, based on the closed-loop approach for assessing GHG emissions from waste management (see Appendix 1).

Table 23: Example data for calculation - Case Study 4

Life cycle stage / process	GHG emissions (kg CO_2 eq.)				Comment
	Reference scenario		Solution scenario		
	Process	AP*	Process	AP*	
Inputs					
Beef mince production	26	-	25.5	-	1.9% less beef required in the solution scenario.
Packaging: Process energy	0.023	-	0.03	-	More energy is needed for the vacuum packaging process in the solution scenario.
Packaging: Vacuum packaging (bio-polymer / EVOH film)	-	-	0.075	-	Lower emissions from packaging material production in the solution scenario due to lightweighting and a reduction in waste.
Packaging: PE tray and film (polyethylene)	0.14	-	-	-	
Distribution and retail: Refrigerated transport and storage	0.112	-	0.115	-	
Waste management					
Beef mince: Anaerobic digestion	0.002	-0.004	0.001	-0.002	Lower emissions in the solution scenario due to the reduction in waste.
Beef mince: EFW*	0.002	-0.002	0.001	-0.001	
Beef mince: Landfill	0.002	-	0.001	-	
Plastic vacuum packaging: EFW	-	-	0.001	-0.022	Lower emissions in the solution scenario due to the lower weight of packaging and reduced wastage.
Plastic vacuum packaging: Landfill	-	-	0.001	-	
Plastic tray and film: Recycling	0.014	-0.032	-	-	
Plastic tray and film: EFW*	0.057	-0.03	-	-	
Plastic tray and film: Landfill	0.001	-	-	-	
Total GHG emissions per kg of beef mince sold	**26.29**		**25.7**		**2.2% reduction in GHG emissions**
AE per kg of beef mince	**0.59 kg CO_2 eq.**				

EFW = Energy from waste (incineration with energy recovery)
AP = Avoided Production.

The calculations show that the GHG emissions in the solution scenario are 2.2% lower than in the reference scenario. This is a small percentage decrease when compared to the large impact from the production of the beef. However, it represents an approximately 50% reduction in the wastage at retail, which is significantly larger than the typical variability in wastage rates over time. Any variation in GHG emissions from beef production will be the same for both scenarios as the source is the same.

It is likely that there would also be AE due to reduced food waste by consumers potentially exceeding those at the retail level. However, it is difficult to accurately assess the effect of the change in packaging on consumer food wastage, so we have not included it (see Table 22).

If a company reports absolute AE for a market or aggregated for the company, then the AE calculation is:

If 1,000,000 kg beef sold by retailer = 1,000,000 x 0.59
= 590,000 kg CO_2 eq.

5.4.3 Identify rebound effects, negative side effects, and co-benefits

Most solutions will have an impact beyond that which was intended – both positive and negative. See Table 24 for a summary of these effects in relation to the bio-plastic packaging solution and how to mitigate them where needed.

Table 24: Rebound and side effects - Case Study 4

Type of effect	*Potential effect*	*Proposed mitigation / assessment approach*
Rebound effects	→ The use of bio-based feedstock could result in direct or indirect land use change, leading to increased deforestation. → A longer shelf-life may encourage consumers to buy more food than they need, resulting in increased wastage.	→ Use certified materials to show there is no direct land use change. → Use agricultural waste to produce the plastic and reduce the competition with food crops. → Educate consumers on how to avoid food waste and reduce incentives for consumers to bulk buy.
Negative side effects	→ Non-biodegradable single-use packaging may increase plastic pollution or generate GHGs during end of life disposal.	→ Promote proper disposal routes for packaging and broaden recycling options.
Co-benefits	→ Improved nutrition and public health due to the food's extended shelf-life. → Fewer food safety incidents. → Less consumer food waste, lower consumer costs and reduced system-wide GHG emissions.	

5.4.4 Uncertainty

We encourage companies to internally track and communicate quantitative estimates or qualitative descriptions of the uncertainty of the results, and list key assumptions and limitations. Table 25 outlines the uncertainties for this case study and potential methods to assess them.

Table 25: Uncertainty assessment - Case Study 4

Life cycle stage / process	*Uncertainty*	*Potential assessment methods*
Meat production	→ GHG emissions from production can vary significantly depending on geography, production system, etc. → A range of data may be available that either represents the market average or specific suppliers.	→ Conduct data quality assessments to select the most reliable source of impact factors and other data. → Conduct a sensitivity analysis to assess how GHG emissions vary when different data sources are used.
Amount of product wastage	→ It is very difficult to measure food waste for specific products based on sales or surveys. → It is possible to apply calculations based on a change in shelf-life, but actual relationships may be complex or inconsistent.	→ Conduct sensitivity or Monte Carlo analysis to produce a range for the results. → Look at sensitivity analysis scenarios to assess the impact per 1% change in food waste.
End of life disposal	→ Which disposal route food or packaging goes down. → Conduct sensitivity or Monte Carlo analysis to produce a range for the results. → Look at sensitivity analysis scenarios to calculate GHG emissions with 100% of waste disposed of via each disposal route. Use this to understand the range of emissions and assess whether it changes the conclusions.	

5.5 Case Study 5: Diet shifts to plant-based products - Plant-based cream cheese

5.5.1 Solution scoping, eligibility, and first steps of the assessment

Animal-based food products typically have higher GHG emissions and place greater pressure on land use[45, 46] than plant-based alternatives. Research indicates that global annual dietary emissions would fall by 17% with the worldwide adoption of the EAT-Lancet planetary health diet, which is characterized by shifts from consuming red meat to legumes and nuts as principal protein sources.

While animal protein provides food and nutrition security in some regions, in many contexts, increasing the share of production and consumption of plant-based alternatives can mitigate the environmental impact of meat and dairy consumption.

This case study considers a plant-based cream cheese alternative to dairy cream cheese. Plant-based alternatives to animal products – intended to be similar in look, taste, or texture – have been available for decades (e.g., margarine as a butter alternative, textured soya protein as a meat alternative). However, the most recent innovations have produced foods that more closely mimic animal-based foods, based on novel ingredients including processed plant extracts, lab-grown fats, cell-based meat, air-based protein, or proteins from precision fermentation. The range of alternatives has also expanded to include substitutes for cheese, fish, and egg whites.

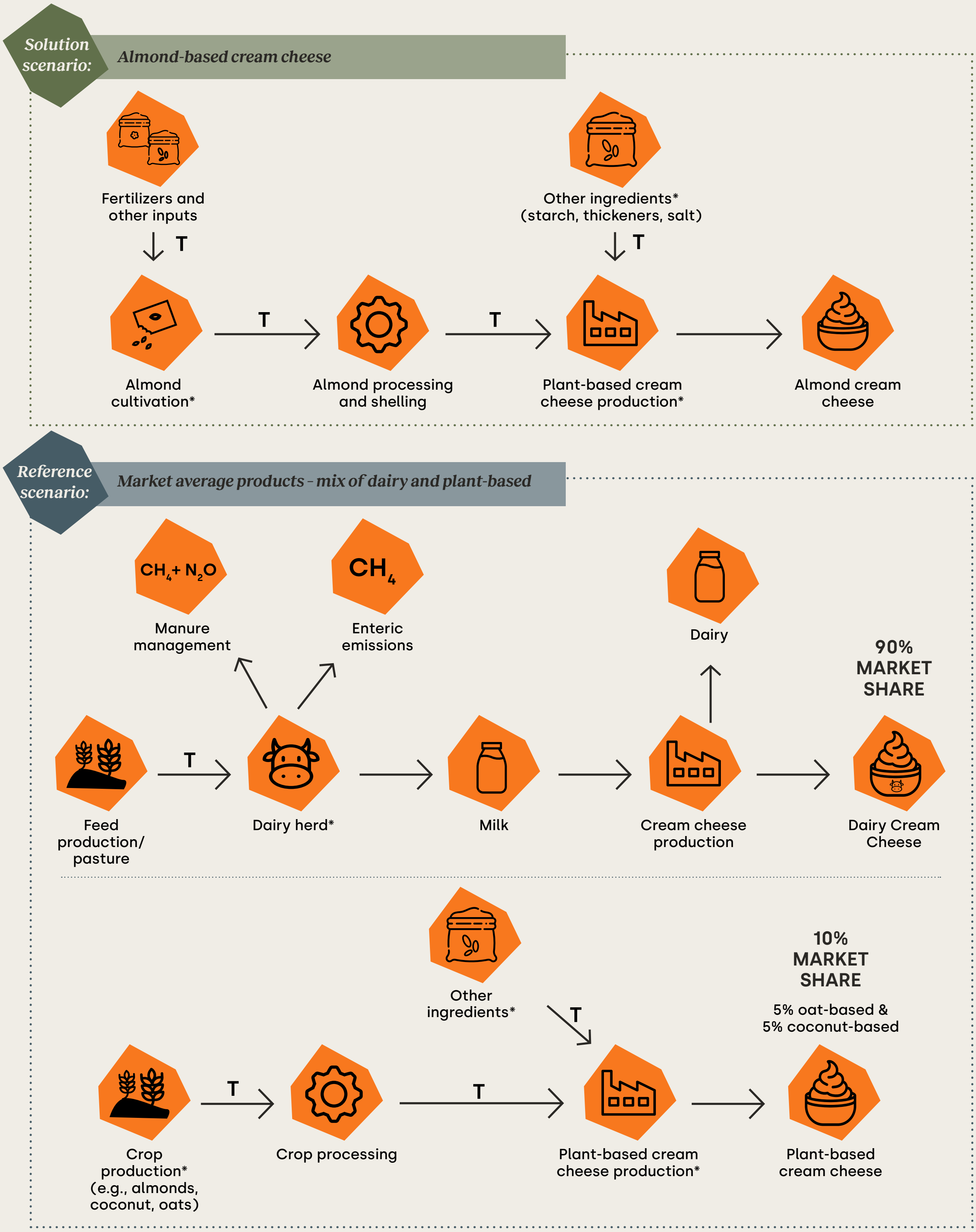
Table 26 and Figure 8 outline details of the solution and the first steps of the assessment. Table 28 shows key data sources and assumptions.

Table 26: Scoping and eligibility assessment - Case Study 5

Criteria	*Description*
A plant-based (almond-based) food product developed to replace traditional dairy cream cheese. Designed to mimic the taste and texture of the original, the product reduces reliance on animal-based ingredients, and the substitution lowers GHG emissions per kilogram of cream cheese by avoiding emissions from dairy production and land use.	
Who is claiming the AE?	Plant-based cream cheese manufacturer
Type of solution	End-use solution: Customers can consume the cream cheese products without further processing. If products would be used as inputs into other end-uses, they could be considered as intermediary products (e.g., plant-based ready meal containing multiple plant-based alternatives).
Market assessed	US market.
How is the solution implemented?	→ Customers use it as an alternative to cream cheese produced from cow's milk, e.g., due to personal preference or sustainable consumption choices → The nutritional content is similar to cream cheese made from dairy milk, but not exactly the same.
Functional unit	1 kg of cream cheese. → 1:1 displacement rate assumed. Scaling factor of 1 per unit of the solution to each reference scenario product (see Section 3.3). → In focus groups, consumers confirm similar serving size of each product (almond-based cream cheese and reference product) despite some nutritional differences (see Table 27). → Sensitivity analysis is necessary to assess the potential impact of differences in function, such as nutritional content. See below for an example of alternative scaling based on protein content. Other scaling factors could also be used, using metrics for nutrition or other variables identified by consumer tests.
System boundary	See Figure 8 and Table 28.
Reference scenario	Based on the main cream cheese products on the market (see Table 27 for distribution). Reference scenario definition: → Existing demand – replacement: Replacement of cream cheese products with almond-based cream cheese. → The solution provider collects market data on consumption and market share of cream cheese products to represent the most likely alternative that would be selected by customers → The use of consumer surveys to establish what their alternative would have been could also be used to improve the accuracy of the assessment. → Required by regulation: No
Timeframe	Year-on-year: The product's useful lifetime is less than one year.
Eligibility gates	
Gate 1: Climate action credibility	→ Yes (for the purposes of this illustrative case study, the hypothetical company fulfils Gate 1 criteria).
Gate 2: Latest climate science alignment	→ The IPCC AR6 Working Group III Report[47] and Project Drawdown[48] both include 'plant-based alternatives to animal-based food products'. → The solution is not directly involved in the extraction, production, or sale of fossil fuels.
Gate 3: Contribution legitimacy	→ Significant decarbonization: Yes. Producing dairy products typically creates more GHG emissions than plant-based alternatives (e.g., almond milk has <50% of the GHG emissions of conventional milk).[49, 50] → Substantial impact: Yes. Plant-based products can directly displace animal-based products with higher GHG emissions.

Note: CO_2 removals are outside the scope of AE, so we have not included any uptake over the life of the orchard (even if not reversed at end of life) in the analysis.

Figure 8: System boundary for solution and reference scenario - Case Study 5



*= Energy/ raw material inputs and wastes included
T = Transport

Key impacts of the solution:

↓ The production and processing of plant-based raw materials have lower GHG emissions than dairy.	↓ Even if the solution is not the plant-based cream cheese product with the lowest GHG emissions available in the market, it still represents a reduction in GHG emissions compared to the market average product (which includes dairy and plant-based products).

Table 27: **Nutritional content comparison and market share in reference scenario - Case Study 5**

Cream cheese products	*Reference scenario market share (%)*	*Nutritional content per 100g*			
		Energy (kcal)	**Protein (g)**	**Fat (g)**	**Calcium (g)**
Solution: Plant-based cream cheese (almond)	N/A	200	4	20	96
Animal-based cream cheese	90%	210	6	20	98
Plant-based cream cheese (oat)	5%	200	4	20	96
Plant-based cream cheese (coconut oil)	5%	220	2	20	20

Table 28: **Key data and assumptions for assessment - Case Study 5**

Category	*Process*	*Reference scenario*	*Solution*
Raw materials	Milk and cream production	→ US average milk production data from secondary data sources based on USDA research → Secondary data on cream production, using a region specific LCI database → Allocation to co-products based on the IDF methodology.	N/A
	Oat and coconut production	→ Secondary data from LCI databases on the average market for the cultivation and processing of oats and coconuts.	N/A
	Almond cultivation and shelling	Secondary data on the production of California almonds from a published region-specific LCA. As a perennial crop, the system must consider the lifetime of the almond orchard, including years for land preparation and growing the trees when no nuts are produced. We have included the sale of almond shells as a co-product for animal feed and the grinding of almonds in the assessment.	We have used the same data as the reference scenario. This is secondary data because the processes are not within the solution provider's operational control.
Production	Cream cheese production	Secondary data from LCI inventory databases and published LCAs on the production of cream cheese.	Primary data from the solution provider's production facility.
	Production of other ingredients (e.g., thickeners, salt, enzymes)	→ Secondary data on the amounts used in cream cheese production, adjusted to match the average of the largest brands, where information is available. → Secondary data from LCI databases on the production of ingredients.	→ Primary data on the amount of ingredients used. → Secondary data from LCI databases on the production of ingredients.
Downstream life cycle stages	Packaging, distribution, use, and disposal	→ We have excluded packaging from this case study, as we have assumed that all products use similar materials and formats with no significant difference expected for storage or use of the products (see Case Study 4 for an example of assessing packaging changes). → It is possible that the change in ingredients could affect the shelf-life of the product. Scoping is necessary to assess the significance of this and establish whether it should be included in the assessment. → We have excluded consumer wastage from this assessment (i.e., assumed it to be the same in both scenarios) as there can be significant uncertainty in assessing how a change in product shelf affects consumer product wastage.	

5.5.2 Next steps: Assessing AE and validating significance

Table 29: Example data for calculation - Case Study 5

Process	*GHG emissions (kg CO_2 eq.)*				*Comment*
	Reference scenario			Solution scenario	
	Dairy	Coconut	Oat	Almond	
Milk (FPCM)	1.4				GHG emissions from the production of dairy products is greater than that for plant-based alternatives.
Cream (40% fat)	1.25	-	-	-	
Almonds (shelled)	-	-		0.9	
Oats	-	0.15	0.85	-	
Coconut oil	-	0.56	-	-	
Water	0.01	0.01	0.01	0.01	
Thickeners	0.2	0.2	0.2	0.1	Additional inputs are typically added in small quantities but could have a greater GHG intensity than main ingredient inputs.
Enzymes, salt, and other additives	0.04	0.02	0.02	0.02	
Energy (electricity and fuel use)	0.25	0.5	0.5	0.5	
Process wastes	0.3	0.25	0.25	0.25	
Total GHG emissions per kg of cream cheese	**3.45**	**1.69**	**1.83**	**1.78**	**46% reduction in GHG emissions**
AE per kg of cream cheese	**See table 30**				

As the reference scenario represents the average product currently consumed in the market, the analysis uses a weighted average of GHG emissions from each product type based on market share (as shown in Table 30). This shows that the GHG emissions in the solution scenario are 46% lower than in the market average for the reference scenario.

This represents substantial AE reduction, as it is primarily driven by the production of milk used to produce conventional cream cheese which has close to 100% market share. There is only minimal variability in the amount of dairy product required for cream cheese and the GHG emissions from milk production are well understood, based on a national LCA for milk production in the USA. The almond-based cream cheese in the solution has similar GHG emissions intensity as the plant-based cream cheeses included in the reference scenario.

Additional sensitivity analysis (see Table 31) assesses the AE when the amount of reference FU is scaled relative to the amount of protein in the products. This shows that GHG emissions in the solution scenario are 24% lower than in the market average for the reference scenario.

There may be further uncertainty with regard to wider consumer diet choices. It is possible to assess the impact of these uncertainties by quantifying potential rebound effects (see Table 32).

If a company is reporting the AE assessment externally, we highly recommend a third party review (see Section 5 of the WBCSD Guidance on Avoided Emissions). This is especially relevant for this case study, as the comparison of the solution to other products can be seen as making comparative assertions between products (i.e., that a product has a lower product carbon footprint than competitor products).

Table 30: **AE per kilogram of cream cheese product (assuming 1:1 substitution of products) - Case Study 5**

Product type	*Market share for reference scenario (%)*	*GHG emissions (kg CO_2 eq. / kg product)*	*Scaling factor (based on product mass)*	*Scaled GHG emissions (kg CO_2 eq. / kg solution product)*
Solution scenario				
Plant-based cream cheese (almond)	-	1.78	1	1.78
Reference scenario				
Animal-based cream cheese	90%	3.45	1	3.45
Plant-based cream cheese (oat)	5%	1.83	1	1.83
Plant-based cream cheese (coconut oil)	5%	1.69	1	1.69
Market average for reference scenario	-	3.28	-	3.28
AE per kg of product in solution scenario				**= 3.28 – 1.78** **= 1.5** **(46% reduction)**

Table 31: **AE per kilogram of cream cheese product (substitution scaled based on protein content) - Case Study 5**

Product type	*Market share for reference scenario (%)*	*GHG emissions (kg CO_2eq. / kg product)*	*Scaling factor (based on protein content)*	*Scaled GHG emissions (kg CO_2eq. / kg solution product)*
Solution				
Plant-based cream cheese (almond)	-	1.78	1	1.78
Reference scenario				
Animal-based cream cheese	90%	3.45	= 4/6 = 0.67	2.31
Plant-based cream cheese (oat)	5%	1.83	= 4/4 = 1	1.83
Plant-based cream cheese (coconut oil)	5%	1.69	= 4/2 = 2	3.38
Market average for reference scenario	-	3.28	-	2.34
AE per kg of product in solution scenario				= 2.34 – 1.78 = 0.56 (24% reduction)

5.5.3 Identify rebound effects, negative side effects, and co-benefits

Most solutions will have an impact beyond that which was intended – both positive and negative. See Table 32 for a summary of these effects related the the plant-based cream cheese solution and how to mitigate them where needed.

Table 32: Rebound and side effects - Case Study 5

Type of effect	*Potential effect*	*Assessment method*	*Proposed mitigation*
Rebound effects	→ Increased almond (raw material) cultivation can result in deforestation and other direct or indirect land use change. → The difference in nutritional content is relatively small for this example. The difference may be greater for other solutions (e.g., comparing a meat-alternative to meat) which could lead to increased consumption of the solution product (or other products) relative to the reference scenario to meet the same dietary intake.	See Table 33 below for additional calculations to assess the impact of a) increased consumption and b) consuming additional foods (in this case, peanuts) to meet the same protein intake as the reference scenario.	→ Use certified materials and engage with farmers to track and mitigate land use change. → Include calculations (see Table 33) as evidence to ensure that rebound effect scenarios would not undermine significant AE impact.
Negative side effects	→ Almond cultivation has high water use: 80% of almonds grow in California, where water scarcity is an issue. (Dairy production may also have high water use, but it is not concentrated in water scarce areas).	A qualitative or quantitative water risk assessment can identify if production requires significant water use in a water scarce area.	Engage with suppliers to promote water stewardship for almond production and assess if almonds produced in alternative locations have reduced sustainability risks, in order to diversify supply and allow potential for growth.
Co-benefits	→ There is potential for improved food safety, as food-producing animals are a major reservoir for food borne pathogens. → There are water quality, land use, and biodiversity benefits, as livestock operations contribute more to nutrient pollution and soil erosion from manure management and animal housing.		

Table 33: AE with supplemental peanuts* for protein - Case Study 5

	Value	*units*
Additional protein required per kg cream cheese	0.02	kg
Protein content of peanuts	25%	%
kg of peanuts required	= 0.02 / 25% = 0.08	kg / kg product
GHG emissions per kg peanuts[51]	3.00	kg CO_2 eq./ kg
Additional GHG emissions	= 0.08 x 3.00 = 0.24	kg CO_2 eq./ kg product
GHG emissions per kg product	= 1.78 + 0.24 = 2.02	kg CO_2 eq./ kg product
AE = (3.28 – 2.02)	= 3.28 – 2.02 = 1.26	kg CO_2 eq./ kg product

* Peanuts were selected as they represent a plant-based protein with relatively high GHG emissions (e.g., compared to lentils or beans)

5.5.4 Uncertainty

We encourage companies to internally track and communicate quantitative estimates or qualitative descriptions of the uncertainty of the results, and list key assumptions and limitations. Table 35 outlines the uncertainties for this case study and potential methods to assess them.

Table 35: Uncertainty assessment - Case Study 5

Life cycle stage / process	*Uncertainty*	*Potential assessment methods*
Functional equivalence of all cream cheese products in market	→ The nutritional content of cream cheeses varies. It is therefore difficult to be certain whether they are direct alternatives to other (animal- or plant-based) cream cheeses.	→ Consider alternative scenarios for the FU, as there are sensitivities (e.g., those based on consumers' consumption behavior in relation to protein).
Market share data	→ Information on all sales of cream cheese in the US market is not available, only for major brands.	→ Assess a range of market share scenarios using sensitivity analysis. → Undertake customer surveys to better establish which alternative they would purchase.
Almond cultivation and shelling	→ The secondary data source on almond production in the source region may not represent actual supplier farms.	→ Engage with suppliers to understand their processes and how these differ from the secondary data source. Assess implications using sensitivity analysis.
Milk production	→ We did not know the specific source location of milk used in animal-based products, so used market average data.	→ Look at the range of GHG emissions by geography and assess the impact on the results using sensitivity analysis.
Cream cheese production process in reference scenario	→ Competitors run production processes, so data are not available unless it is published in reports (e.g., sustainability or CDP reports, EPDs).	→ Use conservative assumptions to avoid overestimating the GHG emissions from these products.

Executive and *managerial guidance*

06.

06. Executive and *managerial guidance*

Executives and managers from diverse business functions recognize the value of quantifying AE. Doing so supports both internal and external communications and helps guide decision making by providing a clear, comparable metric. This metric allows organizations to compare performance both across the market and within their own products and services – helping to guide business planning and strategy.

AE calculations can support R&D teams with stage gate processes, inform product development and help go-to-market teams identifying growth opportunities in the low-carbon transition.

Collaboration with other internal teams is important. Legal teams can help validate AE claims, finance teams can assist with data collection and leverage AE assessment in green finance strategies, and corporate affairs teams can use AE to build a broader narrative for global engagement. By working together, teams can also develop standard operating procedures for how product and R&D teams can collect data from efficacy studies and field trials. This data can inform AE assessments, and also guide marketing strategies for solution technologies.

One multinational food and biotechnology corporation is striving to transform food systems and improve environmental outcomes through its business activities. They have consistently collected CO_2 reduction data as a core component of their business operations. Based on this data, the company has identified products and services within its portfolio that have a high potential to contribute significantly to AE. Their sustainability team has assisted the public relations and marketing team to best support these products and services.

The company's focus is now on maximizing collaboration across corporate divisions, including business units, R&D, and the sustainability team. The goal is to visualize AE at both the business unit and corporate levels, to better leverage it. The company will also strengthen initiatives to communicate AE to external stakeholders – while also using AE to support internal decision making, resource allocation, and business development, including R&D.

6.1 Finance and investor relations

Finance and investor relations teams benefit from using AE as a metric when raising debt capital and in specialised financial instruments such as sustainability-linked loans, green bonds, or project finance. This could, for example, include demonstrating how a new formulation of microbial fertilizers will help reduce systemwide emissions, considering the sustainability attributes of the investment to be financed. Finance and investor relations teams could disclose the AE to lenders over the term of the instrument, or commit to a specific pathway for AE as a condition of receiving a sustainability-linked loan.

Similarly, finance and investor relations teams may find it useful to show the AE potential of alternative investments in order to compete for favorable terms based on the lender's comparison of AE KPIs (this opportunity underscores the importance of using comparable methodologies across companies). They may also benefit from illustrating to current and prospective investors how the company's portfolio of products and services contributes to AE in the value chain.

Currently, financial institutions and large corporations developing sustainable financing frameworks for solutions in the agrifood sector focus primarily on emissions reductions and output-based metrics. For instance, ADM's sustainable financing framework includes KPIs such as farm acres implementing sustainable agriculture practices, % of fully traceable commodity sourcing, units sold of sustainable alternative animal feed.[52]

The use of AE for Sustainability-Linked Loans and other sustainable finance instruments for the Agriculture & Food sector solutions is still emerging. Currently, companies like Rabobank or Mars typically associate AE metrics with renewable energy or green building projects; and financial institutions – such as Credit Agricole, Bank of America, Nomura Asset Management – include AE as a metric within their green bond offering. However, the same ideas could extend to related applications, such as agri-voltaics (i.e., solar energy generation on-farm). For example, some companies are exploring AE as a potential metric for financing the production of green or blue ammonia for fertilizer production.

AE can also serve as a metric to assess the potential investment opportunity throughout the investment cycle – for example, in a comparative analysis of a company's potential to contribute to system-wide decarbonization, and the degree to which the company is protected against regulatory and other transition risks prior to a prospective transaction. Early-stage investors have been known to work with this metric to support their decision making. AE also provides another climate-related metric when engaging with investee companies and as a factor in the valuation calculation during exit.[53]

6.2 R&D and product development

Teams involved in go-to-market activities, product development, marketing, and sales may use AE assessments by incorporating AE into objectives and KPIs to align internal reporting metrics with the company's wider decarbonization strategy. This may alter resource allocation, so companies can prioritize products and services that advance both systemwide GHG reductions and competitive advantage.

R&D teams can usefully incorporate the potential for AE alongside other criteria in formal reviews in the stage gate process. Accurate and comparable AE assessments can help R&D teams to phase out GHG-intensive solutions by pursuing R&D activities to find, create or advance products and services that provide a very similar function (such as bio-fertilizers that deliver the same quantity of effective nutrients as synthetic fertilizers but with lower nitrous oxide emissions, or bio-based polymers that replace petrol-based plastics for food packaging). Similarly, AE assessments can help R&D teams prioritize the development of products and services based on their potential to reduce systemwide emissions. Depending on the relevant tax policies, there could also be opportunities for AE assessment to support subsidies for sustainability-enhancing R&D (e.g., tax credits).

6.3 Communications, external affairs, and marketing

Communications and external affairs teams can use AE assessments by integrating sustainability into the company's core messaging, highlighting practices and products to enhance brand reputation, or contributing to targeted marketing campaigns that showcase emissions-reducing products and services. These messages may emphasize land-based benefits like enhanced soil carbon sequestration, soil health, or reduced emissions. In other contexts, they may emphasize resource efficiency, such as highlighting optimized food processing lines, reduced food loss and waste, and efforts to create valuable products from food by-products. They may also focus on improved nutrition and health, for example by emphasizing the company's role in enabling a dietary shift to more plant-based foods, and providing information that helps consumers make informed choices.

It is important to note that there are regulations (e.g., the EU Green Claims Directive) requiring that claims on products' environmental benefits and associated AE are clear and unambiguous, with methodology, assumptions, and uncertainties transparently stated. This reduces the risk of greenwashing. Companies should make calculations in line with relevant internationally recognized frameworks and in accordance with legal requirements.

6.4 Procurement

Assessing AE can support procurement teams by helping them to evaluate and prioritize lower-carbon suppliers and materials. By quantifying the emissions reductions associated with different sourcing options, procurement can make informed decisions – for example, they might select agricultural suppliers that use bio-fertilizers, sustainable packaging solutions, or resource-efficient processing technologies.

AE assessments may also help procurement teams set clear sustainability criteria for supplier contracts and collaborations, ensuring alignment with the company's broader environmental strategy and decarbonization goals.

In their sustainability report, a global company selling nutritious, natural, plant-based food products has disclosed the AE impact of their three major product groups compared to dairy counterparts. To ensure these claims are credible, the company has also publicly disclosed its methodology, assumptions, and limitations in relation to AE calculations and weightings for each product group. This includes the level of country-specificity and product-specificity of the LCAs used as reference scenarios. They opted for more conservative approaches to avoid overstating AE claims. Thanks to this transparency, the company is boosting its brand reputation by substantiating their claim to being the "first food company to estimate its avoided emissions

Appendix

07.

07. Appendix
Appendix 1: AE due to recycling and waste disposal

When assessing the AE for solutions that change the amount of recycled material used or amount of waste generated, it is important to consider the assessment method. We recommend two main methods (as discussed in Section 9.3.6 of the GHG Protocol Product Standard), which we have summarized below along with two examples of hybrid approaches.[54] Companies should justify their choice of end of life allocation in the AE assessment. If the AE assessment is based on a specific PCR, this may also mandate the use of a particular allocation system.

Table 45: GHG emission reduction due to recycling and waste disposal

Allocation method	*Description*	*Application in GHG assessment*
Recycled content approach (also known as cut-off or 100/0 approach)	→ GHG emissions associated with the recycling process are allocated to the life cycle that uses the recycled material. → This promotes the use of recycled content but offers little incentive to recycle at end of life.	→ The assessment includes emissions from the recycling process for recycled material inputs. → At end of life, all recycled / recovered materials are assumed to have zero emissions (these are borne by the system that uses the material).
Closed-loop approach (also known as avoided burdens, 0/100 or substitution approach)	→ This accounts for the impact that end of life recycling has on the net virgin acquisition of a material. → It promotes recycling at end of life but offers little incentive to increase recycled content.	→ All material inputs are assumed to have no recycled content. → The assessment includes emissions from recycling / recovery processes at end of life, but provides a credit (negative value) for materials recovered.
50/50 approach	→ This accounts for both the impact of using recycled content and recycling at end of life, for all materials.	→ The assessment includes both the 'recycled content' and 'closed-loop' approaches. → 50% of recycled content emissions and 50% of closed-loop emissions are applied.
EC PEF Circular Footprint Formula (CFF)[55]	→ This determines the split of emissions between recycled content and closed-loop approaches based on the material type and other factors (i.e., not always a 50:50 split).	→ Recycled materials enter the current life cycle with a portion of the credits but also a part of the burden. → Recycled materials at end of life generate both credits and burdens for the current life cycle.

Acronyms and abbreviations

AE	Avoided emissions
3-NOP	3-nitrooxypropanol
CDM	The Clean Development Mechanism
CFF	Circular footprint formula
CH4	Methane
CO_2	Carbon Dioxide
COMET	Carbon Management & Emissions Tool
EC PEF	European Commission's Product Environmental Footprint
EfW	Energy from waste
EOL	End of life
EPD	Environmental Product Declaration
EVOH	Ethylene-vinyl alcohol co-polymer
FAO	The United Nations Food and Agriculture Organization
FLAG	Forest, Land and Agriculture Guidance
FLW	Food loss and waste
FPCM	Fat-and-protein-corrected milk
FU	Functional unit
GFLI	Global Food LCA Institute
GHG	Greenhouse gas
GHGP	Greenhouse Gas Protocol
GPS	Global positioning system
Ha	Hectare
IDF	International Dairy Federation
iLUC	Indirect land use change
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization of Standardization (ISO Standards)
KPI	Key performance indicator
LCA	Life cycle assessment
LCI	Life cycle inventory
LEAP	Livestock Environmental Assessment and Performance Partnership
N2O	Nitrous oxide
nLCA	Nutritional life cycle assessment
P2O5	Phosphorus pentoxide
PA	Precision Agriculture
PCR	Product category rules

Acronyms and abbreviations

PE	Polyethylene
R&D	Research and development
SBTi	Science-based Targets Initiative
SOC	Soil organic carbon
SOP	Standard operating procedure
UNFCCC	United Nations Framework Convention on Climate Change
USDA	United States Department of Agriculture
VRT	Variable rate technology
WBCSD	World Business Council for Sustainability Development

List of tables

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Endnotes

1 Food and Land Use Coalition, "Future Fit Food and Agriculture: The Financial Implications of Mitigating Agriculture and Land Use Change Emissions for Businesses," ed. Kitty Parker Brooks, Alex Andreoli, and Paul Limpens (The Food and Land Use Coalition, We Mean Business Coalition, World Business Council for Sustainable Development, March 2024).

2 WBCSD Guidance on Avoided Emissions: Helping business drive innovations and scale solutions toward net zero (2025).

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