D2.2 – PEF-wise PCR methodology to implement LCA for the environmental assessment of alternative fertilizing products – 1st version (for public consultancy)

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Content

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Abbreviations

BBF: Bio-based fertiliser

EC: European Commission

EF: Environmental Footprint

EU: European Union

EPD: Environmental Product Declarations

EPLCA: The EU Platform on LCA

EoL: End-of-life

GHG: Greenhouse Gases

OEF: Organizational Environmental Footprint

LCA: Life Cycle Assessment

LCI: Life Cycle Inventory

LCIA: Life Cycle Impact Assessment

PCR: Product Category Rules

PEF: Product Environmental Footprint

PEFCR: Product Environmental Footprint Category Rules

SOC: Soil Organic Carbon

TS: Technical Secretariat

WP: Work package

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Executive Summary

The NOVAFERT project and the present document aims to define the 1st draft of a PEF-wise methodological guideline, so-called "PEF- wise method for BBFs". The first section of the document is a guideline on how to assess the environmental performance of producing and distributing different alternative fertilizing products (Cradle-to-Gate). The second part of this document presents which changes or modifications of other PEFCRs should be done in multiple PEF studies for agricultural production (e.g. food production, ornamental flowers) from the perspective of utilizing (application and use on field) BBFs in agriculture (according to a specific PEFCR or the PEF guide if no PEFCR is available).

To construct a PEF-wise method for BBFs, this work follows the structure of the recommendations by the European Commission's PEF general guidance (2021) by adding specifying requirements from BBF's perspective. The general PEF method provides detailed and comprehensive technical rules on how to conduct PEF studies that are more reproducible, consistent, robust, verifiable and comparable. The results of PEF studies are the basis for the provision of EF information, and they may be used in a diverse number of potential fields of applications, including in-house management and participation in voluntary or mandatory programs and external communications.

PEFCRs are product category-specific, life cycle-based rules that complement general methodological guidance for PEF studies by providing further specifications at the level of a specific product category. The final version in May 2025 (at the end-of NOVAFERT project) could serve as a base text for a proposal of PEFCR for alternative fertilizing products for the posterior validation by industry, TS and finally, shared in the EU Platform on LCA (EPLCA).

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1. Introduction

Bio-based fertilizers (BBFs) are products with a valuable content of nutrients for soil and plants that come from biomass feedstocks, normally considered co-products, residuals or wastes. BBFs compile, therefore, a wide set of products that can be defined by i) the origin (e.g. wastewater, sewage sludge, animal manure or agro-industrial wastes); ii) the process (e.g. composting, fermentation, etc.); and iii) the chemical composition of the final product (e.g. nutrient content, inorganic or organic composition). That includes, for instance, the compost from animal manure, and the struvite from wastewater among others.

The Environmental Footprint Initiative is an initiative of the European Commission to create harmonized standards for assessing the impact of products (Product Environmental Footprint-PEF) and organizations (Organizational Environmental Footprint-OEF). Each sector and product have its own category rules in what is called the Product Environmental Footprint Category Rules (PEFCR) document.

To enhance the use of the most environmentally friendly BBFs and orientate the market towards the most sustainable BBF products, the NOVAFERT project and the present document, in particular, aims to define a PEF-wise methodological guideline, so-called "PEF- wise method for BBFs", to assess the environmental performance of producing and applying alternative fertilizing products (Cradle-to-Grave).

This PEF-wise method suggests technical rules on how to conduct PEF studies for different specific BBFs that are more reproducible, consistent, robust, verifiable and more comparable. The results of PEF studies are the basis for the provision of EF information, and they may be used in a diverse number of potential fields of applications, including in-house management and participation in voluntary or mandatory programs. This PEF-wise method for BBFs is to be used to supplement The PEF instruction in the parts where things have been recorded here. Compliance with the present PCR is optional for in-house applications, whilst it is mandatory whenever the results of an LCA study or any of its content is intended to be communicated.

This NOVAFERT D2.2. report presents the first draft of the PEF-wise method in two separate sections/contexts, as BBF is not a final product, but an intermediate product used to produce a final good or finished product (e.g. a food product):

1. **The PEF-wise PCR method for BBFs** presents the perspective of BBF production from raw material pre-processing to distribution (Cradle-to-Gate).
2. The second part of this document presents which changes or modifications of other PEFCRs should be done in multiple PEF studies for agricultural production (e.g. food production, ornamental flowers) from **the perspective of utilizing (application and use on field) BBFs in agriculture** (according to a specific PEFCR or the PEF guide if no PEFCR is available).

This 1st draft of the document aims to be a base document for discussion or prototype method. Therefore, the document will be uploaded to the NOVAFERT website for public discussion.

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This document will be under public exposition and with an active stakeholder consultation (consumers, industry, academia and policy makers) in a participatory process from March 2024 until the end of the project in May 2025. This will allow the enrichment of the text, as well as a first trial of its relevance and consensus status.

The consultation of the norm will have as a result a second version of the method that could differ from the present one. The final version will be also uploaded to the NOVAFERT website by the end of the project in May 2025. Comments will be responded personally by the NOVAFERT WP2 team. If needed, meetings with relevant stakeholders could be done to ease major changes.

The final version to be released in May 2025 (at the end-of NOVAFERT project) could serve as a base text for a proposal of PEFCR for alternative fertilizing products for the posterior validation by industry an TS and finally, be shared in the EU Platform on LCA (EPLCA).

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2. Materials and methods

The general PEF method by the European Commission (2021) provides detailed and comprehensive technical rules on how to conduct PEF studies that are more reproducible, consistent, robust, verifiable and comparable. The results of PEF studies are the basis for the provision of EF information, and they may be used in a diverse number of potential fields of applications, including in-house management and participation in voluntary or mandatory programs and external communications. PEFCRs are product category-specific, life cycle-based rules that complement general methodological guidance for PEF studies by providing further specifications at the level of a specific product category.

General information about the PEF-wise PCR method for BBFs

To construct a PEF-wise PCR method for BBFs, this work follows the structure of the recommendations by the European Commission's PEF general guidance (2021) by adding specifying requirements from BBF's perspective. In particular, the requirements for developing PEFCRs are specified in part A of Annex II and follow the PEFCR template (European Commission 2021). Among the aspects this method should achieve, it can be highlighted the comparability, reproducibility, consistency, relevance, focus and efficiency of future BBFs PEF studies among the time limitations, resources and participation process done in the NOVAFERT-project.

Where the requirement in this PEF-wise PCR method is in line with but more specific than those of the PEF guidance such specific requirements are fulfilled as best as possible within the scope of this project e.g. considering the lack of a Technical Secretariat (TS).

Probably, not all specific assessment, data collection or modelling issues of all BBF production systems have been covered. Therefore, this guidance can be utilized for other than most common BBF products only when adequate, but without reference to full conformation.

Technical Secretariat

This 1st draft of the proposal lacks the participation of the organizations, industry, academia, NGO, consultant, etc. and it has been done without the approval and guidance of the Technical Secretariat (TS). Therefore, this document is lacking some chapters (e.g. Representative product) that require the involvement of the TS. Other chapters have needed adjustments and are only described as "PEF-wise PCR method".

Geographic validity

This PEF-wise PCR method is valid for products in scope sold or consumed in the EU and European Free Trade Association (EFTA). Each PEF study shall identify its geographical validity listing all the countries where the product object of the PEF study is consumed/sold with the relative market share. In case the information on the market for the specific product object of the study is not available, EU+EFTA shall be considered the default market, with an equal market share for each country.

Language

This PEF-wise PCR method is written in English.

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Conformance to other documents

This PEF-wise PCR method has been prepared in conformance with the PEF framework (EC 2021) and other relevant documents (see more D2.1). Figure 1 outlines the systematic approach undertaken to conduct a comprehensive literature review and develop a cohesive Proposal for Environmental Footprint (PEF) for Bio-Based Fertilizer Production. The process began with defining the scope, which focused on exploring EU bio-based fertilizer technologies and key inputs in alignment with the objectives of Novafert. A survey of scientific literature was conducted to identify important technologies and raw materials utilized in bio-based fertilizer production. This involved examining peer-reviewed publications and reputable sources to gather relevant data and insights. Furthermore, Life Cycle Assessments (LCAs) in peer-reviewed publications were explored to understand the environmental impacts associated with various stages of bio-based fertilizer production. The analysis encompassed reviewing scientific articles on LCA modelling and incorporating relevant LCA methods to evaluate the environmental footprint comprehensively. The most important aspect of this task is reviewing EU Commission Guidelines, such as guides of LCA, PEF, and Product Environmental Footprint Category Rules (PEFCR), along with main LCA ISO standards, to establish the context of EU Commission instructions and identify applicable guidelines for biomass-based products. Through the identification of commonalities and disparities in LCA approaches, alignment with official standards was reviewed, addressing methodological gaps, and enhancing the credibility and reliability of the proposed PEF for bio-based fertilizer production. Grounded in scientific literature, PEF guidance, and ISO standards, the cohesive PEF proposal aimed to provide a comprehensive framework for evaluating the environmental footprint of bio-based fertilizer production processes, contributing to the advancement of sustainable practices within the EU context.

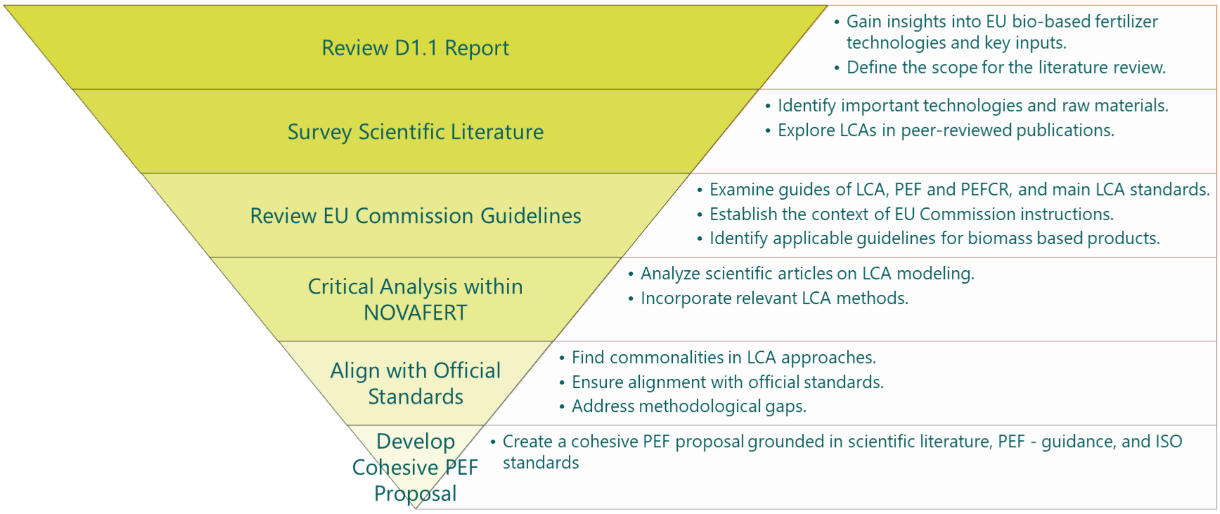

Figure 1.-Methodology for the development of the PEF-wise PCR method.

This NOVAFERT D2.2. report presents the first draft of the PEF-wise PCR method in two separate sections/contexts (Figure 2) as BBF is not a final product, but an intermediate product used to produce a final good or finished product (e.g. a food product):

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1. **Section 1: The PEF-wise PCR method for BBFs:** this first approach assumes that the PEF-wise PCR method for BBFs presents the perspective of BBF production from raw material pre-processing to distribution and highlights the need to change and specify following the PEF method from the BBF perspective. For PEF-wise PCR studies for food or ornamental flower production (according to a specific PEFCR) where BBFs are used, **this gives guidance on how to assess the production of raw materials, transportation of raw materials, manufacturing of BBFs and distribution of BBFs to the cultivation site/farm (Cradle-to-Gate).** This PEF-wise PCR method is applicable in two different contexts:

    - For the Cradle-to-Gate BBF PEF -wise PCR studies for either internal or external use but **without comparison**. BBF is intermediate product, can often fulfil multiple functions and the whole life cycle of the product is not known (see more in 3.3). According to The PEF, for intermediate products declared unit (DU) is used instead of functional (unit FU).
    - For PEF-wise PCR studies for food or ornamental flower production (according to a specific PEFCR) where BBFs are used. This is giving guidance only on how to assess the production/acquisition and distribution of BBFs to the cultivation site/farm (Cradle-to-Gate), not the application of BBFs and use on the field which is presented in section 2 for other agricultural production PEFCRs). This is providing LCI information on BBF in the context of PEF studies of agricultural products.

    This PEF-wise PCR method aims to guide the assessment of the environmental effects of BBF in **a more uniformed manner**. Considering the relative importance of fertilizers in the environmental footprint of cultivation, it is justified to harmonize BBF-specific methodological aspects in all available BBF products.

    This guideline focuses on BBF produced in a manufacturing plant designed specifically for BBF production that farmers buy as an external product.

2. **Section 2:** This document presents which **changes or modifications other PEFCRs** should be done in multiple PEF studies for agricultural production (e.g. food production, ornamental flowers) from **the perspective of utilizing (application and use on field) BBFs in agriculture** (according to a specific PEFCR or the PEF guide if no PEFCR is available).

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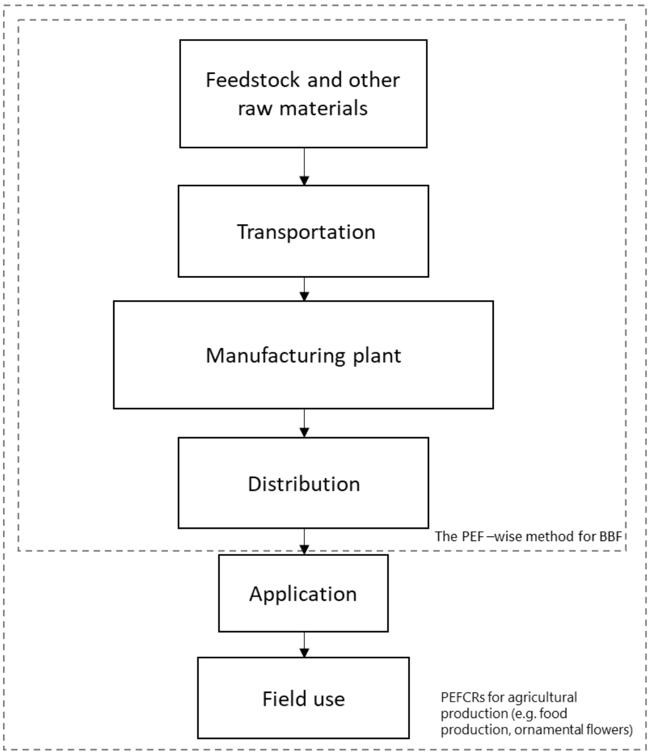

Figure 2.- PEF-wise PCR method or BBFs in two separate sections/contexts

This division to sections 1 and 2 is preventing risks for double accounting which would emerge when the company is using both PEF-wise PCR methods for BBFs as well as Different PEFCRs for agricultural products (food and ornamental flowers) including fertilizer application.

Though there are combinations of organic and mineral/fossil-based compounds in BBFs, the mineral and fossil-based fertilizers are excluded from the scope of the present PEF-wise PCR method, in other words this PEF-wise PCR method gives guidance only how to assess the share of organic biofertilizers in BBFs.

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Section 1: PEF-wise PCR method for BBFs (Cradle to Gate)

IMPORTANT NOTE:

This document is based on EC's Product Environmental Footprint guidelines (2021).

All text marked in blue is directly from the guidance document.

All text marked in black are additions by NOVAFERT - research group.

Boxes marked with red are suggested development needs

The term **"shall"** indicates what is required for a LCA study to be compliant with this PEF -wise PCR method.

The term **"should"** indicates a recommendation rather than a requirement. Any deviation from a "should" recommendation must be justified by the party conducting the study and made transparent.

The term **"may"** indicates an option that is permissible

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3. Scope of the PEF-wise PCR method

The scope of the guideline is BBF products on the EU market. The aim is to provide guidelines for assessing the environmental effects of BBF in a uniform manner. The aim was to cover all the most common BBF products, including raw materials such as recycled waste, residual or co- product. This guideline focuses on BBF produced and commercialised. BBFs that are internally produced and used in the same production chain are not part of this guideline.

It is most likely that not all specific assessment, data collection or modelling issues of all BBF production systems have been covered as BBFs are so diverse with multiple different types. Therefore**, this guidance is recommended to be used only for the most common BBF products defined (see more in 6.1.).** However, it can be utilized for other than most common BBF products only when adequate, but without reference to full conformation.

This BBF's PEF-wise PCR method provides consistent methodological requirements for the entire *cradle-to-gate* LCA of BBF manufacturing.

3.1. Product classification

According to recommendations by commissions (EC 2021), the Classification of Products by Activity (CPA) codes corresponding to the products in scope shall be listed in the PEFCR.

To be further developed:

The total CPA 20.15 including the CPA codes (Table 1) for the products are not necessarily applied for BBFs since it is based on mineral fertilizers and have strict classification according to nutrient content. **This PEF-wise PCR method therefore suggest to create new specific CPA code or codes for bio-based fertilizers.**

Table 1: CPA codes based on mineral fertilizers

CPA Code	Description
20.15.39	Other nitrogenous fertilisers and mixtures N.E.C.
20.15.39	Other nitrogenous fertilisers and mixtures N.E.C.
20.15.49	Other phosphatic fertilisers
20.15.5	Potassic fertilisers, mineral or chemical
20.15.59	Other potassic fertilisers
20.15.74	Fertilisers containing two nutrients: nitrogen and phosphorus
20.15.75	Fertilisers containing two nutrients: phosphorus and potassium
20.15.8	Animal or vegetable fertilisers N.E.C.

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It should be noted that there is combinations of organic and mineral/fossil-based compounds in BBFs. Although the mineral and fossil-based fertilizers could share the CPA they are excluded from the scope of the present PEF-wise PCR method. **We give more insights on this and the assessment in further version.**

3.2. Representative product

The representative product(s) correctly describes the average product(s) sold in Europe (EU+EFTA) for the product category/sub-category in the scope of this PEFCR.

The "representative product" for BBF should be a virtual (non-existing) product when the market is made up of different technologies/materials and there is sufficient market and technical information available.

The virtual product shall be calculated based on average sales-weighted characteristics of all existing technologies/materials covered by the scope of the PEFCR. For example, from the average EU sales-weighted characteristics of all. There are two options for defining the representative product(s): In addition to the sales-weighted average, other weighting sets may be used, for example, weighted average based on mass (ton of material) or weighted average based on product units (pieces).

According to recommendations by Commissions (2021), "the PEFCR shall include a description of the representative product(s) and how it has been derived. The Technical Secretariat shall provide in an Annex to the PEFCR information about all the steps taken to define the 'model' of the RP(s) and report the information gathered]. The PEF study of the representative product(s) (PEF-RP) is available upon request to the TS coordinator who has the responsibility of distributing it with an adequate disclaimer about its limitations.

To be further developed:

As there is no sufficient market and technical information available yet, this document is not able to present representative products for many different BBFs that are not in the market yet. However, we can present different product categories manufactured using currently available technologies that might be useful for further analyses on "representative product:

- Granular, pelletized, and powdered forms
- Ash
- Struvite
- Mineral concentrates
- Biochar
- Digestate
- Compost
- Other biomass products.

In addition, D1.1. report described the raw material inputs within the EU by country and these raw materials, as such, may also function as BBF. However**, BBF materials that are produced on (or**

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under the control of) the farm e.g. manure and digestate as such in farm context, without market price, and applied directly on the farm's field, do not necessarily formally belong to the scope of this PEF-wise PCR method. This PEF-wise PCR method of BBF focuses mainly on compound BBF produced in a manufacturing plant designed specifically for BBF production that farmers buy as an external fertilizer.

Most likely the BBFs are so diverse, that it is no way possible to give a clear representative product for BBF.

Here, we see that the insights for representative products are coming from multiple participatory processes during NOVAFERT project.

3.3. Functional unit

Functional unit – defines the qualitative and quantitative aspects of the function(s) and/or service(s) provided by the product being evaluated. The functional unit definition answers the questions 'what?', 'how much?', 'how well?', and 'for how long?'.

According to PEF, the functional unit (FU) is the quantified performance of a product system, to be used as a reference unit. The functional unit qualitatively and quantitatively describes the function(s) and duration of the product in scope. The reference flow is the amount of products needed to provide the defined function. All other input and output flows in the analysis quantitatively relate to it. The reference flow may be expressed in direct relation to the FU in a product-oriented way. Users of the PEF method shall define the FU and the reference flow for the PEF study. They shall also describe which aspects of the product are not covered by the FU and justify why (e.g. because they are not quantifiable or intrinsically subjective).

Fertilizers and BBF products are intermediate products as they are products used to produce a final good or finished product (e.g. a food product). According to PEF, for intermediate products, the FU is more difficult to define because they can often fulfil multiple functions and the whole life cycle of the product is not known. Therefore, **a declared unit (DU)** (equal to **reference flow**) is applied instead, for example, mass (kilogram) or volume (cubic meter). For BBFs, the suggested reference flow is **1 kilogram of fertilizer product** to agricultural application on the field delivered to the farmer. All quantitative input and output data collected in the study shall be calculated about this reference flow.

However, as stated in D2.1. a significant portion of the BBFs on the European market differ both physically and chemically, and the applications are diverse. Presenting emissions per 1 kilogram of fertilizer product is not appropriate if all fertilizers do not contain the most important nutrients in question in the same proportions. **Presenting emissions per 1 kilogram as FU is acknowledged to be limited to the final aim of PEF which is the comparability of fertilizer products and the creation of environmental standards for guiding the decision-making.** BBF production technologies and the nutrient contents of the products do not directly compare to each other (e.g. a significant portion of fertilizers are to some extent NPK fertilizers, some are a source of nitrogen, and some provide other nutrients).

It should be important to define the FU based on nutrient content and application parameters, specifying the reference flow, considering the time frame, and aligning units with industry

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standards. According to D2.1. applying previous PEFCR guidelines for different products gives insights into BBFs (e.g. PEFCR or feed as intermediate product):

Therefore, when justified by the study objectives and the fertilizer product's functionality to enable comparability, additional more specific FUs can be selected. We recommend here to apply the most common functional units used in the research literature according to Deliverable 2.1 report:

- per mass of nutrient e.g. per kg N, per kg P, per kg K per (most used alternative);
- per mass of feedstock input (second most used alternative);
- per mass of product (the third most used alternative)
- per capita load of feedstock input;
- per hectare of application;
- per size of application facility, and volume of product (Egas et al. 2023).

For example, if a BBF is utilized for its nitrogen content on the field, emissions per kilo of a BBF can be allocated more precisely to the amount of nitrogen and presented as emissions per kilo of nitrogen (e.g. kgCO_2eq per kg N). Emissions from "cradle to gate" per kilo of product are therefore divided by the ratio of nitrogen content, e.g. climate impact of 0,1 kg CO_2 eq/kg of BBF (with 5% N-content) have emissions of 2 kg CO_2eq/kg of nitrogen. In addition, in the case of NPK fertilizers, the emissions are targeted and presented for all nutrient (N, P, K) masses separately but next to each other. These complementary FUs (per nutrient mass and hectare) are taking the emission (Cradle-to-Grave) of BBF reflecting in more depth the functionality of the fertilizer product during its application stage and use on the field.

To be further developed:

Here, it should be also noted, that there are differences between nutrient content and quality in synthetic mineral fertilizers versus BBFs. BBFs usually consist of many different nutrients (N, P, K etc.). In addition, nitrogen in BBFs contains both soluble and nonsoluble nitrogen in contradiction to mineral fertilizers containing mostly only soluble nitrogen. Therefore, for example, in the case of nitrogen, it should be considered to use the soluble nitrogen amount for functional unit instead of the total N amount as only soluble nitrogen is usable for plants on the field. For example, **if a BBF is utilized for its soluble nitrogen content on the field, emissions per kilo of a product can be allocated more precisely to the amount of soluble nitrogen and presented as emissions per kilo of soluble nitrogen (kg $N_{(sol)}$).** Emissions from "cradle to gate" per kilo of the product are therefore divided by the ratio of soluble nitrogen content, e.g. climate impact of 0,1 kg CO_2 eq/kg of bio-based fertilizer (with 5% soluble N-content) have emissions of 2 kg CO_2eq/kg of soluble nitrogen.

As for BBFs can often fulfil multiple functions and the whole life cycle of the product is not known the FU is more difficult to define. There is a need to further develop common FU e.g. investigate wether it possible to develop common FU for all BBF's reflecting the final function of the product e.g. growth of the plant that is cultivated and utilizing BBFs, volume of yield.

Here, we see that more defined insights are coming from participatory processes during the Novafert project (e.g. workshops, seminars) and the LCAs done in this project (Task 2.5) and we add them in the last version after the prototype learnings.

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3.4. System boundaries

The final aim of PEF is the comparability of fertilizer products and the creation of environmental standards for guiding decision-making. According to D2.1., scientific papers on BFF do not directly compare to each other as there can be found many ways to define the system boundaries of a product's life cycle. These include cradle-to-grave, cradle-to-gate, gate-to-gate, and gate-to-grave. The major part of the studies on BBFs use **a cradle-to-gate** system boundary (Egas et al. 2023) as in this PEF-wise PCR method, regardless of the feedstock, functional unit, or type of BFF produced.

The system boundaries shall include a *Cradle-to-Gate* perspective (as described in Figure 3) that includes the following life cycle stages and processes: i) feedstock (defined as co-product or main product with economic value (see more in allocation section 5.7.1.), acquisition and pre-processing (including production of parts and components, including packaging production); ii) the transportation and collections systems of the feedstock until the manufacturing place, including all the reverse logistics, intermediate storages and other processing steps such as concentration or pre-treatment that could be integrated. iii) manufacturing process (BBF processing at the manufacturing plant); and iv)) distribution (storage, loading and distribution) until the farm/retail.

The v)) use/application on the field, and vi) end of life (including packaging recovery or recycling) are not included in this PEF-wise PCR method (Figure 3). The modelling of these sections (v and vi) should be in the PEFCRs of agricultural products. Their integration in these PEFCRs is described in Section 2.

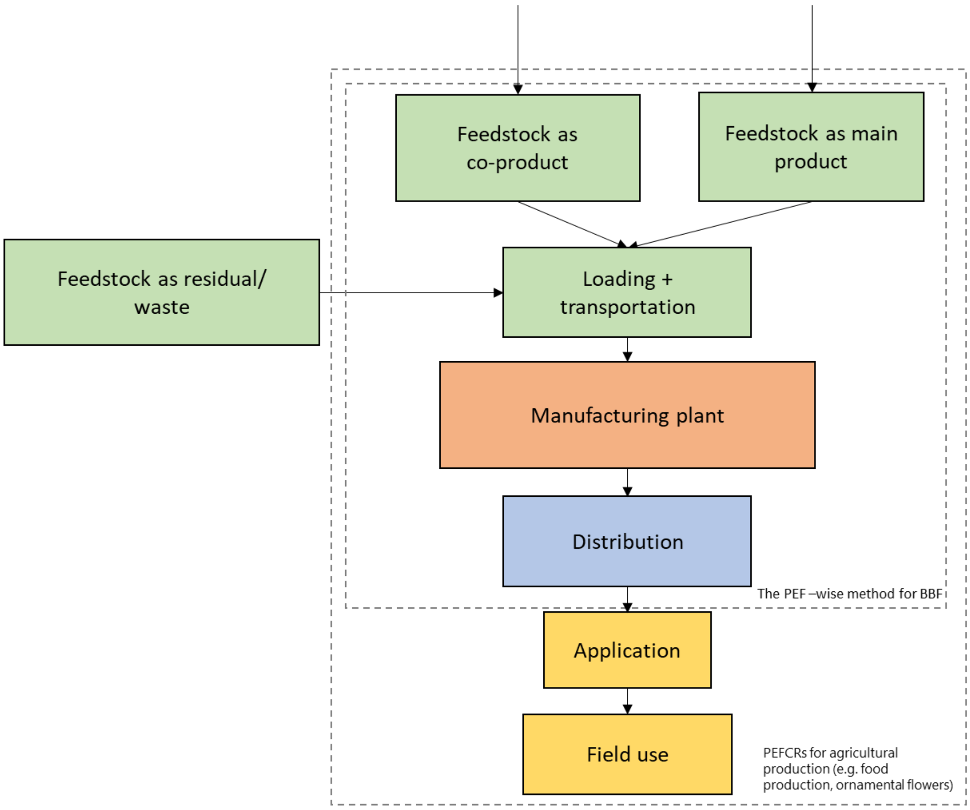

Figure 3.- System boundaries and Scope of the PEF-wise PCR method for BBFs.

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Table 2 describes the life cycle stages and the processes included: feedstock acquisition, processing of BBFs at manufacturing plant and distribution of BBFs to the farm.

Table 2: Life cycle stages to be included in the assessment.

Life cycle stage		**A short description of the areas included**
Feedstock/raw material acquisition	**Production of feedstock/raw-material**	Biomass production as feedstock (only if defined as co-product or main product with market value, see more in 5.7.1.), production of packaging materials and possible production of other components to be used as raw materials in manufacturing of the main BBF product at the manufacturing plant.
	Transport	The delivery of all of the BBF ingredients (feedstock and other components as raw materials) to the BBF production is part of the BBF life cycle. It can consist of a variable number of transportation steps (from in-situ treatments without transportation to a more complex reverse logistic system)
Manufacturing BBF at the manufacturing plant		Manufacturing BBF products at the manufacturing plant. The production stage begins when the product components from other production chains enter the main BBF production site (manufacturing plant) and ends when the finished product leaves the production facility. The manufacturing of BBFs is the main processing phase of a BBF product and is separate from other value chain processes. It may include several process steps (e.g. separation of biomass, composting of different biomass streams collected from other value chains, granulation of biomass, and adding different components (AMS, urea etc.).
Distribution of fertilizers to the farm		Distribution of fertilizers to retail or farms also belongs to the scope of this PEFCR. Delivery is mostly done by trucks.

The following processes are excluded:

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Capital goods (including infrastructure) and their EoL should be excluded, unless there is evidence from previous studies that they are relevant.

If bio-based feedstock does not have an economic value at the farm/factory gate, it is regarded as residual or waste without the emissions related to residual or waste management up to the farm/factory gate, in other words, limited outside the system boundary (see more in 5.7. allocation rules).

Any cut-off shall be avoided, unless under the following rules:

Processes and elementary flows may be excluded up to 3.0% (cumulatively) based on material and energy flows and the level of environmental significance (single overall score). The processes subject to a cut-off shall be made explicit and justified in the PEF report, in particular concerning the environmental significance of the cut-off applied.

This cut-off has to be considered in addition to the cut-off already included in the background datasets. This rule is valid for both intermediate and final products.

The processes that (cumulatively) account for less than 3.0% of the material and energy flow, as well as the environmental impact for each impact category may be excluded from the LCA study.

A screening study (see more in chapter 4) is recommended to identify processes that may be cut off.

To be further developed:

The final aim of PEF is the comparability of fertilizer products and the creation of environmental standards for guiding decision-making. Scientific papers on BFF do not directly compare to each other as there can be found many ways to define the system boundaries of a product's life cycle. These include **cradle-to-grave, cradle-to-gate, gate-to-gate, and gate-to-grave**. The major part of the studies on BBFs use **a cradle-to-gate** system boundary (Egas et al. 2023) as in this PEF-wise PCR method, regardless of the feedstock, functional unit, or type of BFF produced. This is because the utilization phase of BBF on field is difficult to define, as the fertilizer can be used in different ways. I do not understand this last sentence

As this PEF-wise PCR method for BBFs (as an intermediate product) does not take into consideration and give guidance on how to account for emissions during the BBF's use on the field, many environmental benefits may not yet emerge in favour of BBFs. These emerge only when considering agricultural fertilizer emissions calculation by other PEFCRs for agricultural products including the cultivation phase, which this document gives guidance in section 2.

Therefore, it is proposed herein the PEF-wise PCR method (section 1) to include the application stage as **"an additional technical information" (see section 3.6.)** to give insight into BBF's benefits due to major differences e.g. in the nutrient content of the BFFs and their fertilization efficiency happening during application stage on the field. However, this reporting is only added information next to assessment results and not in the internalized with the final environmental burden calculations as the application stage shall be included finally in other agricultural products' PEFCRs (section 2).

In addition, we recommend **the functional unit should be based on nutrient content and application parameters**, specifying the GU based on reference flow justified by the fertilizer product's functionality on fiel.

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3.5. List of EF impact categories

Table 3: List of EF impact categories (EC 2021).

EF Impact category	Impact category Indicator	Unit	Characterization model	Robust-
Climate change, total	Global warming potential (GWP100)	kg CO_2 eq	Bern model - Global Warming Potentials (GWP) over a 100-year time horizon (based on IPCC 2013)	I
Ozone depletion	Ozone Depletion Potential (ODP)	kg CFC-11 eq	EDIP model based on the ODPs of the World Meteorological Organisation (WMO) over an infinite time horizon (WMO 2014 + integrations)	I
Human toxicity, cancer	Comparative Toxic Unit for humans (CTUh)	CTUh	based on the USEtox2.1 model (Fantke et al. 2017), adapted as in Saouter et al., 2018	III
Human toxicity, non-cancer	Comparative Toxic Unit for humans (CTUh)	CTUh	based on the USEtox2.1 model (Fantke et al. 2017), adapted as in Saouter et al., 2018	III
Particulate matter	Impact on human health	disease incidence	PM model (Fantke et al., 2016 in UNEP 2016)	I
Ionising radiation, human health	Human exposure efficiency relative to U235	kBq U235 eq	Human health effect model as developed by Dreicer et al. 1995 (Frischknecht et al, 2000)	II
Photochemical ozone formation, human health	Tropospheric ozone concentration increase	kg NMVOC eq	LOTOS-EUROS model (Van Zelm et al, 2008) as applied in ReCiPe 2008	II
Acidification	Accumulated Exceedance (AE)	mol H^+ eq	Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)	II
Eutrophication, terrestrial	Accumulated Exceedance (AE)	mol N eq	Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)	II
Eutrophication, freshwater	Fraction of nutrients reaching freshwater end compartment (P)	kg P eq	EUTREND model (Struijs et al, 2009) as applied in ReCiPe	II
Eutrophication, marine	Fraction of nutrients reaching marine end compartment (N)	kg N eq	EUTREND model (Struijs et al, 2009) as applied in ReCiPe	II
Ecotoxicity, freshwater	Comparative Toxic Unit for ecosystems (CTUe)	CTUe	based on the USEtox2.1 model (Fantke et al. 2017), adapted as in Saouter et al., 2018	III

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Land use	Soil quality index	Dimensionless (pt)	Soil quality index based on the LANCA model (De Laurentiis et al. 2019) and the LANCA CF version 2.5 (Horn and Maier, 2018)	III
Water use	User deprivation potential (deprivation-weighted water consumption)	m3 water eq of deprived water	Available WAter REmaining (AWARE) model (Boulay et al., 2018; UNEP 2016)	III
Resource use, minerals and metals	Abiotic resource depletion (ADP ultimate reserves)	kg Sb eq	van Oers et al., 2002 as in CML 2002 method, v.4.8	III
Resource use, fossils	Abiotic resource depletion – fossil fuels (ADP-fossil)	MJ	van Oers et al., 2002 as in CML 2002 method, v.4.8	III

Additional technical information

To complement the BBF's environmental information (Cradle-to-Gate) and ensure the right interpretation of the results and the comparability among PEF studies, the following technical information shall be included as mandatory or non-mandatory **(*)** information **reported as additional information next to the environmental burdens**:

Product description:

- Physical state (liquid, solid, pellets, granular….)
- Physical description (colour, odour, …)
- Application method (Fertirrigation, spreading…)
- Apparent density (Kg·m^{-3})

Nutritional content:

- Organic matter content (% organic C)
    - (% inorganic C)*
- Nitrogen content (% total N) (%mineral total, %org)
    - NO_3+NH_4 g/kg of specific forms*
- Phosphorous content (% P)
- Potash content (%K)
- Content of heavy metals (Cu, Zn, Cr, Mg, Fe). Mandatory substances can be found in international and national regulations
- Content of other micro-nutrients (Mg, Fe, Ca)*

Other substances of interest defined by national regulations:

- Content of non-metal xenobiotics*
    - Antibiotics and other pharmaceuticals,
    - Micro(nano)plastics
    - Others (Pesticides, antibiotics phthalates, dioxins, PCBs, PFAS, PAHs,)*
    - Existence of biostimulant substances*
    - Existence of microorganisms/or pathogens*

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3.5.1. Biogenic carbon content

The biogenic carbon content **at the factory gate** (physical content) shall be reported. If derived from a native forest (e.g. wood chips), it shall report that the corresponding carbon emissions shall be modelled with the elementary flow '(land use change)'.

As stated in D2.1., considering emissions from biogenic carbon (**during Cradle-to-Gate of BBFs),** according to The PEF Guide (EC 2021, ISO/DIS 14067 (2012), and the ILCD Handbook 2010) align in stipulating that removals and emissions shall be reported separately for both fossil and biogenic sources.

More specifically on how to assess biogenic carbon environmental burdens/emissions, according to EF3.1. Biogenic CO_2 has a characterization factor of 0 due to short rotation time. PEF guides to take into account biogenic emissions and therefore only biogenic carbon in methane (CH_4) with characterization factor 27 (see section 3.7.).

How to assess removals (carbons sequestration and storage) during Cradle to Gate, The PEF guide (EC2021) indicates that credits from 'temporary carbon storage' are excluded and biogenic carbon emitted later than 100 years after its uptake is considered as permanent carbon storage. Removals as carbon storage on the field, this section 1 presents only agricultural production from the perspective of cultivating raw materials (e.g. agricultural biowaste).

Section 2 presents a carbon storage assessment by utilizing BBFs in agriculture (as modifications of other PEFCRs (food production, ornamental flowers).

3.6. Additional environmental information

Climate impact

The latest characterization factors of IPCC (2013) shall be used, the latest are presented in Table 4:

Table 4: Characterization factors of climate impact EF 3.1

Component	Factor
CO_2, fossil	1
CO_2, biogenic *	0
CO_2, land transformation	1
N_2O	273
CH_4 biogenic *	27
CH_4 fossil	29.8

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CH_4 land transformation	29.8

*According to EF3.1. Biogenic CO_2 has a characterization factor of 0 due to short rotation time. PEF guides to take into account biogenic emissions and therefore only biogenic methane with characterization factor 27.

Biodiversity

The current PEF method includes no impact category named "**biodiversity**" as these are mostly assumed to arise during the application phase and therefore not considered relevant for this PEF-wise PCR method "cradle to gate" scope and only through other agricultural products' PEFCRs. However, at least 6 impact categories have an effect on biodiversity (i.e., climate change, eutrophication of aquatic freshwater, eutrophication of aquatic marine, acidification, water use, land use) and carbon sequestration. Biodiversity impacts are mostly assumed to arise during the application phase and therefore not considered relevant for this PEF-wise PCR method but in other food production, PEFCRs assessing agriculture impacts.

4. Most relevant impact categories, life cycle stages and processes

According to PEF, the identification of most relevant impact categories, life cycle stages, processes, direct elementary flows, benchmark, and classes of performance shall be based on **the screening study.**

The identification of the most relevant impact categories shall be based on the normalised and weighted results of **the representative product(s**) as recalculated after the remodelling. At least three relevant impact categories shall be considered. The most relevant impact categories shall be identified as all impact categories that cumulatively contribute **to at least 80% of the total environmental impact** (excluding toxicity related impact categories). This is to be done in cooperation with Technical Secretariat and based on the final results of the PEF studies of the representative product(s).

Screening step (Annex I 4.1):

An initial screening of the LCI – the 'screening step' – shall be performed because it helps focus data collection activities and data quality priorities. A screening step shall include the LCIA phase and result in further, iterative refinements to the life cycle model for the product in scope, as more information becomes available. Within a screening step, no cut-off is allowed and readily available primary or secondary data may be used, fulfilling the data quality requirements to the extent possible (as defined in section 4.6). Once the screening is performed, the initial scope settings may be refined.

Screening study (ongoing):

With a screening study, the relevant life cycle stages, processes and material flows are to be identified for the product under investigation. As a result, from the screening study focus points can be identified. Also, data requirements are formed based on these relevant processes. Higher quality data (namely primary data) should be collected from more relevant processes,

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which contribute to the environmental impact the most, in comparison to less important processes. Independent of the life cycle stage, all stages and processes should be estimated.

Screening study is performed with less accuracy (secondary data, expert opinion etc.), yet for the whole life cycle and relevant processes associated with the assessed impact category. Inventory processes can be modelled with available database processes such as Ecoinvent, Agrifootprint, etc. Secondary data, literature and expert opinions can be utilized in determining the quantities and details for the inventory.

From the screening study, for each assessed impact category, one must identify 1) company-specific processes with significant impact, 2) non-company-specific processes with significant impact and 3) remaining processes within the system boundary with less importance. Company-specific and other process data with significant impact.

As the screening step is conducted with less accurate data, this might have an impact on the contributions of different processes and life cycle stages. After the initial screening step, iterative screening steps might be needed to refocus when more knowledge of the supply chain is available.

The perspective of the product-producing company is important as the mandatory data for the company's production chain must be collected from those processes associated with products that are managed by the company and have a significant impact (mandatory company-specific data). These processes need to be described separately for each product, as products and production chains vary.

Yet, when products of agricultural origin are considered, major contributions to environmental impacts originate in primary production, which is often not managed by the company responsible for the product of interest.

When these processes contribute significantly to 80% of the assessed impact category’s result, it is mandatory to collect primary data from these processes.

All primary data must fulfil the data quality requirements set specifically for primary datasets.

Table 5: Summary of requirements to define most relevant contributions

Item	At what level does relevance need to be identified?	Threshold
Most relevant impact categories	Single overall score	Impact categories cumulatively contributing at least **80%** of the single overall score
Most relevant life cycle stages	For each most relevant impact category	All life cycle stages contributing cumulatively more than **80%** to that impact category.

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		If the use stage accounts for more than 50% of the total impact of a most relevant impact category, the procedure shall be re-run with the exclusion of the use stage
Most relevant processes	For each most relevant impact category	All processes contributing cumulatively (along the entire life cycle) more than **80%** to that impact category, considering absolute values.
Most relevant elementary flows	For each most relevant process considering the most relevant impact categories	All elementary flows contributing cumulatively to at least 80% of the total impact of a most relevant impact category for each most relevant process. If disaggregated data are available: for each most relevant process, all direct elementary flows contributing cumulatively at least **80%** to that impact category (caused by the direct elementary flows only)

To be further developed:

In The PEF method, the insights into the most relevant impact categories, life cycle stages and processes come from the LCA of the representative product. However, this PEF-wise PCR method lacks the involvement of TS and the representative product is not defined yet in the first draft of the PEF-wise PCR method for BBFs.

Most likely the BBFs are so diverse, that it is in no way possible to give a clear list, but all relevant impact categories, life cycle stages and processes are to be defined by the user of this PCR by conducting the screening on its' BBF product.

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Therefore, we suggest the user of this PEF-wise PCR method shall assess "a light version" of the product and its most relevant impact categories, life cycle stages and process to get a general perspective for the assessment.

Here, we see that the insights are coming from the LCAs done in this project (Task 2.5) and we add them in the last version after the prototype learnings.

4.1. Life cycle inventory (LCI)

4.1.1. List of mandatory company-specific data

In this PEF-wise PCR method, we propose that there should be few data-points (listed by TS) for which **it is mandatory to use company-specific data (e.g., primary data).** These data points are:

- The list of fertilizer ingredients and their volumes
- The nutritional analysis of the fertilizers (hereafter referred to as nutritional analysis data)
- Energy consumption in fertilizer manufacturing operations
- Outbound transport to cultivation site (distribution)

List of fertilizer raw-materials:

- The list of fertilizer ingredients entails the following data:
  - Types and quantities of fertilizer materials
  - Types and quantities of fertilizer additives
  - Type and quantities of pre-mixtures
- Nutrient analyses data:
  - Organic matter content (% organic C)
  - Nitrogen content (% total and soluble N)
  - Phosphorous content (% P)
  - Potassium content (% K)

4.1.2. Allocation rules

Allocations shall be conducted according to the table 6 below:

Table 6: Allocation rules and instructions identified for main processes during life cycle of BBFs.

Process	Allocation rule	Modelling instructions
Allocation of raw material/feedstock processes	Economical	Economic allocation refers to allocating inputs and outputs associated with multi-functional processes to the co-product outputs in proportion to their relative market values. The market price of the co-functions should refer to

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		the specific condition and point at which the co-products are produced.
Processing of fertilizer ingredients	Economical	Economic allocation refers to allocating inputs and outputs associated with multi-functional processes to the co-product outputs in proportion to their relative market values. The market price of the co-functions should refer to the specific condition and point at which the co-products are produced.
Transport	Physical	Allocation based on a relevant underlying physical relationship refers to partitioning the input and output flows of a multi-functional process or facility in line with a relevant, quantifiable physical relationship between the process inputs and co-product outputs (for example, a physical property of the inputs and outputs that is relevant to the function provided by the co-product of interest).
BBF processing operations at the manufacturing plant	Economical	Economic allocation refers to allocating inputs and outputs associated with multi-functional processes to the co-product outputs in proportion to their relative market values. The market price of the co-functions should refer to the specific condition and point at which the co-products are produced.

4.1.3. Criteria for the definition of the status of the nutrient's sources: waste, residual or co-product

The multiple different feedstocks used in BBF manufacturing, and their by-products are separate products with different purposes and physicochemical characteristics. The environmental burdens related to feedstock production and management up to the gate before the biomass feedstock enters the processing phase (manufacturing plant) shall be allocated by using the relative economic value (market price) of feedstock. Economic allocation is commonly used when co-products have very different physical relationships or end use in the market. This is the case also with the production of BBFs.

Economic allocation refers to allocating inputs and outputs associated with multi-functional processes to the co-product outputs in proportion to their relative market values.

In this PEF-wise PCR method for BBFs, The PEF guide (EC 2021) allocation guidance related to classification of manure relative to their market value is applied in for all biomass flows as feedstock and raw materials for BBF processing. The PEF guide (EC 2021) gives further guidance related to the allocation of manure under chapter *4.5.1 "Allocation in animal husbandry: Manure exported to another farm shall be considered as one of the following:*

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- ***Residual (default option):*** *if manure does not have an economic value at the farm gate, it is regarded as residual without allocation of an upstream burden. The emissions related to manure management up to the farm gate are allocated to the other farm outputs where manure is produced.*
- ***Co-product:*** *when exported manure has an economic value at the farm gate, an economic allocation of the upstream burden shall be used for manure by using the relative economic value of manure compared to milk and live animals at the farm gate. However, biophysical allocation based on International Dairy Federtion (IDF) rules shall be applied to allocate the remaining emissions between milk and live animals.*
- ***Manure as waste:*** *when manure is treated as waste (e.g. landfilled[1]), the circular footprint formula shall be applied. "*

Adapting the abovementioned chapter on manure to be applicable to nutrient biomass feedstocks exported to another farm, the *biomass feedstocks exported to another farm shall be considered as one of the following*:

- **Co-product:** If biomass has an economic value (market price), it is considered as a product or co-product. The biomass feedstock will enter the foreground system (manufacturing plant) with environmental burdens assigned by its system of origin thus, the user of these flows will account for a share of the feedstock production environmental burdens. For example, if manure has an economic value at the farm gate, it is regarded as co-product and burdens allocation of the upstream burden shall be used for manure by using the relative economic value of manure compared to milk and live animals at the farm gate (EC 2021).

- **Residual:** If biomass feedstock is utilized, exported to further biofertilizer processing (manufacturing plant), does not have an economic value (market price) but has a use value (e.g. fertilization value), it is regarded as a residual with zero emissions allocation of an upstream burden. For example, as a default, the emissions related to manure management up to the farm gate are allocated to the other farm outputs (e.g. meat, milk) where manure is produced and digestate for bioenergy production.

- **Waste:** If biomass feedstock has no economic value (no market price) and is treated as waste (e.g. landfilled[1]) the Circular Footprint Formula (CFF) shall be applied. If biomass feedstock is not utilized, does not have an economic value (market price) or either use value (e.g. fertilization value) but is treated as waste (e.g. landfilled[1]), in that case the CFF is to be applied (manure as waste). According to CFF, environmental burdens and possible credits are shared between the producer and the user of the reusable/recyclable waste flow through its "A" factor.

  The PEF gives specific guidance on CFF use for compost, digestate, sewage sludge and ash when considered as "waste" materials:

[1] Manure treated as waste and landfilled is illegal in EU

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Compost and anaerobic digestion/ sewage treatment: **Compost**, including **digestate** coming out of the anaerobic digestion, shall be treated in the 'material' part of CFF like recycling with A = 0.5. The energy part of **the anaerobic digestion** (e.g. biogas production) shall be treated as a normal process of energy recovery under the 'energy' part of CFF, with "B" factor 0.

Recovery bottom **ashes/slag** from incineration: Recovery of bottom ashes/slag shall be included in the R2 value (recycling output rate) of the original product/material. Their treatment is within the ErecEoL.

To be developed further:

This section aims to discuss the criteria where the nutrient source should be considered waste, residual or co-product and how emissions are allocated between these products based on the status of the source. The main criterion to define this is the market price of the material. If there is a market price, then is a co-product. On the contrary, if the market price is zero or below, then is a waste. It could be possible to find situations of the same technology where both options coexist. Nutrient source quality (e.g. nutrient content, impurities, water content) is the main factor that defines further profitability and transformation costs. Nonetheless, it must be remarked that this status can change with time a varies depending on the N and P market prices situation.

The use of CFF is recommended by The PEF (EC 2021) in case of manure (when it is defined as waste, e.g. landfilled), and also at least for compost and anaerobic digestion/ sewage treatment. However, the CFF model, it is to be updated during becoming years and until then it is recommended to assess according to economic allocation. In other words, to treat biomass feedstocks as "residual" rather than "waste" with CFF method. In addition, as stated in D2.1., CFF has received some critique: Pedersen & Remmen (2022) scrutinize the CFF and in their systematic review, they highlight challenges, including the formula's failure to account for the number of material reuse cycles, inadequate default data for recycled material quality, and a departure from ISO 14044.

In addition, due to the precautionary principle, there is a risk for underestimating the emissions of biofertilizers by using credits. According to the EPD (2021) if biomass feedstock is considered waste that could be recycled/reused neither the producer nor user of the waste as secondary material/fuel is allowed to account for credits from system expansion in the international EPD system. This modelling approach is to "make information traceable, documented, and possible to verify, and to support the concept of modularity" as stated in the General Program Instructions for the International EPD system (EPD 2021).

4.1.4. Carbon flows and Climate change modelling

The impact category 'climate change' shall be modelled considering three sub-categories:

1. **Climate change – fossil:** This sub-category includes emissions from peat and calcination/carbonation of limestone. The emission flows ending with '(fossil)' (e.g., 'carbon dioxide (fossil)' and 'methane (fossil)') shall be used, if available.

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2. **Climate change – biogenic:** This sub-category covers carbon emissions to air (CO_2, CO and CH_4) originating from the oxidation and/or reduction of biomass by means of its transformation or degradation (e.g. combustion, digestion, composting, landfilling) and CO_2 uptake from the atmosphere through photosynthesis during biomass growth – i.e. corresponding to the carbon content of products, biofuels or aboveground plant residues, such as litter and dead wood. Carbon exchanges from native forests shall be modelled under sub-category 3 (incl. connected soil emissions, derived products, residues). The emission flows ending with '(biogenic)' shall be used. [Choose the right statement] For some countries, this option is a best case rather than a worst case. 135 Native forests – represents native or long-term, non-degraded forests. Definition adapted from Table 8 in the Annex of Commission Decision C (2010)3751 on guidelines for the calculation of land carbon stocks for the purpose of Annex V of Directive 2009/28/EC. A simplified modelling approach shall be used when modelling foreground emissions. [OR] A simplified modelling approach shall not be used when modelling foreground emissions. [If a simplified modelling approach is used, include in the text: 'Only the emission 'methane (biogenic)' is modelled, while no further biogenic emissions and uptakes from atmosphere are included. If methane emissions can be both fossil or biogenic, the release of biogenic methane shall be modelled first and then the remaining fossil methane.'] [If no simplified modelling is used, include the text: 'All biogenic carbon emissions and removals shall be modelled separately.'] [For intermediate products only:] The biogenic carbon content at factory gate (physical content and allocated content) shall be reported as 'additional technical information'.
3. **Climate change – land use and land use change:** This sub-category accounts for carbon uptakes and emissions (CO_2, CO and CH_4) originating from carbon stock changes caused by land use change and land use. This sub-category includes biogenic carbon exchanges from deforestation, road construction or other soil activities (including soil carbon emissions). For native forests, all related CO_2 emissions are included and modelled under this sub-category (including connected soil emissions, products derived from native forest136 and residues), while their CO_2 uptake is excluded. The emission flows ending with '(land use change)' shall be used.

   For land use change, all carbon emissions and removals shall be modelled following the modelling guidelines of PAS 2050:2011 (BSI 2011) and the supplementary document PAS2050-1:2012 (BSI 2012) for horticultural products. PAS 2050:2011 (BSI 2011): 'Large emissions of GHGs can result as a consequence of land use change. Removals as a direct result of land use change (and not as a result of long-term management practices) do not usually occur, although it is recognized that this could happen in specific circumstances. Examples of direct land use change are the conversion of land used for growing crops to industrial use or conversion from forestland to cropland. All forms of land use change that result in emissions or removals are to be included. Indirect land use change refers to such conversions of land use because of changes in land use elsewhere. While GHG emissions also arise from indirect land use change, the methods and data requirements for calculating these emissions are not fully developed. Therefore, the assessment of emissions arising from indirect land use change is not included.

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The GHG emissions and removals arising from direct land use change shall be assessed for any input to the life cycle of a product originating from that land and shall be included in the assessment of GHG emissions. The emissions arising from the product shall be assessed based on the default land use change values provided in PAS 2050:2011 Annex C, unless better data is available. For countries and land use changes not included in this annex, the emissions arising from the product shall be assessed using the included GHG emissions and removals occurring as a result of direct land use change in accordance with the relevant sections of the IPCC (2006). The assessment of the impact of land use change shall include all direct land use change occurring not more than 20 years, or a single harvest period, prior to undertaking the assessment (whichever is the longer). The total GHG emissions and removals arising from direct land use change over the period shall be included in the quantification of GHG emissions of products arising from this land on the basis of equal allocation to each year of the period.

1. Where it can be demonstrated that the land use change occurred more than 20 years prior to the assessment being carried out, no emissions from land use change should be included in the assessment.
2. Where the timing of land use change cannot be demonstrated to be more than 20 years, or a single harvest period, prior to making the assessment (whichever is the longer), it shall be assumed that the land use change occurred on 1 January of either: the earliest year in which it can be demonstrated that the land use change had occurred; or Following the instantaneous oxidation approach in IPCC 2013 (Section 2). In case of variability of production over the years, a mass allocation should be applied. 169 on 1 January of the year in which the assessment of GHG emissions and removals is being carried out.

The following hierarchy shall apply when determining the GHG emissions and removals arising from land use change occurring not more than 20 years or a single harvest period, prior to making the assessment (whichever is the longer):

3. where the country of production is known and the previous land use is known, the GHG emissions and removals arising from land use change shall be those resulting from the change in land use from the previous land use to the current land use in that country (additional guidelines on the calculations can be found in PAS 2050-1:2012);
4. where the country of production is known, but the former land use is not known, the GHG emissions arising from land use change shall be the estimate of average emissions from the land use change for that crop in that country (additional guidelines on the calculations can be found in PAS 2050- 1:2012); 3. where neither the country of production nor the former land use is known, the GHG emissions arising from land use change shall be the weighted average of the average land use change emissions of that commodity in the countries in which it is grown. Knowledge of the prior land use can be demonstrated using a number of sources of information, such as satellite imagery and land survey

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data. Where records are not available, local knowledge of prior land use can be used. Countries in which a crop is grown can be determined from import statistics, and a cutoff threshold of not less than 90% of the weight of imports may be applied. Data sources, location and timing of land use change associated with inputs to products shall be reported.' [end of quote from PAS 2050:2011] [Choose the right statement] Soil carbon storage shall be modelled, calculated and reported as additional environmental information. [OR] Soil carbon storage shall not be modelled, calculated and reported as additional environmental information. [If it shall be modelled, the PEFCR shall specify which proof needs to be provided and include the modelling rules.] The sum of the three sub-categories shall be reported. [If climate change is selected as a relevant impact category, the PEFCR shall (i) always request to report the total climate change as the sum of the three sub-indicators, and (ii) for the sub-indicators 'Climate change – fossil', 'Climate change – biogenic' and 'Climate change - land use and land use change', request separate reporting for those contributing more than 5% each to the total score.] [Choose the right statement] The sub-category 'Climate change-biogenic' shall be reported separately.

[OR]

The sub-category 'Climate change-biogenic' shall not be reported separately. The sub-category 'Climate change-land use and land transformation' shall be reported separately. [OR] The sub-category 'Climate change-land use and land transformation' shall not be reported separately

4.2. Life cycle stages

4.2.1. Raw material acquisition and pre-processing (i.e. production of fertilizer ingredients)

4.2.1.1 Industrial production stage for feedstocks from industrial streams

The common processes taking place at this life cycle stage are:

- Production of animal-based fertilizer ingredients (blood and bones from slaughterhouse)
- Production of municipal biodegradable waste streams (food industry by-products e.g. bio-waste)
- Wastewater treatment (sewage sludge and compost as by-product)
- Energy production
    - Burning coal (ash as by-products)
    - Pyrolysis (biochar as by-product)
    - Biogas production/Anaerobic digestion (digestate as by-product)
- Processing of fertilizer ingredients as part of other value chain processes (e.g. nutrient recovery, mechanical separation)

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- Production of other types of fertilizer ingredients (AMS, urea,...)
- Production of packaging in case BBF is delivered in a bag (very limited number of situations)
- Inbound transport (to manufacturing plant manufacturing BBFs)

There are some **common feedstocks** in BBF production within the EU which are not directly from agriculture production system but goes through pre-processing stage as industrial production stage before entering the main BBF production stage at manufacturing plant. These potential common feedstocks according to D1.1. are:

- Biological by-products including
    - animal by-products (bones and blood from slaughterhouse)
- Municipal biodegradable waste streams
    - bio-waste
    - sewage sludge
- Digestate
- Compost

If raw material for BBF production has an economic value, it is considered as **a product** or **co-product**. The biomass feedstock will enter the foreground system (manufacturing plant) with environmental burdens assigned by its system of origin thus, the user of these flows will account for a share of the feedstock production environmental burdens.

Data collection

In many cases secondary data will be used, as the process (e.g. digestion at biogas plant, composting at wastewater treatment plant) at is not run or under the control of the company applying the PEF-wise PCR method for BBFs. However, when considered relevant and feasible, it is possible to model the production of fertilizer ingredients and to use primary data instead of secondary data.

Considering secondary data, IPCC (2006) is giving N_2O and CH_4 emission factors for composting and anaerobic digestion of waste (Table 7, For composting, the emission factors suggested by the IPCC is (4 kg Mg^{-1}) and for anaerobic digestion (0.8 kg Mg^{-1}) (IPCC, 2006, IPCC, 2006). However, there is need to measure emissions during these both processes since these are dependent upon many different technology and management alternatives.

Table 7: IPCC (2006) N_2O and CH_4 emission factors for composting and anaerobic digestion of waste

DEFAULT EMISSION FACTORS FOR CH4 AND N2O EMISSIONS FROM BIOLOGICAL TREATMENT OF WASTE			
Type of biological treatment	CH_4 Emission Factors (g CH_4/kg waste treated)	N_2O Emission Factors (g N_2O/kg waste treated)	Remarks

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	on a dry weight basis	on a wet weight basis	on a dry weight basis	on a wet weight basis	
Composting	10 (0.08 - 20)	4 (0.03 - 8)	0.6 (0.2 - 1.6)	0.24 (0.06 - 0.6)	Assumptions on the waste treated: 25-50% DOC in dry matter, 2% N in dry matter, moisture content 60%. The emission factors for dry waste are estimated from those for wet waste assuming a moisture content of 60% in wet waste.
Anaerobic digestion at biogas facilities	2 (0 - 20)	0.8 (0 - 8)	Assumed negligible	Assumed negligible	
Sources: Arnold, M.(2005) Personal communication; Beck-Friis (2002); Detzel et al. (2003); Petersen et al. 1998; Hellebrand 1998; Hogg, D. (2002); Vesterinen (1996). *Note: Default emission factors for CH_4 for anaerobic digestion already account for CH_4 recovery.*					

According to the PEF, packaging shall be modelled as part of the raw material acquisition stage of the life cycle. PEFCRs that include reusable packaging from third party operated pools shall provide default reuse rates. PEFCRs with company-owned packaging pools shall specify that the reuse rate shall be calculated using supply chain-specific data only. The two different modelling approaches as presented in Annex I shall be used and copied in the PEFCR. The PEFCR shall include the following: 'The raw material consumption of reusable packaging shall be calculated by dividing the actual weight of the packaging by the reuse rate.'

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According to the recommendation, "for the different ingredients transported from supplier to factory, the user of the PEFCR needs data on (i) transport mode, (ii) distance per transport mode, (iii) utilization ratios for truck transport and (iv) empty return modelling for truck transport. The PEFCR shall provide default data for these or request these data in the list of mandatory company-specific information. The default values provided in Annex I shall be applied unless PEFCR-specific data is available."

4.2.1.2 Agricultural production stage for feedstocks from agriculture

The processes in agricultural production taking place at this life cycle stage are:

- Cultivation of plant-based fertilizer ingredients (straw, green maize, grass, wastewater)
- Production of animal-based fertilizer ingredients (manure)
- Production of packaging in case BBF is delivered in bag (very limited number of situations)
- Inbound transport (to manufacturing plant of BBF product)

These processes are producing some **common feedstocks** as raw material in BBF production (at manufacturing plant) are directly from agricultural production (cultivation process or animal husbandry) before entering BBF production at manufacturing plant. These are:

- Biological by-products including
    - agricultural by-products (straw, green maize, grass, wastewater)
    - animal by-products (manure)
- Agricultural biodegradable waste streams (bio-waste, plant residues)

If raw material directly from agricultural production has an economic value, it is considered as **a product** or **co-product**. The biomass feedstock will enter the foreground system (manufacturing plant) with environmental burdens assigned by its system of origin thus, the user of these flows will account for a share of the feedstock production environmental burdens.

In many cases secondary data will be used, as the process is not run or under the control of the company applying the PEF wise PCR method for BBF's. However, when considered relevant and feasible, it is possible to model the production of fertilizer ingredients and to use primary data instead of secondary data. Replacing secondary data with primary data for fertilizer ingredients shall fulfil the requirements described below.

<u>Cultivation data collection</u>

The following activities regarding crop production shall be included:

1. Input of seed material (kg/ha)
2. Input of peat to soil (kg/ha + C/N ratio)
3. Input of organic fertilizer use (kg N/ha, kg P/ha, kg K/ha)
4. Input of mineral fertilizer use (kg N/ha, kg P/ha, kg K/ha)*
5. Input of lime (kg $CaCO_3$/ha, type)*
6. Field operations and machine use (hours, type)

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7. Input N from crop residues that stay on the field or are burned (kg residue + N content/ha)
8. Crop yield (kg/ha)
9. Drying and storage of products
10. Soil type (mineral soil % and organic soil %

* NOTE: BBF production raw materials can be cultivated by using different types of fertilizers (organic and inorganic) and inputs in the agriculture.

Cultivation data shall be collected over a period of time sufficient to provide an average assessment of the life cycle inventory associated with the inputs and outputs of cultivation that will offset fluctuations due to seasonal differences:

1) For annual crops, an assessment period of at least three years shall be used (to level out differences in crop yields related to fluctuations in growing conditions over the years such as climate, pests, and diseases, etc.). Where data covering a three-year period is not available i.e. due to starting up a new production system (e.g. new greenhouse, newly cleared land, shift to another crop), the assessment may be conducted over a shorter period, but shall be not less than 1 year. Crops/plants grown in greenhouses shall be considered as annual crops/plants unless the cultivation cycle is significantly shorter than a year and another crop is cultivated consecutively within that year. Tomatoes, peppers, and other crops which are cultivated and harvested over a longer period through the year are considered as annual crops.

2) For perennial plants (including entire plants and edible portions of perennial plants) a steady state situation (i.e. where all development stages are proportionally represented in the studied time period) shall be assumed and a three-year period shall be used to estimate the inputs and outputs .

3) Where the different stages in the cultivation cycle are known to be disproportional, a correction shall be made by adjusting the crop areas allocated to different development stages in proportion to the crop areas expected in a theoretical steady state. The application of such correction shall be justified and recorded. The life cycle inventory of perennial plants and crops shall not be undertaken until the production system actually yields output.

4) For crops that are grown and harvested in less than one year (e.g. lettuce produced in 2 to 4 months) data shall be gathered in relation to the specific time period for production of a single crop, from at least three recent consecutive cycles. Averaging over three years may best be done by first gathering annual data and calculating the life cycle inventory per year and then determining the three years average.

Fertiliser (and manure) emissions shall be differentiated per fertilizer type and cover as a minimum. These are the fertilizer emissions emerging from cultivation of feedstock and not necessarily BBF's):

1) NH_3 and NO_X, to air (from N-fertiliser application)

2) N_2O, to air (direct and indirect) (from N-fertiliser application)

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3) CO_2, to air (from lime, urea, and urea-compounds application)

4) NO_3, to water unspecified (leaching from N-fertiliser application)

5) PO_4, to water unspecified or freshwater (leaching and run-off of soluble phosphate from P-fertiliser application)

6) P, to water unspecified or freshwater (soil particles containing phosphorous, from P-fertiliser application).

Table 8: Parameters to be used when modelling nitrogen emission in soil

Emission	Compartment	Value to be applied
N_2O (synthetic fertiliser and manure; direct and indirect; soil)	Soil	*0.022 kg N_2O/ kg N fertilizer applied* *NOTE: this emission factor is combining both organic and inorganic fertilizer impact
NH_3 (synthetic fertiliser)	Soil	kg NH_3= kg N * FracGASF= 1*0.1* (17/14)= 0.12 kg NH_3/ kg N fertilizer applied
NH_3 (manure)	Soil	kg NH_3= kg N*FracGASF= 1*0.2* (17/14)= 0.24 kg NH_3/ kg N manure applied
NO_3^- (synthetic fertiliser and manure)	Soil	kg NO_3-= kg N*FracLEACH = 1*0.3*(62/14) = 1.33 kg NO_3^-/ kg N applied
P based fertilisers	Soil	0.1 kg P/ kg P applied

FracGASF: fraction of synthetic fertiliser N applied to soils that volatilises as NH_3 and NO_X. FracLEACH: fraction of synthetic fertiliser and manure lost to leaching and runoff as NO_3^-.

According to PEF, the PEFCR shall list all technical requirements and assumptions to be applied by the user of the PEFCR.

According to the PEF, packaging shall be modelled as part of the raw material acquisition stage of the life cycle. PEFCRs that include reusable packaging from third party operated pools shall provide default reuse rates. PEFCRs with company-owned packaging pools shall specify that the reuse rate shall be calculated using supply chain-specific data only. The two different modelling approaches as presented in Annex I shall be used and copied in the PEFCR. The PEFCR shall include the following: 'The raw material consumption of reusable packaging shall be calculated by dividing the actual weight of the packaging by the reuse rate.'

According to the recommendation, "for the different ingredients transported from supplier to factory, the user of the PEFCR needs data on (i) transport mode, (ii) distance per transport mode, (iii) utilisation ratios for truck transport and (iv) empty return modelling for truck transport. The PEFCR shall provide default data for these or request these data in the list of

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mandatory company-specific information. The default values provided in Annex I shall be applied unless PEFCR-specific data is available."

4.2.1.3 Agricultural production stage for feedstocks from animal production

If manure has an economic value at the farm gate, it is regarded as co-product and an emission allocation of the upstream burden shall be used for manure by using the relative economic value of manure compared to milk and live animals at the farm gate (see more in Allocation section 5.7.1., EC 2021).

If the calculator does not have access to primary data, PEF studies shall use secondary datasets that are EF compliant for manure emissions (at farm gate before entering slaughterhouse).

4.2.2. Manufacturing of bio-based fertilisers at manufacturing plant

The phase focuses on compound BBFs produced in a manufacturing plant designed specifically for BBF production that farmers buy as an external fertilizer. The processes taking place at this life cycle stage may have same features as raw material production processes (composting, anaerobic digestion, separation etc.).

The technologies used for nutrient recycling that were in use throughout the EU region included (applied from D1.1.):

- Biological Nutrient Recovery
- Physical-Chemical Nitrogen Recovery
- Thermochemical Nutrient Recovery
- P Precipitation.

And the most prevalent technologies in the EU area were:

- Composting
- Anaerobic digestion
- Mechanical separation

Other potential processes are:

- Granulation
- mechanical mixing of feedstocks and fertilizer ingredients

The data mentioned in Table 8 shall be collected (repeated below). The data shall be recorded according to the format in the table 9. In the fourth column, the method of measurement should be explained. This includes the sources of information and any conversion of information and related assumptions.

Table 9: Collection of activity data at the manufacturing plant

Activity data	Unit per tonne of feed out	Quantity	Source and method of measurement (if relevant)

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Electricity use	kWh		
Gas use	MJ LHV		
Heat use	MJ LHV		
Other energy inputs	MJ LHV (specify type)		
Water	m^3 (specify type)		
Packaging (only in case of fertilizer sold in small units)	Kg (specify type)		

Data can be derived on different levels of accurateness which needs to be determined in relation to the scope of the study. If the fertilizer operation is not part of assessing differences in a comparison between alternatives or changes in time the minimum level of accurateness shall be average fertilizer manufacturing plant data determined for 1 year of normal operation. (Normal operation is data corrected for calamities).

If comparisons are made (between alternatives or in time) that include changes in the BBF manufacturing plant operation (e.g. pelleting or not) specific manufacturing plant technology (e.g. processing line) processing data shall be collected. This can either be done on the basis of measurements or an analysis where use of energy and auxiliary materials is derived on technical specifications of equipment. Also if specific data are collected all use of energy and auxiliary materials of the manufacturing plant shall be divided over the specific products (see sections 9.8 and 9.9). Thus, any estimate of specific energy and auxiliary materials use for a feed product shall be done on the basis of allocating the use of the complete factory to subprocesses.

Completeness of data: Data on electricity use, fuel use, heat use and shall always be recorded and collected on the basis of annual usage data based on consolidated information from manufacturing plant bookkeeping. The collected activity data shall be connected with the secondary data for energy.

4.2.3. Distribution stage

The transport from factory to final client shall be modelled within this life cycle stage. The final client is defined as a farm. Bio-based fertilizers are usually delivered to farm by truck. The delivery of biofertilizer product to the farm is a mandatory company specific data. The format below shall be used for data collection.

Table 10: Data collection for feed transport to farm if fuel use can be collected.

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Activity data	Unit	Quantity	Technology (EURO-class 1, 2, 3, 4, 5, 6)	Source and method of measurement
Fuel use (type 1)	unit/tonne delivered feed (specify unit)			
Fuel use (type 2)	unit/tonne delivered feed (specify unit)			
Fuel use (type 3)	unit/tonne delivered feed (specify unit)			
Fuel use (type 4)	unit/tonne delivered feed (specify unit)			

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Section 2: Agricultural production utilizing BBF's to be applied in PEF studies including agricultural production

Different PEFCR's for agricultural products (foods, feed and ornamental flowers) include the fertilizer application and use on field assessment in the agricultural production stage. These PEFCRs recommend how to calculate the nitrogen and phosphate emissions derived from the application of different fertilizer types. Therefore, following the same model, section 2 proposes how to assess the BBF application and use on the field is to be applied inside other PEFCR's agricultural assessment stage. The second part of this document (section 2) presents which changes or modifications other PEFCRs should be done in multiple PEF studies for agricultural production (e.g. food production, ornamental flowers) from the perspective of utilizing (application and use on field) BBFs in agriculture (according to a specific PEFCR or the PEF guide if no PEFCR is available). That is giving guidance to include BBF application and use on the field.

This is not to be confused with PEF-wise PCR method for BBF's (section 1) which is giving guidance how to assess production/acquisition and distribution of BBF's to the cultivation site/farm (Cradle-to-Gate) including the raw material production assessment (e.g. cultivation phase with different potential fertilizers inc. mineral fertilizer application see more in section 4.2.5).

This guidance is to be applied in other products' PEFCR documents since the scope of the PEF wice method for BBFs (presented in section 1) runs only from the fertilizer raw material sourcing stage up to delivery of BBFs to a cultivation site (Cradle-to-gate) and is not taking into consideration the application and use stage of BBFs.

5. Life cycle stage

5.1. Agriculture phase (use on field)

According to PEF, the amount of emissions ending up in the different air and water compartments per amount of fertilisers applied on the field shall be modelled within the LCI.

BBFs emissions shall be differentiated per BBF type and cover as a minimum:

- NH_3, to air (from N-fertiliser application)
- N_2O, to air (direct and indirect) (from N-fertiliser application)
- CO_2, to air (from inorganic compound mixed with BBF's)
- NO_3, to water unspecified (leaching from N-fertiliser application)
- PO_4, to water unspecified or freshwater (leaching and run-off of soluble phosphate from P-fertiliser application)

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- P, to water unspecified or freshwater (soil particles containing phosphorous, from P-fertiliser application).

The LCI for N emissions shall be modelled as the amount of emissions ending up in the different emission compartments per amount of fertilisers applied. The nitrogen emissions shall be calculated from Nitrogen applications of the farmer on the field and excluding external sources (e.g. rain deposition).

To avoid strong inconsistencies among different PEFCRs, within the EF context it is decided to fix a number of emission factors by following a simplified approach. For nitrogen based fertilisers, emissions factors of IPCC 2019 should be used, as presented in Table 11-13. In case better data is available, a more comprehensive Nitrogen field model may be used by the PEFCR, provided

i. it covers at least the emissions requested above,
ii. N shall be balanced in inputs and outputs and
iii. it shall be described in a transparent way.

Note that the values provided shall not be used to compare different types of synthetic fertilizers. More detailed modelling shall be used for that.

N_2O emissions caused by nitrogen fertilization added to arable land are estimated based on the total nitrogen content of the fertilizer. Fertilizer produces in the field as well as **direct and indirect gaseous N_2O emissions**. For the use of direct and indirect N_2O emissions for recycled fertilizers, **IPCC (2019) emission factors for organic nitrogen fertilizer (manure) are used.**

Direct gaseous N_2O emissions are formed from the total nitrogen contained in the fertilizer when it is applied to the soil. Regarding direct N_2O emissions, in the case of bio-based fertilizers, the IPCC (2019) default nitrogen fertilizer emission factor of 0.006 kg N_2O-N/ kg N fertilizer for other N inputs in wet climates is applied. Other N input refers to "organic amendments, animal manures (e.g. slurries, digested manures), N in crop residues and mineralized N from soil organic matter decomposition" (IPCC 2019). In case of dry climates, the IPCC (2019) emission factor of 0.005 kg N_2O-N/ kg N fertilizer for other N inputs is applied. If the climate conditions are uncertain the IPCC (2019) emission factor of 0.01 kg N_2O-N/ kg N fertilizer for other N inputs is applied.

Table 11: Emissions factors to estimate direct N2O emissions from organic fertilzers from IPCC (2019)

DEFAULT EMISSION FACTORS TO ESTIMATE DIRECT N2O EMISSIONS FROM ORGANIC FERTILIZERS					
	Aggregated		Disaggregated		
Emission factor	Default value	Uncertainty range	Disaggregation4	Default value	Uncertainty range

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EF_1 for N additions from organic amendments and crop residues, and N mineralised from mineral soil as a result of loss of soil carbon[1] [kg N_2O–N (kg N)$^{-1}$]	0.01	0.002 – 0.018	Synthetic fertiliser inputs[2] in wet climates	0.016	0.013 – 0.019
			Other N inputs[3] in wet climates	0.006	0.001 – 0.011
			All N inputs in dry climates	0.005	0.000 – 0.011

Sources:

[1]Stehfest & Bouwman 2006; van Lent et al. 2015; Grace et al. 2016; van der Weerden et al. 2016; Albanito et al. 2017; Cayuela et al. 2017; Liu et al. 2017; Rochette et al. 2018.

[2]This emission factor should be used for synthetic fertiliser applications, and fertiliser mixtures that include both synthetic and organic forms of N.

[3]Other N input refers to organic amendments, animal manures (e.g. slurries, digested manures), N in crop residues and mineralised N from soil organic matter decomposition. EF1: Uncertainty range of disaggregated EF1 based on the 95% confidence interval of fitted values. Uncertainty range of aggregated EF1 is based on the 2.5th to 97.5th percentile of the dataset (See methods, data and results in Annex 11A.2).

Indirect N_2O emissions are formed by leaching of the nitrogen contained in the fertilizer and ammonia that evaporates from the nitrogen in the fertilizer. Regarding indirect N_2O emissions from leaching, in the case of recycled fertilizers, the default emission factor for organic nitrogen fertilizer (manure) of 0.011 kg N_2O-N/kg of N leaching. Regarding indirect N_2O emissions from ammonia, the default emission factor of organic nitrogen fertilizer (manure) of 0.021 kg N_2O-N/kg N deposited.

Table 12: Emissions factors to estimate indirect N2O emissions from organic fertilsersfrom IPCC (2019)

DEFAULT EMISSION FACTORS TO ESTIMATE INDIRECT N2O EMISSIONS FROM ORGANIC FERTILIZERS					
	Aggregated		Disaggregated		
Factor	Default value	Uncertainty range	Disaggregation[4]	Default value	Uncertainty range
EF_5 [leaching/runoff][1], kg N_2O–N (kg N leaching/runoff)$^{-1}$	0.011	0.000 - 0.020	–	–	–

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FracGASM [Volatilisation from all organic N fertilisers applied, and dung and urine deposited by grazing animals][2], (kg NH_3–N + NO_x–N) (kg N applied or deposited)$^{-1}$	0.21	0.00 - 0.31	–	–	–

Sources:

[1]Tian et al. 2019.

[2]NH3: Bouwman et al. 2002; Cai & Akiyama 2016. NOx: Liu et al. 2017.

Notes:

EF5: This emission factor incorporates three components: EF5 = EF5g + EF5r + EF5e. EF5g: Emission factor for groundwater and surface drainage, including upstream supersaturated with N2O (N2O emitted mainly from degassing of groundwater); EF5r: Emission factor for rivers and reservoirs, including downstream (supersaturated N2O was already degassed and N2O mainly produced by nitrification/denitrification in situ); EF5e: Emission factor for estuaries. See methods in Annex 11A.6. Uncertainty range is based on the 2.5th to 97.5th percentile.
FracGASM: See methods in Annex 11A.8. Uncertainty range is based on the 2.5th to 97.5th percentile.

For Tier 2, country specific FracLEACH-(H) can be estimated for N losses by leaching/runoff for regions where Σ(rain) - Σ(ET0) > soil water holding capacity, OR where irrigation (except drip irrigation) is used. ET0 = Kpan * Ep, where ET0: reference evapotranspiration, Kpan: pan evaporation coefficient, Ep: pan evaporatio n. When Kpan is not available, reference evaporation can be estimated as ET0= 0.5 * Ep (Explanations of reference and pan evaporation: see Allen et al. 1998). Long-term mean of annual rainfall data should be used for estimating FracLEACH-(H). Precipitation and potential evapotranspiration data are available from global datasets, such as the CRU climate dataset (https://crudata.uea.ac.uk/cru/data/hrg/), if country-specific data are not available.

NOTE: Other possible emissions from arable land, not derived from fertilizers, are not taken into account (these will only be taken into account when the effects of different agricultural products are calculated according to the PEFCR).

Table 13: Tier 1 emissions factors to estimate ammonia NH3 emissions from organic fertilsers from IPCC (2019)

Emission	Compartment	**Value to be applied**
NH_3 (manure)	Air	kg NH_3= kg N*FracGASF= 1*0.2* (17/14)= 0.24 kg NH_3/ kg N manure applied

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The LCI for P emissions should be modelled as the amount of P emitted to water after run-off and the emission compartment 'water' shall be used. When this amount is not available, the LCI may be modelled as the amount of P applied on the agricultural field (through manure or fertilisers) and the emission compartment 'soil' shall be used. In this case, the run-off from soil to water is part of the impact assessment method.

The impact assessment model for freshwater eutrophication should start:

i. when P leaves the agricultural field (run off) or
ii. from manure or fertilizer application on agricultural field.

The impact assessment marine Eutrophication starts after N leaves the field (soil). Therefore, N emissions to soil shall not be modelled.

Table 14: The Tier 1 emissions factors of IPCC 2006.

Emission	Compartment	Value to be applied
P based fertilisers	Water	0.05 kg P/ kg P applied

Carbon sequestration: As stated in D2.1., The PEF Guide (European Comissions 2021), ISO/DIS 14067 (2012), and the ILCD Handbook (2010) align in stipulating that removals (carbon sequestration, carbon storage) and emissions shall be reported separately for both fossil and biogenic sources.

Considering about the biogenic carbon sequestration and storage during agriculture phase, The PEF guide (European Comission 2021) indicates that credits from 'temporary carbon storage' are excluded. More specifically as stated in D2.1., emissions emitted within a limited amount of time after their uptake shall be counted for as emitted "now" and there is no discounting of emissions within that given time frame (also in line with ISO/TS14067). The term 'limited amount of time' is here defined as 100 years, in line with other guiding documents such as in ILCD handbook (JRC 2016) and PAS2050:2011.

Therefore, biogenic carbon emitted later than 100 years after its uptake is considered as permanent carbon storage. If the carbon of a component of BBF is considered to meet this definition of permanent carbon and will end up as fertilizer or as a soil conditioner on field, it is considered to return and bind carbon to the soil, in this case, an examination of carbon storage, i.e. how much carbon dioxide is bound to BBF. This shall be modelled separately next to emissions.

Calculation example:

When assessing permanent carbon share in a BBF it is recommended to use appropriate models e.g. Yasso model.

When assessing further storage potential nex to emissons as CO_2 equivalents i.e. how much carbon dioxide is bound to different components of biofertilizers in addition to the carbon footprint (emissions) of different biofertilizers, the CO_2 binding potential is calculated with a coefficient, the 1 kg of carbon contained in biomass (e.g. in biochar) binds 3.6667 kg of CO_2 emissions (molecular mass ratio C/CO_2 = 44.01/12.01).

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In LCA, the use of BBF should be handled in a same way as any management practice that would change the soil C content. So it would produce negative emissions that would be included in the carbon footprint of the agricultural product. How these can be reported, depends on the guidelines that are followed, for example in PEF this would only be "additional information."

But should these be part of the carbon footprint of fertilizers? If the system boundary is cradle-to-grave (including the use phase), then technically yes. However, probably in most LCA guidelines, the fertilizer production chain is considered as cradle-to-gate, which is understandable as the producer cannot handle the use phase, and the variation there can be considerable.

In case of organization environmental footprint, the use of fertilizers could be considered in downstream Scope 3 emissions of the fertilizer producer. But the rules for C sequestration may not be very well established there?

Then, in voluntary carbon market, companies who are creating CO_2 removals, can sell those as carbon credits. But how the income from these sales is shared between the producers and farmers, is not quite clear to me; it and may be case specific and depend on the certification scheme. Anyway, such markets currently exist for biochar, but probably not for organic fertilizers. It would be much more difficult to demonstrate for example the durability and additivity of CO_2 removals based on the use of fertilizers. Further, according to the (questionable) guidelines of Finnish ministries, increase of SOM should not be accepted as voluntary carbon credits, as it is already included in national GHG inventory, and therefore would be interpreted as 'double counting'. In contrast, biochar would be acceptable, because (so far) it is not part of NIR."

For development:

Due to the wide chemical compositions of BBFs, in case there are not specific EFs, assimilation of EFs of those which chemical composition is more similar could be a temporary solution until the publication of specific EFs.

It is recognized that the nitrogen field model has its limitations and shall be improved in the future.

The chemical composition of products under the BBF concept embraces inorganic and organic compositions. In the case of inorganic, it is common to find products such as ammonium sulphate whose behaviour in the environment is the same as their mineral counterpart. In these cases, the application emissions should be assumed or assimilated, if there is existing data, to the mineral counterparts. For instance, if a ammonium sulphate form pig slurry. Then, ammonium sulphate Tier 1 factors should be applied. On the contrary, organic BBFs can have a variety of compositions (in terms of nutrient content, nutrient form, and organic matter). Then, manure or sludge Tier 1 factors should be applied to. Until now, the existing information about the import number of BBF products do not have clear measures or enough replicates to propose specific Tier 1 factors.rs.

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