Klimato
PRODUCT CARBON FOOTPRINT METHODOLOGY

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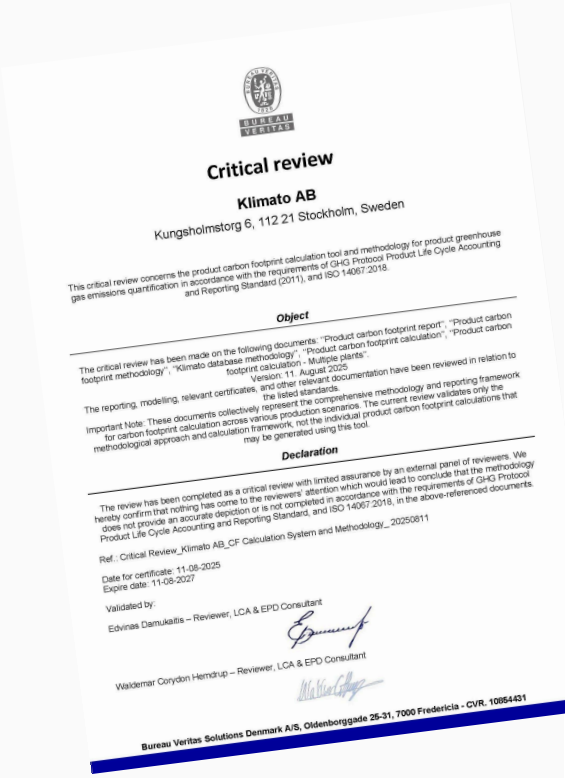
Product Carbon Footprint

SUMMARY METHODOLOGY

Introduction

This document explains how Klimato measures the carbon footprint (CF) of food products, providing the transparency and reliability needed for both internal decisions and external communication—including product labeling.



Critical review

Klimato AB

Kungsholmstorg 6, 112 21 Stockholm, Sweden

This critical review concerns the product carbon footprint calculation tool and methodology for product greenhouse gas emissions quantification in accordance with the requirements of GHG Protocol Product Life Cycle Accounting and Reporting Standard (2011), and ISO 14067:2018.

Object

The critical review has been made on the following documents: "Product carbon footprint report", "Product carbon footprint methodology", "Klimato database methodology", "Product carbon footprint calculation", "Product carbon footprint calculation - Multiple plants".
Version: 11. August 2025

The reporting, modelling, relevant certificates, and other relevant documentation have been reviewed in relation to the listed standards.

Important Note: These documents collectively represent the comprehensive methodology and reporting framework for carbon footprint calculation across various production scenarios. The current review validates only the methodological approach and calculation framework, not the individual product carbon footprint calculations that may be generated using this tool.

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Ref.: Critical Review_Klimato AB_CF Calculation System and Methodology_ 20250811

Date for certificate: 11-08-2025
Expire date: 11-08-2027

Validated by:

Edvinas Damukaitis – Reviewer, LCA & EPD Consultant

Waldemar Corydon Herndrup – Reviewer, LCA & EPD Consultant

Bureau Veritas Solutions Denmark A/S, Oldenborggade 25-31, 7000 Fredericia - CVR. 10054431

Our approach follows two internationally recognized standards: the **GHG Protocol Product Life Cycle Accounting and Reporting Standard** and **ISO 14067:2018**. The methodology and calculation processes have been independently reviewed by experts at **Bureau Veritas Solutions Denmark A/S**, confirming both compliance with these standards and the robustness of our approach.

Klimato's CF assessments follow a **cradle-to-distribution system boundary**, capturing emissions from:

- **Material acquisition and pre-processing** (including land use change)
- **Materials transport**
- **Production** (manufacturing, storage, waste treatment)
- **Packaging** (primary and secondary)
- **Packaging transport**
- **Distribution of the finished product to regional centres**

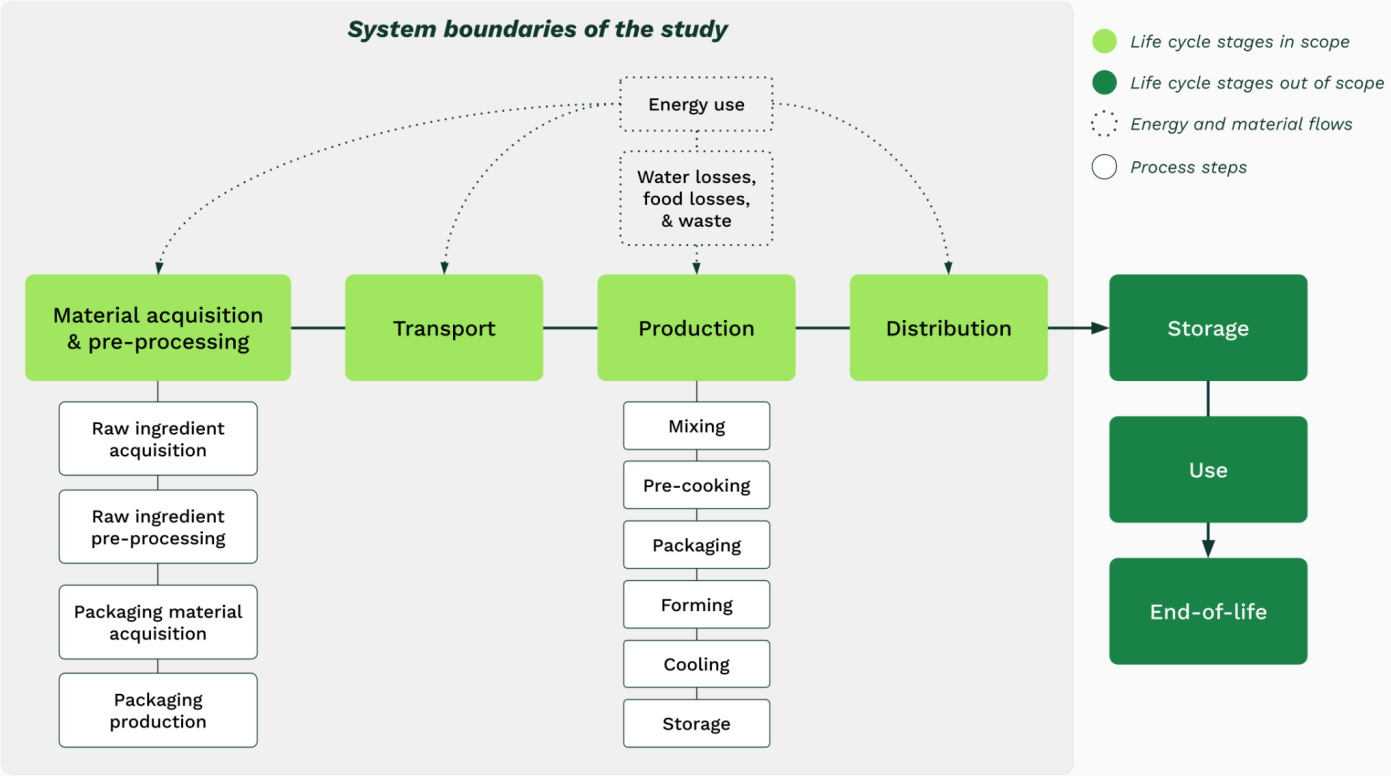


Figure a) System boundaries of Klimato's CF assessment (illustrative example)

Klimato's CF assessments focus on **Global Warming Potential (GWP)**, expressed in kilograms of CO_2-equivalents (kg CO_2e), and include all seven greenhouse gases (GHG) covered by the Kyoto Protocol. We exclude emissions beyond distribution—such as use-phase, end-of-life treatment, and broader corporate activities—because these vary widely and depend heavily on consumer behaviour.

Primary activity data provided by the reporting company is prioritised, covering energy use, ingredient sourcing and quantities, packaging materials and weights, and transport modes and distances. This data is combined with country- and ingredient-specific emission factors from the **Klimato Database**.

Additional emission factors for energy, transport, and waste treatment are sourced from globally recognised datasets (e.g., DEFRA, Mobitool, AIB).

The **Klimato Database** is the backbone for estimating emissions from the material acquisition and pre-processing stage, where extensive ingredient-specific data is required. It contains CF values for over **4,000 food ingredients** and more than **20,000 variations** across origins and farming methods (organic and conventional). The database is:

- **Certified**: Reviewed by IVL (Swedish Environmental Research Institute) and Coolfood (World Resources Institute) (Read more here).
- **Science-based**: Uses attributional Life Cycle Assessment (LCA) peer-reviewed studies that follow ISO 14040, 14044, and 14067 standards.
- **Comprehensive**: Includes emissions from agriculture, processing, packaging, and food losses.

Table a) provides an overview of the main data sources used in Klimato's CF assessments, distinguishing between primary data collected from the reporting company and secondary data drawn from recognised emission factor databases.

Table a) Overview of data sources in Klimato's CF assessments

Data Type	Data Source	Examples
Primary Activity Data	*Reporting company*	• Ingredient sourcing and quantities, • Energy consumption at the production facility, • Packaging materials and weights, • Transport modes and distances.
Emission Factors – Ingredients & Packaging	*Klimato Database (country- and ingredient-specific)*	Emission factors for production of ingredients (e.g., soy protein, flour, food additives) and packaging materials
Emission Factors – Energy, Transport, Waste	*External datasets (e.g., DEFRA 2025, Mobitool 2023, AIB 2024)*	• Grid electricity, • Freight transport, • Waste treatment processes

Allocation

In some cases, processes within the system boundaries of the studied product's life cycle generate multiple outputs, making allocation necessary. In Klimato's CF assessments, allocation is based on either the economic value or the physical characteristics of the outputs, depending on which is most appropriate, and in line with the requirements and recommendations of the GHG Protocol.

The treatment of multi-output processes is determined not only by the nature of the outputs (e.g., co-product vs. by-product) but also by the life cycle stage in which they occur.

An overview of the allocation methods applied at different stages of the product life cycle is presented in **Table b)**.

Table b) Allocation methods applied at different life cycle stages.

Life Cycle Stage/Process	Type of Output	Allocation Method	Description
Material acquisition & pre-processing	*All outputs*	Follows that of the original data sources	Secondary emission factors are used for this stage. The allocation method follows that of the original data sources in the literature.
Production	*Co-products*	Physical allocation by mass	Physical allocation by mass is applied. This method is applied as a neutral and proportionate basis, consistent with GHG Protocol guidance.
	By-products	Economic allocation	Economic allocation is used to distribute emissions, based on the market value of each output.
Recycling & waste treatment	*Recycled materials/ Recovered energy*	Recycled content (cut-off) approach	This approach assigns the impacts of recycling/recovering to the life cycle of the product which uses the recycled material/recovered energy.

On-Pack Carbon Labelling

Klimato's methodology underpins its on-pack carbon labels, providing a clear and accessible way to communicate a product's climate impact and help consumers make climate-conscious purchasing decisions.

In line with the GHG Protocol Product Standard, ISO 14067:2018, the EU Green Claims Directive, and the UK Green Claims Code, each carbon label produced through this methodology includes all required elements for compliance:

- A clear statement of the **functional unit** (e.g., per kg of product).
- A definition of the **system boundary** (e.g., cradle-to-distribution).

- A **link to the publicly available methodology**, enabling stakeholders to verify the underlying calculation approach.

Klimato recommends that food producers publish the product CF report. However, it is always available upon request.

Figure b) On-pack Carbon Footprint Label for the production of 1kg of product.

Results

The outcome of the assessment is presented in a comprehensive report that includes both the applied methodology and the calculated emissions.

Results are expressed in **kg CO_2e per kilogram of product** and per selling unit, with a clear breakdown of emissions by life cycle stage. In line with international standards, certain emission sources are reported separately:

- **Cradle-to-gate emissions** – as required by the *GHG Protocol*.
- **Gate-to-gate (production) emissions** – as required by the *GHG Protocol*.
- **Land Use Change (LUC) emissions** – required by both the *GHG Protocol* and *ISO 14067:2018*, and reported separately to highlight their impact.
- **Biogenic emissions** – required by *ISO 14067:2018*.
- **Aircraft transport emissions** – reported separately per *ISO 14067*:2018.
- **FLAG emissions** - as required by SBTi's forestry, land and agriculture (FLAG) guidance by Anderson et al. (2022), presenting overall FLAG, land management, and LUC (CO_2 and non-CO_2) emissions.

Figure c), **Table c)**, and **Table d)**, provide an example of how results are presented.

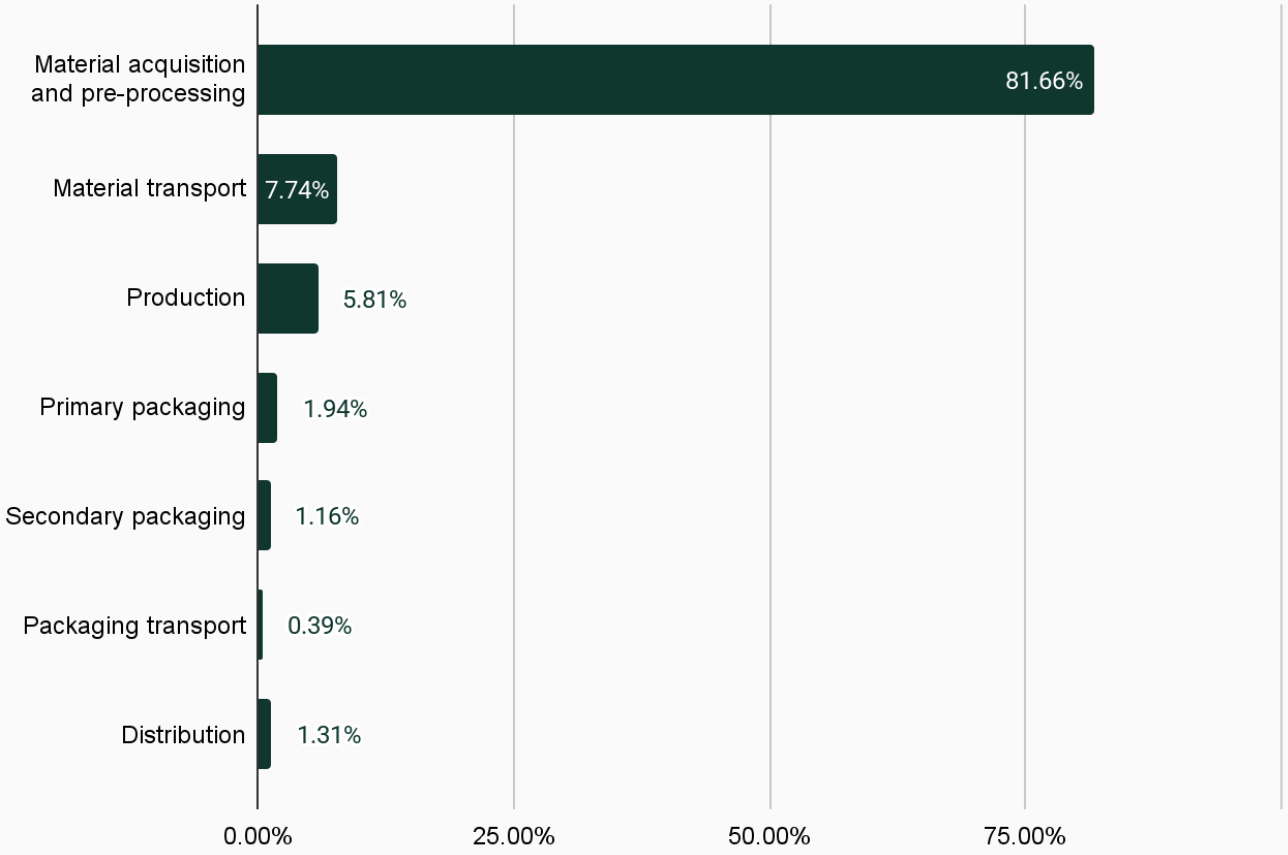


Figure c) Breakdown of emissions per life cycle stage (Illustrative example)

Table c) Share of emissions per life cycle stage (Illustrative example)

LCA stage	kg CO_2e/kg	Share of emissions
Material acquisition and pre-processing	2.11	81.66%
Materials transport	0.20	7.74%
Production	0.15	5.81%
Primary packaging	0.05	1.94%
Secondary packaging	0.03	1.16%
Packaging transport	0.01	0.39%
Distribution	0.03	1.31%
Total	2.58	**100%**

Table d) Breakdown of emissions, showing total cradle-to-distribution emissions and separate reporting of key emission sources in line with international standards (Illustrative example)

Inventory results	kg CO_2e/kg
Cradle-to-distribution emissions	2.11
Cradle-to-factory gate emissions	2.08
Gate-to-gate emissions	0.15
LUC emissions	0.08
Biogenic GHG emissions	0.12
Aircraft transport emissions	0.00
SBTi FLAG emissions (forestry, land and agriculture)	
FLAG emissions	2.11
of which land management (agriculture)	2.03
of which land use change (CO2 and non-CO2)	0.08

This detailed reporting helps identify emission hotspots, enabling businesses to understand which life cycle stages offer opportunities for emission reductions, and to effectively communicate the product's CF to stakeholders.

Data quality assessment

Klimato's CF assessment combines company-specific activity data with emission factors from the Klimato Database and internationally recognized sources.

To evaluate key data quality aspects—including reliability, completeness, and representativeness—a quantitative data quality assessment is conducted, with the findings detailed in the report. This process supports transparency, enables third-party assurance, and shows stakeholders the level of confidence in the data behind the product footprint.

Data quality is assessed using a **pedigree matrix**, applied separately to:

- **Activity data** collected from the reporting company.
- **Emission factors** applied across the assessment.

The pedigree matrix evaluates five key indicators for both datasets:

- **Technological representativeness** (TE)
- **Geographical representativeness** (GE)
- **Temporal representativeness** (TI)
- **Completeness** (CO)
- **Reliability** (RE)

The data quality assessment occurs in different steps. First, a set of questions is answered (by the reporting company for the activity data and by Klimato for the emission factors) regarding the characteristics of the data used. Based on these answers, each indicator is scored on a 1–4 scale (● 1 = very good, ● 2 = good, ● 3 = fair, ● 4 = poor). Second, the individual scores are aggregated into a DQR for each life cycle stage. Finally, the stage-level DQRs are combined to calculate an aggregated DQR.

A visual representation of this process is provided in **Figure d)**.

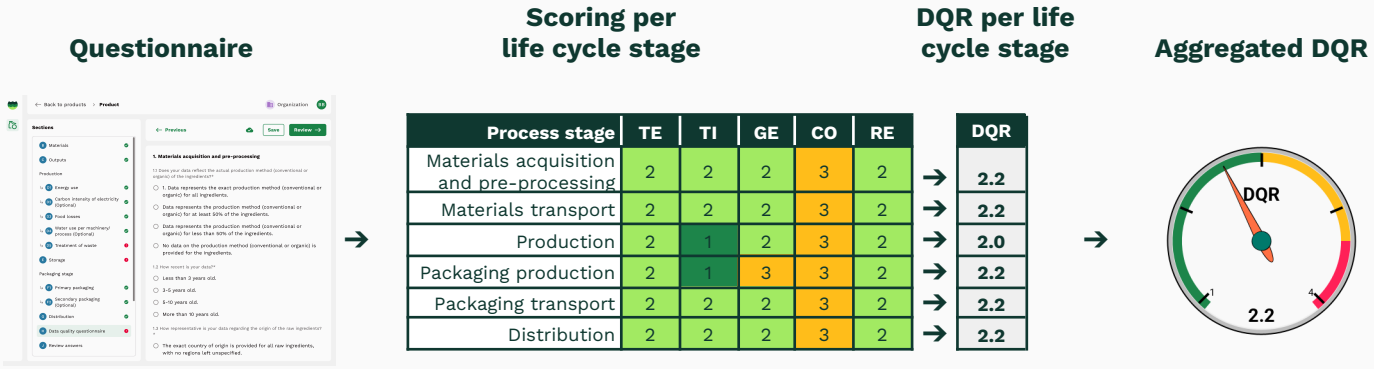


Figure d) The comprehensive data quality assessment process, from indicator scoring to the aggregated DQR.

Table e) and **Figure e)** show, respectively, the results of the quantitative data quality assessment conducted on Klimato's emission factors per life cycle stage and an example of the aggregated DQR.

Table e) Quantitative data quality assessment of Klimato emission factors used to quantify GHG emissions *(TE: technological representativeness, TI: time representativeness, GE: geographical representativeness, CO: completeness, RE: reliability, DQR: data quality rating; scored from ● 1 = very good, ● 2 = good, ● 3 = fair, ● 4 = poor).*

Process stage	TE	TI	GE	CO	RE	DQR
Materials acquisition and pre-processing	2	2	2	3	2	**2.2**
Materials transport	2	2	2	3	2	**2.2**
Production	2	1	2	3	2	**2.0**
Packaging production	2	1	3	3	2	**2.2**
Packaging transport	2	2	2	3	2	**2.2**
Distribution	2	2	2	3	2	**2.2**

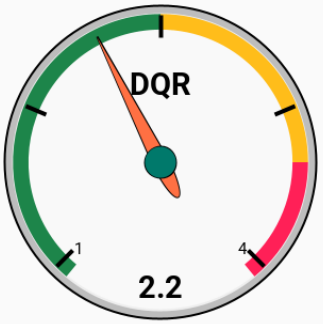


Figure e) Aggregated Data Quality Rating (DQR) (Illustrative example)

Sensitivity Analysis

A sensitivity analysis is performed to assess how variations in key input parameters and methodological assumptions influence the CF results. Overall, three types of sensitivity analyses are conducted: on **input parameters**, **transport distance calculations**, and **the methodological treatment of biogenic carbon**.

Uncertainty and limitations

While Klimato applies best-practice methodologies and high-quality data, several sources of uncertainty and limitations are inherent to carbon footprinting and LCA:

- **Allocation Uncertainty:** The choice of allocation method (e.g., physical or economic) can affect results. Market prices used in economic allocation may fluctuate, and assumptions in physical allocation may not fully reflect energy consumption patterns. Klimato mitigates this by using reliable data and aligning with internationally recognized standards.

- **Parameter Uncertainty:** Variations in emission factors, activity data, and production processes—influenced by regional differences, market fluctuations, and technological changes—can introduce uncertainty.

- **Scope:** Certain life cycle stages are excluded from this assessment. For example, the use-phase and end-of-life stages are omitted because they vary widely based on consumer behavior and fall outside the producer's control, making consistent data collection difficult. Other processes, such as emissions from manufacturing capital goods in the production stage, are excluded as non-attributable because they fall below the study's 1% cut-off threshold, meaning they contribute less than 1% to the overall footprint.

- **Data Availability:** Gaps in supplier-specific or geographically detailed data are addressed using proxy values and assumptions, with default scenarios applied where product- or site-specific data is unavailable.

- **Variability in Emission Factors and LCIA Methodologies:** Emission factors are sourced from various databases and may be based on different life cycle impact assessment (LCIA) methods and versions. As a result, a single harmonized LCIA approach cannot be applied across the full dataset.

- **GWP Characterization Factors:** Literature sources do not always specify which IPCC assessment report (e.g., AR4, AR5, AR6) underlies their GWP values, especially for gases like nitrous oxide. Consequently, the dataset includes a range of characterization factors, reflecting methodological diversity across sources.

These uncertainties are acknowledged and managed transparently to support informed interpretation of the results.

Klimato

For more information,
contact Klimato at klimato.com/contact

Product Carbon Footprint

EXTENSIVE METHODOLOGY

1. Introduction

This document outlines Klimato's methodology for assessing the carbon footprint (CF) of food products. The methodology ensures the transparency and reliability required for both internal decision-making and external communication, including product labeling.

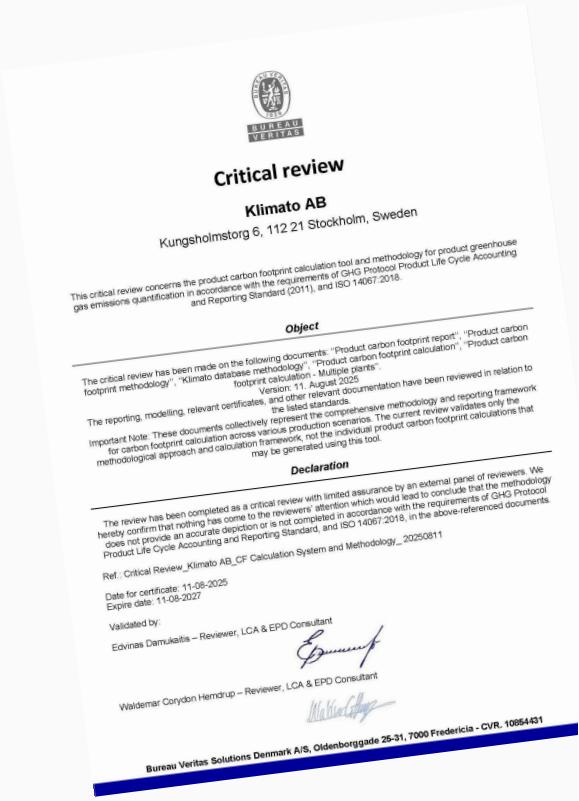
1.1. Compliance with International Standards and Critical Review

Klimato's CF assessments are conducted in accordance with leading international standards for environmental accounting:

- **The GHG Protocol Product Life Cycle Accounting and Reporting Standard:** This globally recognized standard provides a comprehensive framework for quantifying and reporting greenhouse gas (GHG) emissions associated with individual products.

- **ISO 14067:2018: Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification:** The International Organisation for Standardisation (ISO) standard specifies principles, requirements, and guidelines for quantifying the carbon footprint of products.

Klimato's CF calculation methodology, data infrastructure, and reporting framework have been **critically reviewed** by a panel of independent experts from **Bureau Veritas Solutions Denmark A/S,** by namely Edvinas Damukaitis (Chairperson), LCA & EPD Consultant, and Waldemar Corydon Hemdrup (Reviewer), LCA & EPD Consultant, who confirm that it aligns with the principles and requirements of the aforementioned standards. This critical review pertains to Klimato's general approach and systems and does not constitute a third-party critical review of the specific product assessment, nor of the data provided by the reporting company.



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A summary of the assurance process and its conclusions is provided in the assurance statement by Bureau Veritas Solutions Denmark A/S, dated 11-08-2025, included in Appendix A of this document.

1.2. Intended Use and Audience

Klimato's reports and labels are designed for both internal and external stakeholders. Internally, they help identify climate impact hotspots, guide product development, and shape

sustainability strategies. Externally, they equip business partners, consumers, auditors, and investors with transparent, credible insights into a product's environmental performance.

The findings in Klimato's CF reports reflect the assumptions, methodologies, and practices used by the reporting company. They are **not** intended for direct comparison with other companies or products. Even similar products can show different results due to differences in unit of analysis, data quality, or life cycle stages considered (such as use-phase or end-of-life).

1.3. On-Pack Carbon Labelling

Klimato's product CF methodology is the foundation for on-pack carbon labels—built for transparency and aligned with international standards and green claims regulations. These labels offer a straightforward way to communicate a product's climate impact, fostering trust and helping customers make informed purchasing decisions.

Figure 1: On-pack Carbon Footprint Label for the production of 1kg of product.

In line with the GHG Protocol Product Standard, ISO 14067:2018, the EU Green Claims Directive, and the UK Green Claims Code, every carbon label produced using this methodology includes the following elements to ensure transparency, credibility, and compliance:

- **Functional unit:** clearly stated (e.g., per kg of product) to support understanding and fair comparisons.
- **System boundary:** defined (e.g., cradle-to-distribution) to specify which life cycle stages are included in the footprint.
- **Methodology link:** direct access to the publicly available calculation approach, allowing stakeholders to verify the results.
- **Clear language:** avoiding vague or unqualified terms such as "carbon neutral" or "sustainable."
- **Supporting report:** each label is backed by a detailed CF report. Reporting companies are encouraged to make these reports public, but they are always available upon request.

2. Carbon Footprint Methodology

2.1. Goal

The primary goals of the assessment are to:

- Quantify the CF of the product under study.
- Identify emission hotspots and opportunities for reduction.
- Support stakeholder communication and transparency.
- Enable Klimato users to apply primary data in carbon accounting.

2.2. Scope

2.2.1. Impact Category: Global Warming Potential

Klimato's assessments focus on the **Global Warming Potential (GWP)** impact category. GHG emissions are expressed in carbon dioxide equivalents (CO_2e), calculated using GWP over a 100-year time horizon and characterization factors from the Intergovernmental Panel on Climate Change (IPCC).

In line with ISO 14067:2018, Section 6.5.1, the 100-year GWP measures the cumulative warming effect of a GHG over a century, relative to CO_2. This is the required basis for calculating climate change impact in CF studies. All GHG emissions in Klimato assessments are converted to CO_2e using these 100-year values.

The assessment covers the seven GHGs defined by the Kyoto Protocol:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulphur hexafluoride (SF_6)
- Nitrogen trifluoride (NF_3)

2.2.2. Functional Unit

The functional unit—the reference point for quantifying all associated GHG emissions—is **1 kilogram (kg) of food product**.

2.2.3. System boundaries

Klimato's assessments use a cradle-to-distribution approach. This means emissions are calculated from the earliest stages of a product's life cycle ("cradle") through to its distribution, including:

- Material acquisition & pre-processing
- Material transport
- Production
- Packaging
- Packaging transport
- Distribution to regional distribution centers

This boundary focuses on stages typically under the reporting company's control or direct influence, ensuring consistency in data and methodology. Stages beyond distribution—such as consumer use-phase and end-of-life—are excluded due to high variability and reliance on consumer behavior.

The process map in Figure 2 shows an example of the key production steps and emission sources considered within the system boundaries of a Klimato CF study.

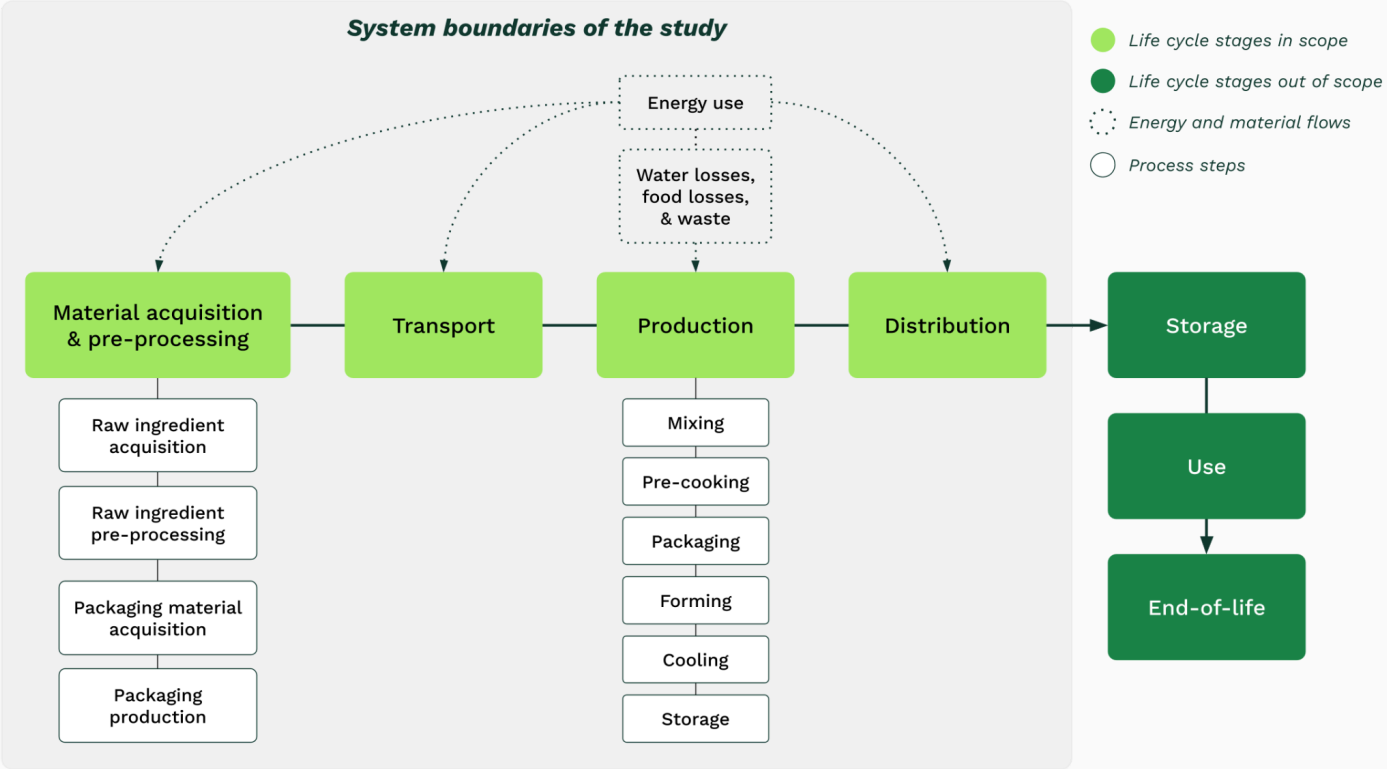


Figure 2: System boundaries (Illustrative example)

All relevant attributable processes within the cradle-to-distribution boundary are included in the assessment, provided data is available and they meet the inclusion threshold. A cut-off criterion is applied, excluding processes that contribute less than 1% of total GHG emissions.

Non-attributable processes that fall below this threshold and are therefore excluded:

- Maintenance and production of farm equipment
- Albedo effects from land use change
- Manufacturing of capital goods of the production stage (e.g., factory equipment, storage infrastructure, transport vehicles)

Activities outside the scope of this assessment:

- Consumer energy use for food preparation
- Transportation from store shelves to consumers
- End-of-life treatment of food products (except packaging)
- Corporate activities such as marketing, administration, and research & development
- Personnel commuting and housing at farms and production facilities

2.3. Life Cycle Inventory

The following sections describe the processes included at each stage of the assessment, the applied methodology, and the key limitations.

2.3.1. Material Acquisition & Pre-Processing

This stage covers activities from the extraction of natural resources up to the point where produced materials (ingredients) enter the production facility.

Emissions are calculated using activity data on ingredient sourcing and quantities, combined with ingredient-level emission factors from the Klimato database. For details on the database methodology, see Section 3.

Included mechanisms related to agricultural production are:

- Emissions from land use and LUC, including CO_2 from deforestation
- CO_2 emissions from organic soils and soil disturbances
- N_2O emissions from fertilizer use and natural soil processes
- CO_2 emissions from lime and urea application
- Emissions from pesticide and fertilizer production
- Energy consumption associated with irrigation and farm operations
- CH_4 emissions from enteric fermentation in ruminants
- N_2O and CH_4 emissions from manure management
- Emissions from feed production and grazing

Included mechanisms related to wild aquatic products:

- Fuel consumption for fishing vessels
- Refrigeration energy use and refrigerant leakage on vessels
- Allocation of emissions considering the edible portion of the catch

When ingredient-specific data is unavailable, assumptions and models are applied, considering:

- Different production origins
- Different production methods (organic or conventional)
- Food variants (variety, processed ingredient types)

Food losses at harvest, post-harvest, and processing stages of the materials are included and estimated using reported loss percentages by FAO (2011) and Waite et. al (2019).

The emissions estimated at this stage include those related to LUC. The methodology used to estimate LUC emissions is detailed in the following section.

2.3.1.1. Land Use Change

LUC refers to the transformation of natural landscapes into agricultural or industrial areas, leading to carbon stock changes and GHG emissions. LUC emissions primarily stem from deforestation, peatland drainage, and land conversion for agriculture. These emissions contribute significantly to the CF of food products, particularly for crops cultivated in regions with active deforestation.

LUC impacts are accounted for using a tiered approach, prioritising data sources by their accuracy and specificity (Figure 3). Methodologies are applied in the following order of preference (from most to least accurate) with Step 1 being the most accurate. Less specific approaches are used only when higher-quality data are not available.

The assessment follows these four steps:

1) Supplier-specific values: Direct supplier certifications of deforestation-free sourcing are considered to confirm the absence of LUC emissions.

2) Literature-derived LUC values: When primary data are not available, LUC emissions are sourced directly from peer-reviewed studies that provide either statistical or direct land use change data. As standardized indirect LUC (iLUC) emission factors are not widely available or consistently defined, Klimato's product CF studies don't include iLUC emissions, in line with ISO 14067:2018.

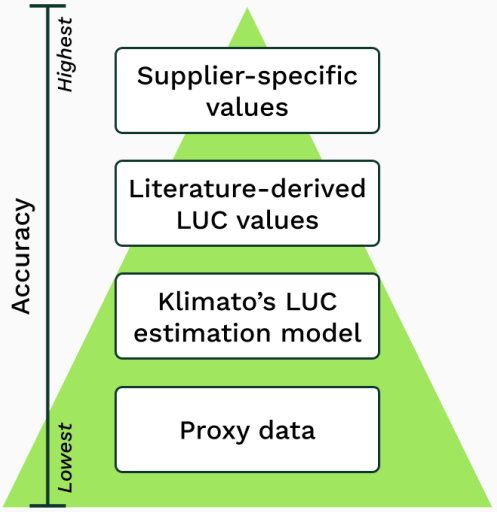


Figure 3: Hierarchy of data quality for assessing LUC emissions.

3) Klimato's LUC estimation model: For cases where literature does not provide explicit LUC values, a proprietary model is used to estimate emissions based on historical land conversion data and global land use trends.

4) Proxy data: If neither literature nor modeling data is available, LUC values are approximated based on similar crops or assumed negligible if data supports a low risk of land conversion. Klimato's LUC model is developed in accordance with the PAS 2050-1 methodology by the BSI (2012), using factors and parameters from IPCC and statistical data from FAO. It follows a linear amortization approach over a 20-year period, in line with GHG Protocol Land Sector Guidance.

The selection of the linear amortization approach ensures that recent land use changes are weighted more heavily, aligning with the Science-Based Targets initiative (SBTi) recommendations.

Further details about Klimato's LUC emissions model are provided in Appendix B.

2.3.2. Production

The production stage covers all on-site processes that transform materials into the final product.

Mechanisms related to food production included are:

- Energy consumption for food manufacturing and production;
- Overhead energy consumption (e.g., facility lighting, ventilation, air conditioning);
- Food losses;
- Storage between production and distribution.
- Treatment of waste generated during production.

The CF of this stage is determined using primary data. The reporting company is required to provide:

1. Machine-specific data on **power ratings and operational durations, from which electricity consumption is derived (“Per equipment” approach)**, for the most granular assessment, or...
2. Total facility energy consumption allocated based on production volumes (**“At the factory” approach)**.

Figure 4 visually represents these two approaches.

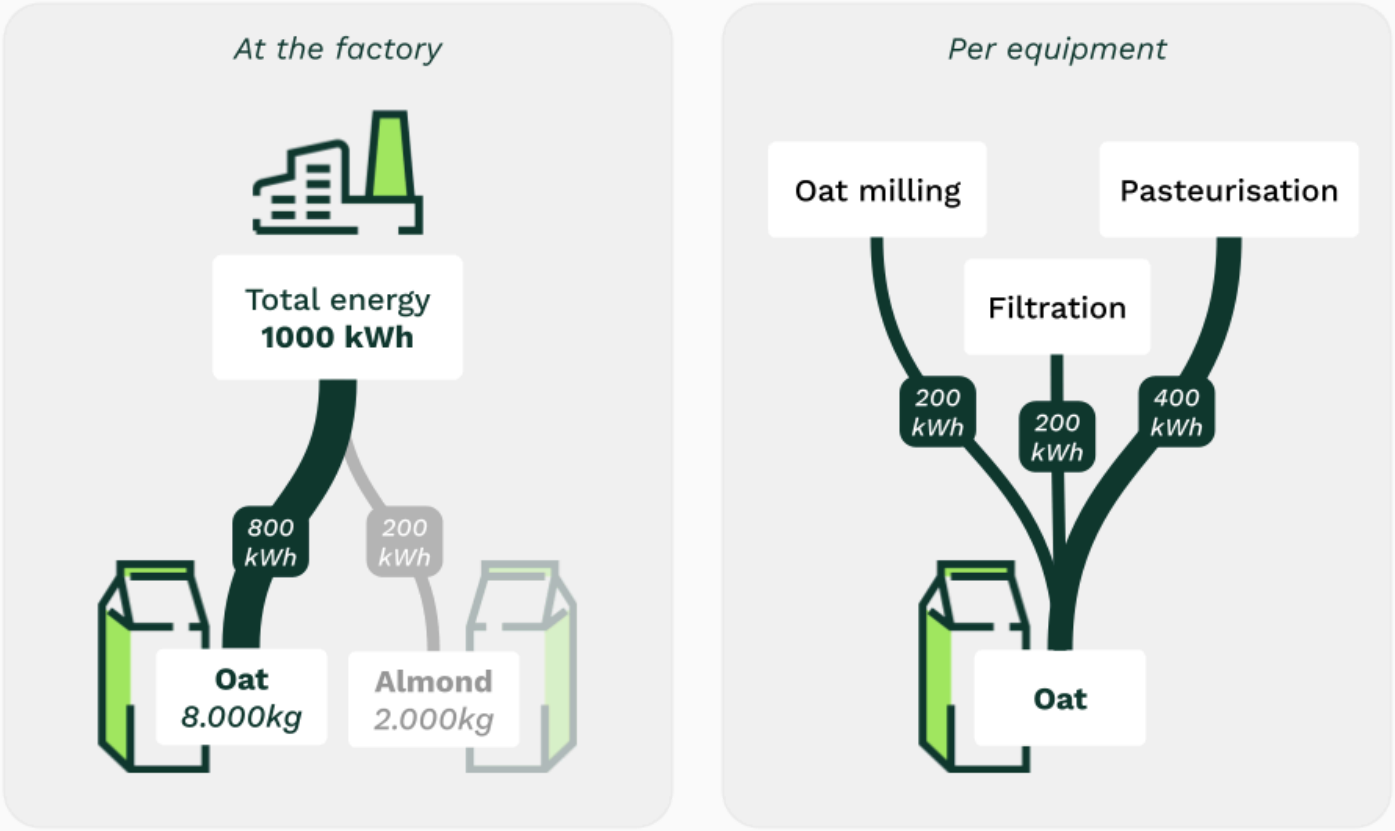


Figure 4: Klimato’s two alternative approaches for estimating production-stage emissions with the example of oat milk: ‘At the factory' (based on total-facility level data) VS 'Per equipment' (based on individual equipment-level data).

Emissions from fuel combustion and electricity use are included in the assessment. Energy-related emissions are calculated using supplier-specific carbon intensity data where available, or country-specific electricity emission factors where such data is not provided.

When supplier-specific data is unavailable for European countries, Klimato uses residual mix emission factors from the Association of Issuing Bodies (AIB), based on the most recent dataset (2024). The residual mix reflects the average grid emission intensity after removing explicitly tracked renewable energy (e.g., through guarantees of origin). This provides a more accurate and conservative estimate of electricity emissions, avoids over-crediting low-carbon electricity use, and ensures renewable claims are backed by contractual instruments.

The use of residual mix factors is currently limited to Europe, as harmonized residual mix data is not available for other regions. For non-European countries, the methodology applies country-specific electricity emission factors (kg CO_2e) from Our World in Data, ensuring comprehensive and transparent coverage of global electricity systems.

2.3.2.1. Waste treatment

Emissions from waste generated during production are included within the system boundaries of the assessment, as waste management is considered an attributable process under the GHG Protocol and ISO 14067:2018.

Waste-related emissions are calculated using a tiered approach, prioritizing the most accurate and specific data available (Figure 5). The hierarchy, from most to least precise, is as follows:

1. **Waste type and treatment method known:** When both the type and quantity of waste, as well as the treatment method, are known, emissions are calculated using treatment-specific emission factors from DEFRA (2025) and the US EPA (2025), corresponding to the relevant waste type. The potential waste treatment methods include reuse, recycling, incineration with energy recovery, biological treatment (composting or anaerobic digestion), landfill, and incineration (without energy recovery), with reuse regarded as having a neutral waste emission contribution.

2. **Waste type known, treatment method unknown:** When the waste type is known but the specific treatment method is unknown, emissions are estimated by applying the worst-case scenario treatment for that waste type. This means assuming:

    - Landfill for *general waste*, *food losses*, and *paperboard*;
    - Incineration without energy recovery for *metals*, *plastics*, and *glass*.

3. **Mixed or unknown waste composition and unknown treatment method:** In this case, when the waste stream is mixed and cannot be broken down by material, or its composition is unknown, and the treatment method is also unknown, the waste stream is categorized as general waste. Emissions are then estimated using the most emission-intensive treatment for this category: landfilling.

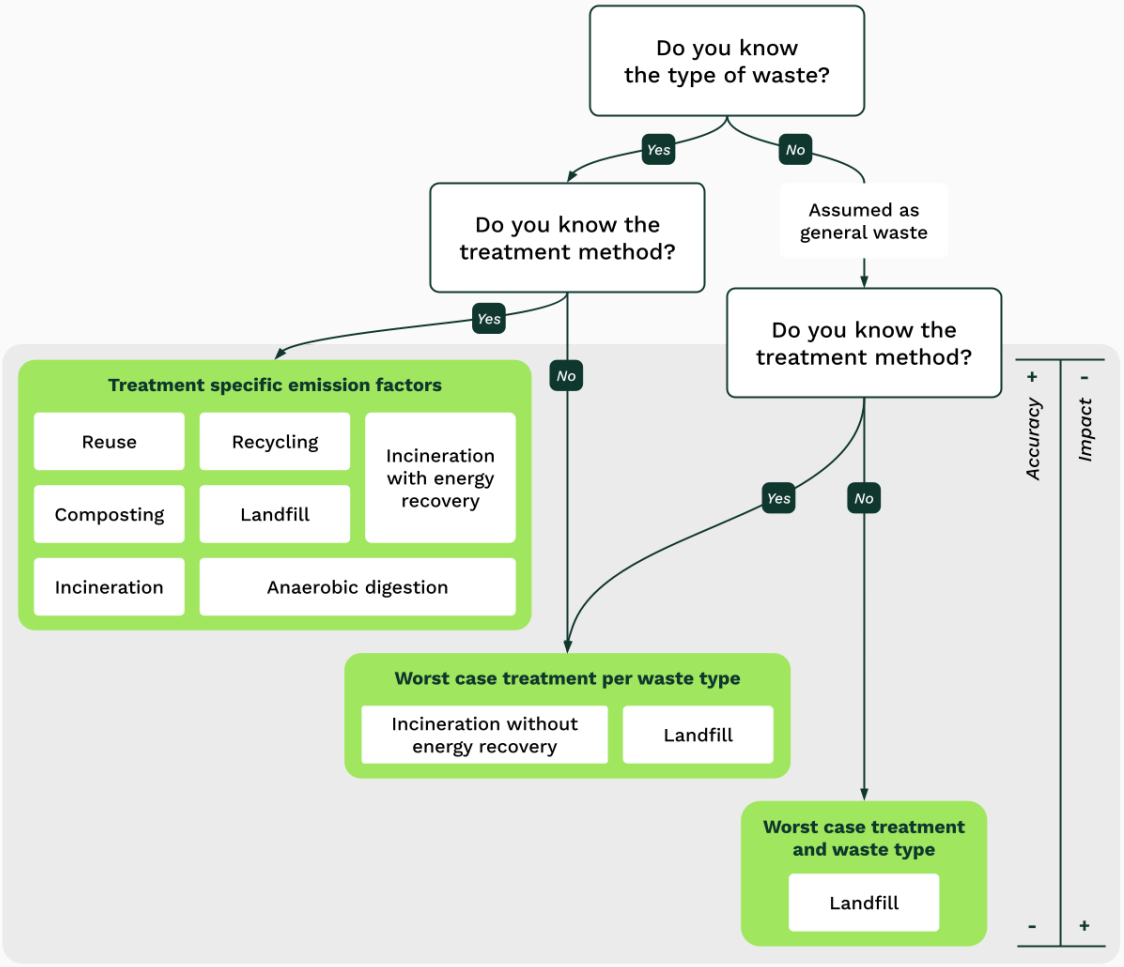


Figure 5: Tiered approach for waste treatment emissions, showing how reduced data availability leads to lower accuracy and potentially higher impact.

2.3.2.2. Storage

Emissions from the storage of the product at the production facility, prior to distribution, are included within the system boundaries of the assessment. These emissions are calculated following the methodology outlined in the Partnership for Carbon Transparency (PACT) framework.

A tiered approach is applied to estimate storage-related emissions (Figure 6), prioritising the most specific and accurate data sources:

1. **Primary site-specific data**:
   When energy consumption data is available, along with information on storage area used and total facility size over the storage period, emissions are calculated using the actual energy use of the facility, adjusted for the product's share of the storage area and the duration of storage. This approach is based on Equation 1:

$$CF\ storage = \frac{Area\ product}{Area\ total} \times Energy\ consumption\ site \times \frac{T\ storage}{365} \times EF\ country \quad (1)$$

2. **Hybrid approach using secondary storage benchmarks**:
   If primary energy data is unavailable, the assessment uses default energy demand values per storage type (ambient or cold) from the PEF 2021/2279 methodology (paragraph 4.4.5, p. 58), in combination with the product's storage area and time. Emissions are calculated using the following formulas:

$$CF\ storage\ =\ ((30\ +\ 100)\times EFcountry)\times Area\ product\times\frac{T\ storage}{365} \quad \textbf{(2)}$$

$$CF\ storage\ =\ ((30\ +\ 40\ +\ 100)\times EFcountry)\times Area\ product\times\frac{T\ storage}{365} \quad \textbf{(3)}$$

3. **Estimated emissions based on storage type**:
   In the absence of both energy data and facility-specific parameters, storage emissions are estimated using the method developed by Dobers, Perotti, and Fossa (2024). This approach approximates emission intensity for ambient and chilled storage based on typical storage conditions. It is continuously updated, and future revisions will be reflected in the Klimato methodology.

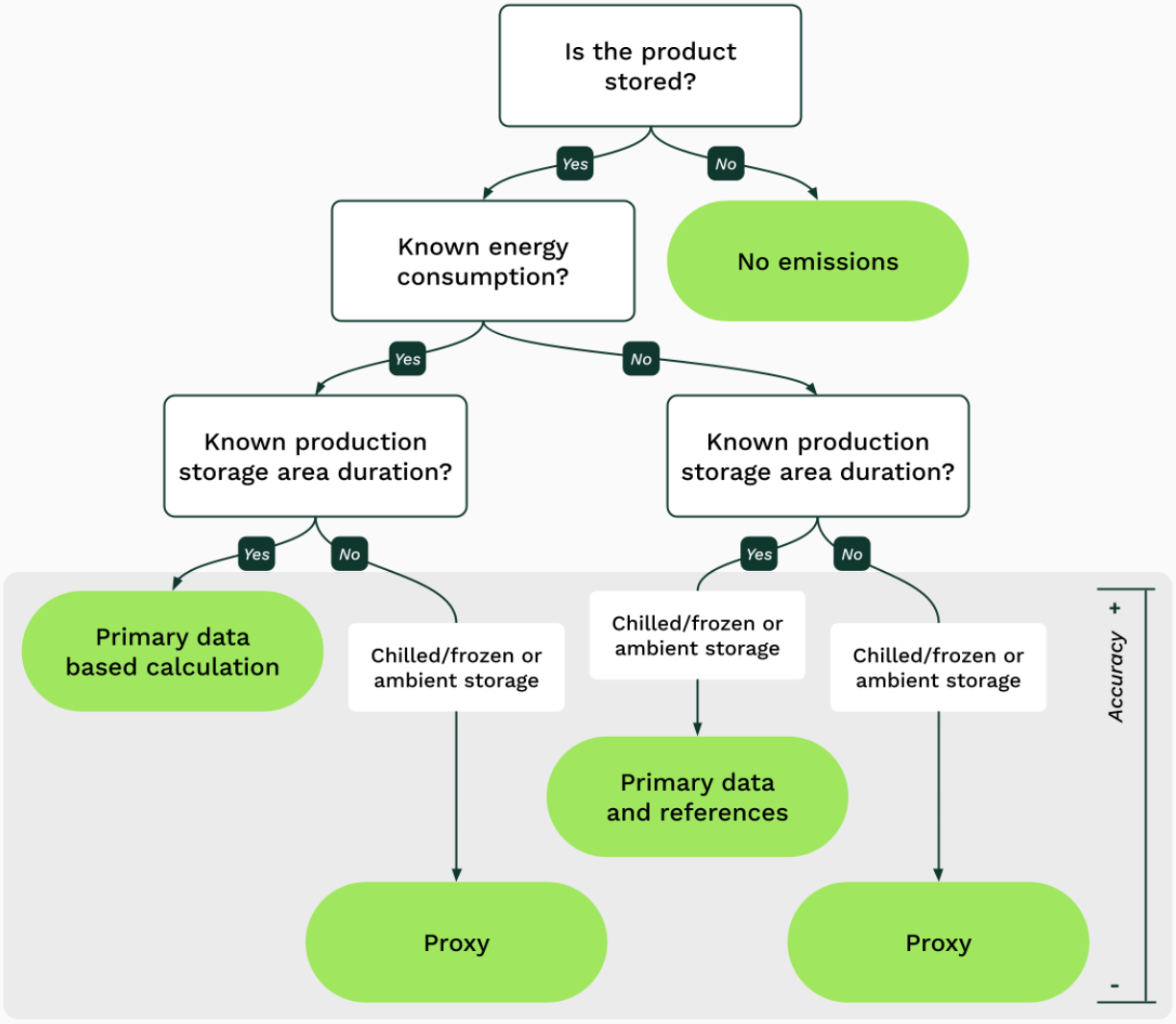


Figure 6: Tiered approach for storage emission estimation, showing how data availability influences estimation accuracy.

2.3.3. Packaging

Packaging emissions are included from material extraction through to distribution. This covers:

- Extraction and production of materials for packaging
- Manufacturing of primary and secondary packaging
- Transportation of packaging materials to production facilities
- Generation of packaging material waste

For packaging-related emissions, the reporting company provides primary data on the weight and material composition of both primary and secondary packaging. Specifically, the company must specify:

1. Total weight (kg) of each packaging material per unit of product.
2. Type of packaging material used (e.g., PET, paper, glass, cardboard).

The CF of each packaging type is calculated using packaging-specific emission factors, primarily sourced from DEFRA (2025) and supplemented by peer-reviewed literature, including Vink & Davies (2015), Stramarkou et al. (2021), K.K. Weththasinghe et al. (2022), Del Borghi et al. (2021), and technical reports such as Metsä (2023).

2.3.4. Material & packaging transport

This stage includes emissions from transporting materials and packaging from suppliers to the production site. While emissions from material and packaging transport are reported as separate sources, the methodology for estimating them is the same.

Both international and domestic transport, utilising various modes such as truck, ship, train, and plane, are incorporated into the calculations. Emissions are calculated in kg CO_2e per kg of product per km transported, using mode-specific emission factors from Mobitool (2023). These factors reflect a typical mix of transport operations that include refrigerated loads.

GHG emissions from aircraft transportation, when applicable, are included in the CF of the final product using emission factors from DEFRA (2025). More details are provided in the Aircraft Transport paragraph below.

The included mechanisms are as follows:

- Sourcing, production, transportation, and combustion of fuels;
- All relevant materials transportation activities within the study's system boundary;

The following aspects of **transport** are considered:

- Distance
- Transport mode (internal combustion and battery-electric vehicles)
- Transport geography

The calculation of the transport emissions is based on primary transportation data, when available, directly provided by the reporting company, accounting for both provided

transportation distance and transportation mode. When primary data are not available, the following assumptions are made:

➔ International Transport

- Distance Calculation:
    - Transport distances are calculated using the Harvesine formula based on latitude and longitude coordinates for the origin and destination. A multiplication factor of 1.3 by Diaz, Hendey and Winters (2003) is applied for road and train transport to account for the real-life distance between direct air distance and ground transport.
    - For air transport, a conservative estimate of the longest reasonable direct distance is applied.
- Transport Modes & Assumptions:
    - Within Europe: Truck transport is assumed as the dominant and Diesel Articulated truck with a Euro 4 - 2006 rating.
    - Within North America (U.S., Canada, Mexico): Truck transport is assumed based on predominant freight logistics.
    - Within Latin America: Truck transport is used within the region.
    - Europe to Non-European regions: Cargo shipping is assumed for intercontinental transport.
    - Within the UK & Ireland: Primarily truck transport, as ship transport is negligible in emission contribution.
    - Within the UAE: Imports arrive primarily by ship; truck applies only to Gulf Cooperation Council neighbors.
    - Within Hong Kong: Truck transport is used for imports from China; shipping is assumed for other global imports.

  These assumptions are informed by a combination of academic literature, government data, and trade publications. Key sources include Gleave et al. (2015), national freight statistics (e.g., BTS Freight in America), industry reports (e.g., Kan-Haul's U.S. Food Transportation Infographic), and international trade snapshots (e.g., UAE Food and Agriculture Snapshot, 2022; Li et al., 2022 on global food miles).

➔ Domestic Transport

When the country of origin of the materials and the country where the product under study is manufactured coincide, domestic transport emissions are assigned from Klimato's transport database based on the typical transportation method in the specified country.

To estimate the CF associated with domestic food transport, Klimato applies a region-specific methodology. The approach focuses on identifying the dominant transport

modes, estimating average transport distances, and applying appropriate emission factors to calculate transport-related emissions. The methodology varies by region depending on data availability, infrastructure, and transport practices. More detailed information can be found in Appendix C.

➔ Aircraft Transport

In line with section 6.4.9.7 of ISO 14067:2018, GHG emissions from aircraft transportation, where applicable, are included in the CF of the finished product and reported separately. The emission factors are sourced from the GHG reporting: conversion factors 2025 reported by DEFRA (2025).

More specifically, Klimato applies DEFRA's 2025 emission factor of 0.531 kg CO_2e per tonne.km, which **does not** include a RF-multiplier. RF reflects the additional climate impact of non-CO_2 emissions at high altitude, such as contrails, water vapour, and nitrogen oxides, whose warming effects are not captured by CO_2 alone.

DEFRA's RF-inclusive value of 0.899 kg CO_2e per tonne.km reflects a RF multiplier of approximately 1.69, in line with DEFRA's 70% uplift guidance.

Klimato applies the RF-exclusive factor in line with ISO 14067 (section 6.4.9.7.) as aviation multiplier effects shall not be included in overall CF of the product, acknowledging the scientific uncertainty still associated with quantifying indirect effects of non-CO_2 aviation emissions.

➔ Default transport scenarios

If no specific data is available on transport distances and/or modes, and the origin of the material or packaging material used in the production of the main product is unknown as well, covered distances and transport modes are assumed by following the PEF 2021/2279 default scenarios (paragraph 4.4.3.4., p. 56), depending on whether the supplier is located within Europe or not. When applicable, aircraft transport is identified using industry-standard supply chain logistics, and its emissions are reported separately to enhance transparency.

2.3.5. Distribution

The distribution stage includes emissions from transporting the finished product from the production site to regional distribution centers, based on the list of destination countries provided by the reporting company.

Where available, additional data—such as transport mode, transport distance, and the percentage of total volume shipped to each country—are used to calculate a weighted average distribution footprint. This ensures the footprint reflects the actual share of product volume transported to each market. If distribution shares are not provided, a simple average is applied instead.

Calculations use the same assumptions and emission factors as those applied to material transport.

2.4. Allocation

When a production process generates multiple outputs (e.g., co-products or by-products), environmental impacts must be allocated among them. Allocation is necessary when impacts cannot be separated or avoided by subdividing processes, redefining the functional unit, or expanding the system boundaries.

In Klimato's assessments, allocation is applied to processes that produce multiple outputs, taking into account their distinct economic and physical characteristics. The following sections outline the specific allocation methods used for different processes and life cycle stages.

2.4.1. Material Acquisition and Pre-Processing

For upstream stages—such as raw material extraction and pre-processing—where secondary emission factors are applied, the allocation method follows that of the original literature sources.

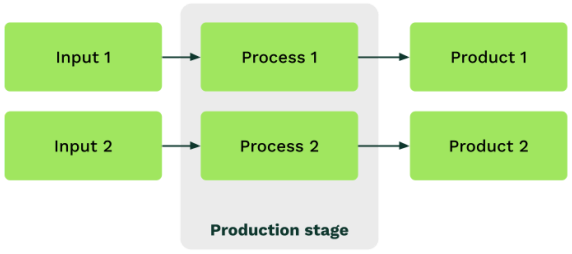
These methods are chosen for their relevance, consistency with comparable studies, and alignment with industry best practices. While Klimato does not control their initial selection, we ensure they are rooted in established guidelines, providing a reliable and defensible basis for CF analysis.

2.4.2. Production Stage

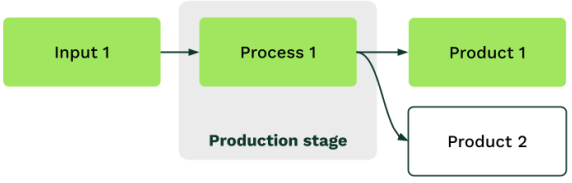
At the production stage level, the method of allocating emissions between outputs depends on whether the facility produces **co-products** or **by-products**, and, in the case of co-products, also on the approach chosen by the reporting company to assess emissions from the production stage (Section 2.3.2.).

Co-product vs. By-product

Co-products: Outputs produced in the same facility as the product under study, but from different ingredients or production lines. They have a similar market value to the main product.



By-products: Secondary outputs with significantly lower market value than the product under study, generated from the same production line.



2.4.2.1. Co-products (“per equipment” approach)

If emissions are calculated based on energy use data for specific equipment with the “per equipment approach” (Approach 1):

- In the presence of co-products, **no allocation is needed**, as the reporting company provides data about the machinery used per process for the product under study (e.g., duration, power in kW, and batch size). From this data, the energy use is calculated per process and is already linked to the specific product. No allocation is needed, as energy use is directly tied to each product.

2.4.2.2. Co-Products, “at the factory” approach

If the facility generates co-products:

- Emissions are distributed across products based on **physical allocation by mass**.
- Methodological consistency is ensured when no single product dominates.
- While this approach does not account for potential differences in energy intensity or density among co-products, it is considered transparent, neutral, and conservative.

Example: **Oat Milk and Almond Milk**

Scenario
A factory makes oat milk and almond milk. They use the same energy system, so it’s not possible to measure exactly how much energy each product uses.

What we do
We split the emissions based on how much of each product is made.

In this case
The factory emits 1,000 kg CO_2e per month from energy.

Every month, it produces:
- 8,000 kg of oat milk
- 2,000 kg of almond milk
- Total = 10,000 kg

So we split emissions like this

- Oat milk = 80% of the output
  → gets 800 kg CO_2e
- Almond milk = 20% of the output
  → gets 200 kg CO_2e

2.4.2.3. By-Products

When the process generates by-products, economic allocation is applied based on the market value of each output.

Market value is defined as the price received by the food producer when selling the main product and by-product to the next buyer in the value chain, and therefore the selling price paid by the downstream customer at the point of allocation.

Example: **By-product Allocation: Oat Milk and Oat Meal**

Scenario
A food manufacturer produces milk using oats as the main ingredient. When making the milk, a lower-value by-product called oat meal is also produced (e.g., sold for animal feed or other uses).

Application of economic allocation
Since the process generates two outputs, oat milk and oat meal, the emissions between the two products are allocated between them based on market value. This is achieved by calculating an allocation factor for each product, defined as its total economic value (mass multiplied by market value) divided by the sum of the total economic values of all outputs **(Equation 4)**:

$$Allocation\ Factor_{Product\ 1}(\%) = \frac{Mass_{Product\ 1} \times Market\ Value_{Product\ 1}}{\sum_{i=1}^{n} Mass_{Product\ i} \times Market\ Value_{Product\ i}} \times 100 \quad \textbf{(4)}$$

In this case
The factory emits 1,000 kg CO_2e per month from energy for the combined process.

Every month, it produces:
- 8,000 kg of Oat Milk
- 1,500 kg of Oat Meal

Market values:
- Oat Milk: €3.00 / kg
- Oat Meal: €0.20 / kg

Calculation of Economic Value per Product
- Economic Value of Oat Milk
  = 8,000 kg * €3.00/kg = €24,000
- Economic Value of Oat Meal
  = 1,500 kg * €0.20/kg = €300
- **Total Combined Economic Value**
  = €24,000 + €300 = €24,300

We split the emissions like this
- **Oat Milk:**
  Allocation Factor
  = (€24,000 / €24,300) * 100% ≈ **98.77%**

  This means Oat Milk is allocated 98.77% of the emissions.

  Emissions allocated to Oat Milk
  = 98.77% * 1,000 kg CO_2e = **987.7 kg CO_2e**

- **Oat Meal:**
  Allocation Factor
  = (€300 / €24,300) * 100% ≈ **1.23%**

  This means Oat Meal is allocated 1.23% of the emissions.

  Emissions allocated to Oat Meal
  = 1.23% * 1,000 kg CO_2e = **12.3 kg CO_2e**

Why?
Because the Oat Milk is the product driving the process economically. Thus, more emissions are assigned to the high-value product.

2.4.3. Recycling and Waste Treatment

Allocation is also applied to processes involving recycling or waste treatment, particularly when energy recovery is part of the process. In these cases, the environmental impact is shared between more than one product life cycle—the product that provides the recycled material or recovered energy, and the subsequent product that uses them. Proper allocation ensures impacts are distributed fairly and consistently.

Klimato's assessments use the recycled content (cut-off) approach, which assigns the environmental impacts of recycling and/or energy recovery to the life cycle of the product that uses the recycled material or recovered energy, rather than the one that generates the waste.

Under this approach:

- The product **incorporating recycled materials** (e.g., the product from Food Producer 2 in Figure 7 is assigned the emissions from the recycling process itself.
- The product **from which the waste originated** (e.g., the product from Food Producer 1 in Figure 7 is responsible only for the emissions from waste collection and pre-treatment. The recycling stage falls outside its system boundary.

This methodology is fully aligned with the GHG Protocol and is also recommended by other leading frameworks, including PACT and the Product Environmental Footprint (PEF) 2021/2279.

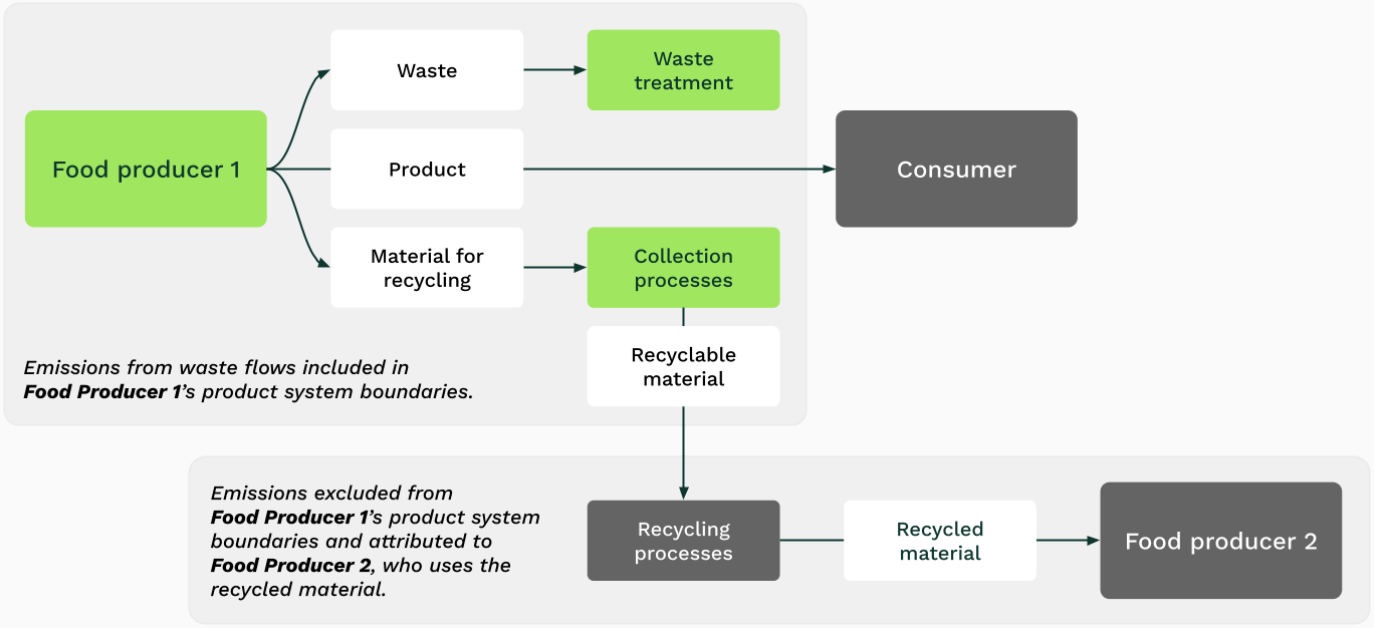


Figure 7: Allocation of waste treatment and recycling emissions illustrating how emissions from waste treatment and recycling are allocated between Food Producer 1, who generates waste and recyclable material, and Food Producer 2, who uses the recycled material. Adapted from PACT (Section 3.3.2.3., p. 34).

2.5. Biogenic Emissions

Biogenic GHG emissions are reported separately from fossil and land-use change (LULUC) emissions, in line with ISO 14067:2018. These emissions include CO_2, CH_4, and N_2O released from biological sources such as crops and livestock.

Biogenic CO_2 is typically considered climate-neutral when uptake and release occur within the system boundary. However, biogenic **methane (CH_4)** and **nitrous oxide (N_2O)** must always be included due to their high global warming potentials. To enable separate reporting of biogenic emissions, Klimato applies **biogenic emission shares** from **Agribalyse 3.2**, a peer-reviewed life cycle inventory database maintained by ADEME.

Calculation approach:

1. Each ingredient's biogenic share, the percentage of its emissions attributable to biogenic sources, is taken from Agribalyse.
2. This share is weighted based on the ingredient’s contribution to the product's total weight.
3. The weighted biogenic shares are summed across all ingredients to determine a product-level biogenic share.
4. This final percentage is applied to the total product CF to calculate the biogenic emissions in kg CO_2e.

Only emissions from agriculture, production, packaging, and distribution stages are included, in line with Klimato’s cradle-to-distribution system boundary.

Biogenic emissions are reported only when they constitute ≥5% of the total product carbon footprint, consistent with ISO’s materiality threshold. When a direct match is unavailable in Agribalyse, conservative estimates based on average values for similar the ingredient’s food group is applied.

2.6. Reporting Carbon Footprint Results

This section explains how the CF results are presented in the product report.

The total CF is reported in kilograms of CO_2e per kilogram of product and per selling unit.

To ensure transparency and identify key impact areas, emissions are broken down by life cycle stage. For each stage, the report shows both the absolute emissions and their percentage share of the total footprint, in alignment with GHG Protocol requirements.

Figure 8 and **Table 1** provide an example of how results are presented.

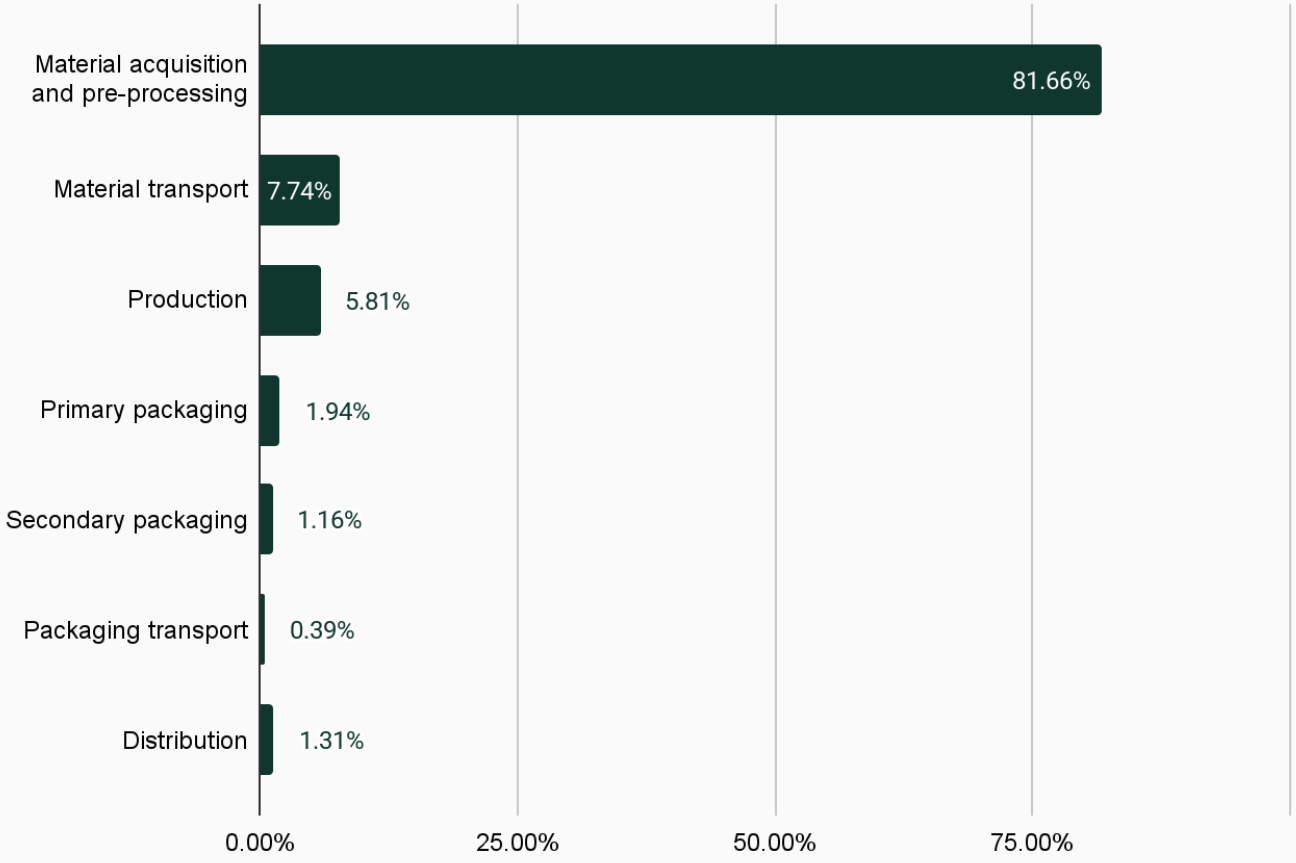


Figure 8: Breakdown of emissions per life cycle stage (Illustrative example)

Table 1: Share of emissions per life cycle stage (Illustrative example)

LCA stage	kg CO_2e/kg	Share of emissions
Material acquisition and pre-processing	2.11	81.66%
Materials transport	0.20	7.74%
Production	0.15	5.81%
Primary packaging	0.05	1.94%
Secondary packaging	0.03	1.16%
Packaging transport	0.01	0.39%
Distribution	0.03	1.31%
Total	2.58	**100%**

In alignment with the *GHG Protocol* and *ISO 14067:2018*, specific breakdowns of emissions are also provided:

- **Cradle-to-factory gate emissions:** All emissions from material acquisition up to the point when the product leaves the reporting company's factory.
- **Gate-to-gate emissions:** Emissions occurring while the product is under the ownership or control of the reporting company, corresponding to the 'Production' stage.
- **Land Use Change (LUC) emissions:** Reported separately to highlight their contribution to the material production stage.
- **Biogenic emissions**
- **Aircraft transport emissions**
- **FLAG emissions:** As required by SBTi's FLAG guidance.

Table 2: Breakdown of emissions, showing total cradle-to-distribution emissions and separate reporting of key emission sources in line with international standards (Illustrative example)

Inventory results	**kg CO_2e/kg**
Cradle-to-distribution emissions	2.11
Cradle-to-factory gate emissions	2.08
Gate-to-gate emissions	0.15
LUC emissions	0.08
Biogenic GHG emissions	0.12
Aircraft transport emissions	0.00
SBTi FLAG emissions (forestry, land and agriculture)	
FLAG emissions	2.11
of which land management (agriculture)	2.03
of which land use change (CO2 and non-CO2)	0.08

To help interpret the results and place the CF of the finished product into context, the Klimato report also includes the average cradle-to-distribution emissions of several widely consumed food commodities for reference as shown in Figure 9. These figures are obtained using the WRI Coolfood Calculator (2019) for the EU, which provides regularly updated, cradle-to-distribution CF values based on Poore & Nemecek (2018) and other peer-reviewed data sources.

Figure 9: Average cradle-to-distribution emissions of several widely consumed food commodities.

Including these reference values in the report allows the results of the assessed product to be viewed in relation to commonly consumed foods, providing an indicative sense of scale. These values are provided for indicative purposes only and are not intended for comparison or claim for environmental superiority. Due to methodological variability, regional differences, and product-specific characteristics, such comparisons do not constitute a validated comparative assertion under ISO 14067:2018 or the GHG Protocol Product Standard.

2.7. Data

Klimato CF assessment is based on activity data collected by the reporting company for energy use, ingredient sourcing, transportation, and packaging, combined with emission factors from the latest version of Klimato's food CF database and emission factors sourced from internationally recognized sources such as DEFRA (2025), Mobitool (2023), Our World in Data, and the AIB residual electricity mix (2024).

Table 3 below provides an overview of the main data sources used in Klimato's CF assessments, distinguishing between primary data collected from the reporting company and secondary data drawn from recognised emission factor databases:

Table 3: Overview of data sources in Klimato's CF assessments

Data Type	Data Source	Examples
Primary Activity Data	*Reporting company*	• Ingredient sourcing and quantities, • Energy consumption at the production facility, • Packaging materials and weights, • Transport modes and distances.
Emission Factors – Ingredients & Packaging	*Klimato Database (country- and ingredient-specific)*	Emission factors for production of ingredients (e.g., soy protein, flour, food additives) and packaging materials
Emission Factors – Energy, Transport, Waste	*External datasets (e.g., DEFRA 2025, Mobitool 2023, AIB 2024)*	• Grid electricity, • Freight transport, • Waste treatment processes

The calculations and assumptions for each life cycle stage are described in Section 2. For more information on the Klimato database, see Section 3.

2.7.1. Data Quality

To evaluate key data quality aspects, including reliability, completeness, and representativeness, a quantitative data quality assessment is conducted.

The data quality assessment supports transparency, facilitates third-party assurance, and demonstrates to stakeholders the level of confidence in the data behind the product footprint.

Data quality is assessed using a **pedigree matrix**, which scores the five key indicators presented in Table 4.

Table 4: Description of data quality indicators

Indicator	Description
TE: Technological representativeness	How closely the data reflects the actual technology or process
TI: Temporal representativeness	How recent the data is compared to the activity year
GE: Geographical representativeness	Whether the data reflects the region where the activity occurred
CO: Completeness	Coverage of GHGs, stages, and variability in the data
RE: Reliability	Whether the data is measured, calculated, estimated, or assumed

Klimato assesses the quality of both:

- **Activity data** provided by the reporting company
- **Emission factors** used in the calculations

The data quality assessment occurs in different steps: a visual representation of this process is provided in Figure 11.

Activity Data Scoring

1. The **reporting company completes a self-assessment**, answering questions (Appendix C) based on the five indicators per each life cycle stage.

   By replying to the questions, they rate each indicator on a 1–4 scale:
   1 = Very good, 2 = Good, 3 = Fair, 4 = Poor

2. Each life cycle stage now has several scores, one per indicator. Therefore, it is necessary to obtain one single score per each life cycle stage.

   For this purpose, a **Data Quality Rating (DQR)** is calculated per life cycle stage (Figure 4) using the PEF 2021/2279 formula (2021/2279, paragraph 4.6.5.1., p.96) as shown in Equation 5:

   $$^{1}DQR = \frac{(TeR + GeR + TiR + Co + Re)}{n} \quad \textbf{(5)}$$

3. Finally, An aggregated DQR is calculated according to Equation 6 from the PACT framework (2021):
   $$DQRindicator = DQRcomponent1 \times \left(\frac{PCFcomponent1}{PCFtotal}\right) + \ldots + DQRcomponent6 \times \left(\frac{PCFcomponent6}{PCFtotal}\right) \quad \textbf{(6)}$$

Table 5 presents the output of the data quality assessment, showing exemplary scores based on a hypothetical set of responses to the questionnaire. The last column reports the Data Quality Rating (DQR) for each life cycle stage. Figure 10 provides an example of how an aggregated DQR is presented within the report, while Table 6 shows how the DQRs should be interpreted.

Table 5: Example of a qualitative data quality assessment on activity data provided by the reporting company.

Process stage	TE	TI	GE	CO	RE	DQR
Materials acquisition and pre-processing	1	2	2	2	3	**2.0**
Materials transport	2	1	/**	1	4	**1.8**
Production	1	1	1	1	1	**1.0**
Packaging production	/*	2	4	3	2	**2.8**
Packaging transport	4	2	/**	4	4	**3.5**
Distribution	1	1	/**	1	2	**1.3**

*Technological representativeness is excluded as a quality indicator for packaging data because the collected data only covers the type and quantity of packaging materials used (e.g., PET, cardboard)—not the specific manufacturing technologies (e.g., injection

[1] *TeR, GR, TiR, Co, Re: DQR key indicators*
n: number of quality indicators considered for the specific stage.

molding, thermoforming). Klimato applies LCI datasets that already incorporate representative industry-average technologies for packaging materials. Since the technological representativeness of these datasets is evaluated as part of the emission factor quality assessment, including it again at the activity data level would be redundant and would not enhance overall data quality. Adding it at this stage could also introduce unnecessary complexity.

**Geographical representativeness is excluded as a quality indicator for transport data because the geographical context is already captured through other indicators—particularly technological representativeness and completeness. The precision of geographical information (e.g., how accurately the origin, destination, and route are reflected) is inherently linked to the level of detail provided on transport mode and distance. As such, geographical representativeness is a direct outcome of these factors. Including it as a separate indicator would be redundant and unlikely to improve the overall assessment of transport data quality. For further detail on how these aspects are evaluated, see the transport data quality questionnaire in the Appendix.

Figure 10: Example Aggregated Data Quality Rating (DQR)

Table 6: Interpretation of the aggregated DQRs.

DQR Range	Overall Data Quality Level
DQR ≤ 1.5	● Very Good Quality
1.5 < DQR ≤ 2.5	● Good Quality
2.5 < DQR ≤ 3.5	● Fair Quality
DQR > 3.5	● Poor Quality

Emission Factors Scoring

1. Klimato conducts a separate assessment of its **emission factors database** using the same indicators (Table 4). The scoring criteria are slightly different from the ones used in assessing activity data as, for the **completeness** indicator, criteria are adapted from WRAP's *Scope 3 GHG Measurement & Reporting Protocols* (Version 2, 2024), as standard definitions (e.g., those in the ILCD Handbook or the GHG Protocol) are less suitable for assessing emission factor data (Table 8).

2. DQRs are calculated for each stage using **Equation 5**, following the same approach applied to the activity data.

3. An aggregated DQR is calculated according to **Equation 6**, following the same approach applied to the activity data.

Table 7: Quantitative data quality assessment of Klimato emission factors used to quantify GHG emissions *(TE: technological representativeness, TI: time representativeness, GE: geographical representativeness, CO: completeness, RE: reliability, DQR: data quality rating; scored from ● 1 = very good, ● 2 = good, ● 3 = fair, ● 4 = poor).*

Process stage	TE	TI	GE	CO	RE	DQR
Materials acquisition and pre-processing	2	2	2	3	2	**2.2**
Materials transport	2	2	2	3	2	**2.2**
Production	2	1	2	3	2	**2.0**
Packaging production	2	1	3	3	2	**2.2**
Packaging transport	2	2	2	3	2	**2.2**
Distribution	2	2	2	3	2	**2.2**

Table 8: Klimato Emission Factor Quality Scoring Criteria

Quality indicator	Very good	Good	Fair	Poor
TE	Emission factors based on the exact technology or process used.	Similar but not identical technology.	Different technology or proxy data.	Unknown technology.
TI	Emission factors are less than 3 years old relative to the activity year.	3 to less than 6 years old.	6 to 10 years old.	More than 10 years old, or the publication year of the emission factor is unknown.
GE	The emission factors refer to the same geographic region as the activity (i.e., same country).	The emission factors refer to a similar region.	The emission factors refer to a different region.	The geographic origin of the emission factors is unknown.
CO	All appropriate life cycle stages and GHG are covered in both modelling and reporting. Emission factors (EFs) are highly representative of the studied system, derived from multiple high-quality and relevant data sources. Data account for variability (e.g., seasonal or annual fluctuations) and reflect actual production practices.	All appropriate life cycle stages and GHGs are included in both modelling and reporting. EFs are generally representative of the studied system, derived from a reasonable number of relevant sources. Data may not capture all variability, but still provide a sound basis for assessment.	All appropriate life cycle stages and GHGs are included in modelling, but not consistently in reporting. EFs are only partially representative of the studied system being based on a limited number of sources.	Some appropriate life cycle stages or GHGs are missing from the model and/or reporting. EFs are not representative of the studied system, being based on irrelevant or outdated sources, or derived using unclear or unreliable methodologies.
RE	The emissions factors are based on measurement or observation.	Based on measurement and partly on modeling/calculations .	Based on assumptions or qualified estimates (e.g., by a sector expert).	Non-qualified estimate.

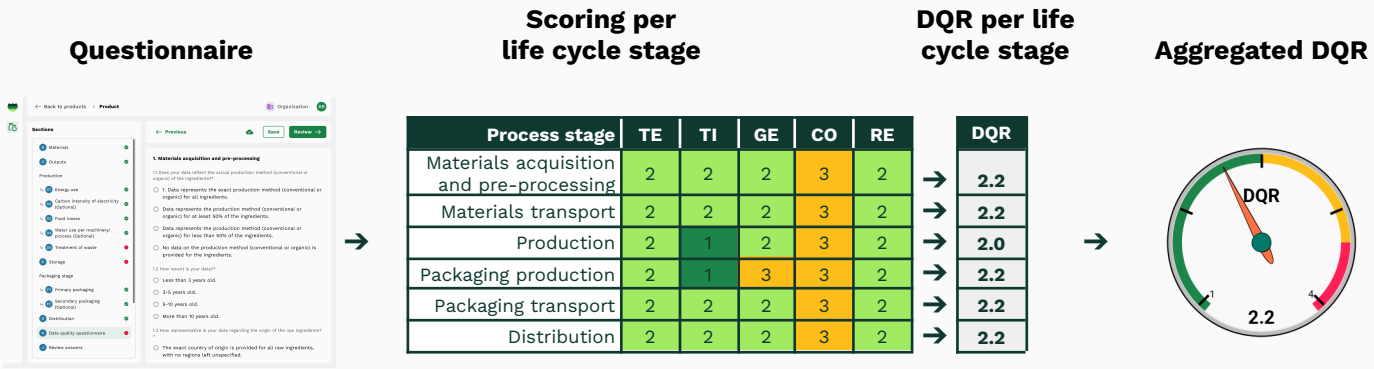


Figure 11: The comprehensive data quality assessment process, from indicator scoring to the aggregated DQR.

2.8. Sensitivity Analysis

Klimato assesses the sensitivity of key parameters involved in the CF calculation of the product. In addition, it evaluates the sensitivity of key methodological assumptions, such as the approach used for distance calculations and the treatment of biogenic emissions. Results indicate that both methodological choices introduce only limited deviations, supporting their use.

2.8.1. Parameters

As required by ISO 14067, an analysis is conducted to assess the sensitivity of the CF results by evaluating the impact of key parameters. The purpose of this analysis is to identify how variations in significant assumptions and data inputs affect the total CF of the finished product.

Following ISO 14067 guidelines, all relevant input parameters are systematically assessed by increasing each by 10%, and the corresponding change in total emissions is assessed.

An example of how sensitivity analysis results are presented is shown in Figure 12.

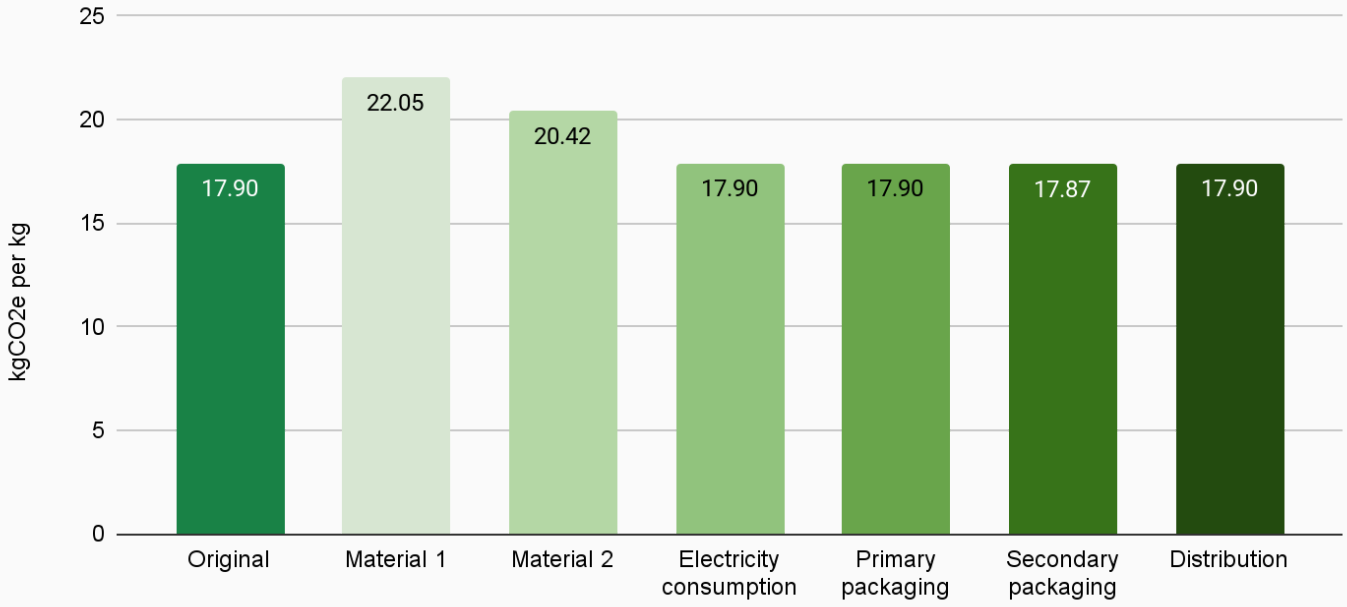


Figure 12: This exemplary graph illustrates how the total carbon footprint would change for each selected parameter when its input is increased by 10%, shown parameter by parameter.

2.8.2. Transport distance

A sensitivity analysis is also conducted on the report's transport distance calculation. As explained in Section 2.3.4., when primary data on transport distances are unavailable, distances are estimated using the Haversine formula based on the latitude and longitude of the origin and destination. A multiplication factor of 1.3 is then applied to approximate the real-world difference between straight-line (air) distance and actual ground transport routes.

To evaluate the impact of using direct air distances adjusted by a factor of 1.3, versus actual road distances, a sample of transport routes was assessed. The results displayed in Table 9 show that the adjusted distances deviate slightly from actual travelled distance, with an average deviation of only 2.58%, suggesting that the adjustment factor provides a sufficiently accurate approximation for actual road and rail transport distances.

Table 9: Sensitivity analysis of ground transport distances using the Harvesine formula and adjustment factor of 1.3, compared to real-life transport distances.

Origin	Destination	Air distance	Adjusted distance	Actual distance	Deviation
Finland	France	2298	2987.4	3134	-4.91%
Ukraine	Portugal	3270	4251	4106	3.41%
Italy	Netherlands	1266	1645.8	1618	1.69%
	Switzerland	649	843.7	837	0.79%
Sweden	Germany	1119	1454.7	1424	2.11%

2.8.3. Biogenic emissions

A sensitivity analysis was conducted to evaluate the robustness of biogenic emission shares from Agribalyse across diverse product categories and data sources. This was necessary due to inherent uncertainties related to the French context of the database.

Comparison datasets included:

- The Hestia inventory (for crops), which separates fossil, LUC, and biogenic emissions.
- Peer-reviewed literature and Environmental Product Declarations (EPDs), where biogenic emissions were explicitly stated or derivable.

All comparisons were standardized using the Klimato database total CF as the baseline. The absolute deviation in biogenic GHGs was calculated using Equation 7 below:

$$[2]Absolute\ Deviation = \frac{(KlimatoCF\ x\ BIOreference) - (KlimatoCF\ x\ BIOagribalyse)}{KlimatoCF} \quad \textbf{(7)}$$

A diverse range of ingredients was analysed to capture variation across plant-based and animal-based products, as well as different geographical production contexts.

The results of the sensitivity analysis are visualized in Figure 13, which presents the relative biogenic GHG shares for each product, based on Agribalyse, Hestia, and literature values, where available from adequate sources. Each chart also shows the absolute deviation from the Agribalyse biogenic share as a percentage value, calculated using the Klimato CF baseline. Full numerical results are detailed in Table 12 in Appendix E.

[2] BIOreference refers to the biogenic GHG emission share of the selected reference (e.g. Hestia, EPD, publication)

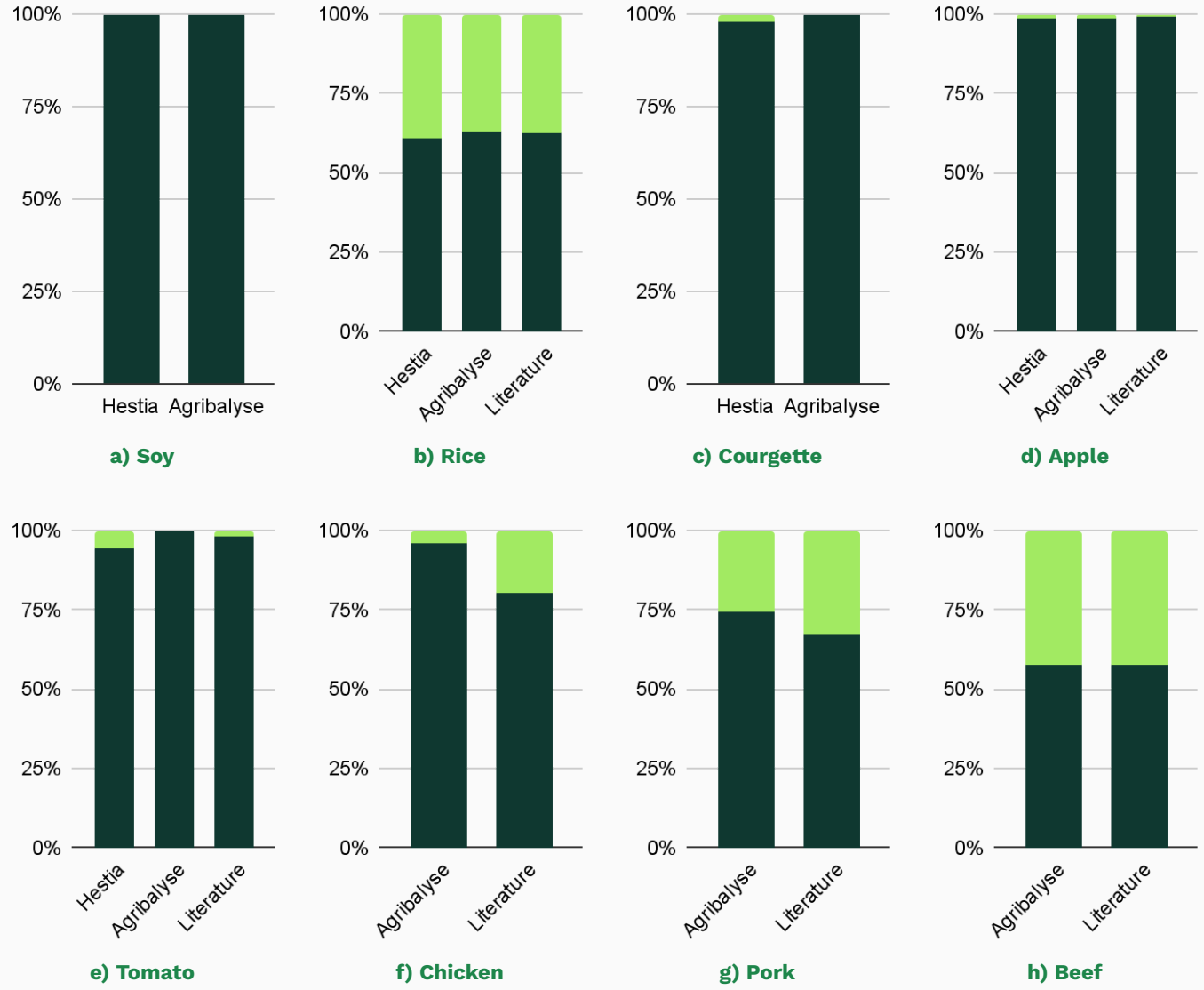


Figure 13: Result of the sensitivity analysis of variation in biogenic GHG contributions across datasets for a) soy, b) rice, c) courgette, d) apple, e) tomato, f) chicken, g) pork, h) beef.

Key findings:

- For ingredients with low biogenic contributions (e.g., soy), deviations between sources were minimal and had negligible impact on total biogenic emissions.
- For ingredients with high biogenic components (e.g., rice, beef, pork), greater variation was observed, mainly due to differences in CH_4 modelling and emission source categorisation.
- Deviations are expected due to differences in system boundaries, allocation methods, and treatment of biogenic vs. fossil sources.

Despite these differences, results confirm that Agribalyse provides consistent and suitable biogenic shares for most food products assessed. The analysis also highlights opportunities for further granularity, especially in animal-based systems where upstream emissions play a critical role in GHG classification.

2.9. Uncertainty and limitations

2.9.1. Allocation Uncertainty

The choice of the allocation method can introduce uncertainty when determining a product's CF, as different approaches may yield varying results depending on assumptions and data availability.

For example, when applying economic allocation (Section 2.4.2.3.), results could be uncertain due to market prices of product and by-products fluctuating over time and across regions or being uncertain, affecting how impacts are distributed. To address these challenges, Klimato ensures that allocation is based on the most up-to-date price data available.

When applying physical allocation based on mass (see Section 2.4.2.2.), it is important to acknowledge that uncertainties may arise. The direct relationship between mass and energy consumption may not always capture the full complexities of the production process. Factors such as process efficiency, material properties, operational conditions, and technology used could influence energy use and, thus, impact the accuracy of the allocation. Despite these potential uncertainties, physical allocation remains a widely recommended and commonly applied method, particularly when a clear and justifiable relationship between inputs and outputs exists.

2.9.2. Parameter Uncertainty

Parameter uncertainty refers to the variability in key inputs such as emission factors, activity data, and process-specific information. Although the Klimato database provides scientifically robust emission factor estimates, uncertainties may exist due to regional differences and data age.

Uncertainty can also result from activity data, for example, due to changes in production over time.

To enhance transparency and reliability, all parameter sources used in the calculations are clearly documented.

2.9.3. Model Uncertainty

The estimation of biogenic GHG emissions is based on ingredient-level biogenic carbon shares from the Agribalyse 3.2 database, which reflects French agricultural conditions. While Agribalyse provides high-quality, peer-reviewed LCI data, its geographic specificity introduces some uncertainty when applied to ingredients sourced from other regions. Variations in farming practices, climate, and supply chain structures can influence the actual biogenic share.

To address this, only life cycle stages up to distribution are included to ensure alignment with the defined system boundaries, and a 5% materiality threshold is applied to exclude immaterial values. Even so, as with any CF assessment, the biogenic carbon estimate should be viewed as an approximation and may vary depending on the ingredient's origin.

2.9.4. Methodological Limitations

While the study is based on the best available primary and secondary activity data, as well as Klimato's third-party validated emission factor database, some limitations remain due to the nature of carbon footprinting and LCA. These limitations are:

➔ ***Excluded life cycle stages:***
The use-phase and end-of-life stages are excluded because:

- They exhibit high variability due to consumer behavior;
- They fall outside the control of the producer, making consistent data collection difficult

➔ ***Excluded processes:***
Emissions from manufacturing capital goods in the production stage are excluded as non-attributable because they fall below the study's 1% cut-off threshold (emissions contributing less than 1% to the overall footprint).

➔ ***Use of default or average data***
Default or average data is used whenever product- or site-specific information is unavailable, including situations such as:

- Lack of primary data on transport modes and distances
- Lack of supplier-specific electricity consumption data
- Limited access to geographically precise sourcing information for certain ingredients

In these cases, Klimato:

- Uses assumed transport mode and estimated transport distances;
- Applies representative grid emission factors
- Relies on **proxy values** and **regionally averaged data**
- Addresses uncertainty through **clear and transparent assumptions**

➔ ***Heterogeneity of emission factors:***
Emission factors are drawn from various studies that are published at different times, use different life cycle impact assessment (LCIA) methodologies and are based on different assumptions and data contexts.

Because of this diversity, it is **not feasible to apply a single, harmonized LCIA method** across the entire dataset.

Therefore, emission factors reflect the **LCIA approach and version (e.g., method year)** in use at their time of publication. This results in methodological variation across the dataset, which is a recognized and documented aspect of the study.

➔ ***Characterization Factor Uncertainty:***
There are also limitations specific to the GWP values used as open-source databases (e.g., DEFRA) do not always disclose the characterization factors used for specific gases. This is especially critical for nitrous oxide (N_2O), whose GWP has varied significantly across different IPCC assessment reports (e.g., AR4, AR5, AR6).

As a result, the dataset contains GWP values from different IPCC reports, reflecting methodological diversity across sources. This variability in LCIA methods and GWP values is recognized as a methodological limitation of the study.

3. Klimato Database Methodology

At the core of Klimato's carbon footprinting is the Food Carbon Footprint Database—a comprehensive resource containing country-specific CF values for more than 4,000 food ingredients and over 20,000 variations across conventional and organic production systems.

This database is the foundation for generating emission factors for food commodities and ingredients in Klimato CF studies, particularly during stages such as material acquisition and pre-processing, where detailed, ingredient-specific data is essential.

The Klimato Database is verified by IVL, the Swedish Environmental Research Institute, and Coolfood, an initiative by the World Resources Institute (WRI), founding member of the GHG Protocol and Science Based Targets Initiative (access validation certificate).

3.1. Literature Review and Study Selection

The Klimato database is built on peer-reviewed studies that follow the LCA methodology to ensure the accuracy and relevance of its CF values. To develop the database, a systematic approach is employed for selecting studies that focus on the most relevant production regions and methods for food commodities. The specific criteria guiding this systematic selection process are detailed below.

3.1.1. Study Inclusion Criteria

Studies are evaluated against a comprehensive set of criteria to determine their suitability for inclusion in the database. Table 10 outlines these requirements along with the actions taken if criteria are not met, ensuring a transparent and consistent selection process.

Table 10: Evaluation Criteria for Inclusion.

Criterion	Requirement	Action if Not Met
LCA Type	Must be attributional.	Exclude study.
Publication Type & Credibility	The database primarily includes peer-reviewed journal articles by authors with strong credentials and affiliations. Citation count and journal reputation are considered indicators of reliability. University theses, conference papers, Environmental Product Declarations (EPDs), and certified LCA databases (e.g., Agribalyse) are also included when their methodologies are transparent and robust. Studies with unclear or inconsistent assumptions are flagged or excluded.	Gray literature (e.g., blogs, newspaper articles, social media posts) is generally avoided unless it directly links to a scientific source or peer-reviewed reference

Criterion	Requirement	Action if Not Met
Assumptions Transparency	Clear documentation of methodology, emission factors, and assumptions is required.	The study is rejected or flagged if assumptions are unclear or inconsistent.
Functional Unit (FU)	The FU shall be expressed per kg of edible product or be convertible to it.	Converted to the correct functional unit using appropriate factors (e.g., from carcass to bone-free meat).
System Boundaries (SB)	The SB should cover Material acquisition and pre-processing, Production, and Packaging.	Missing stages's emissions are estimated using Klimato modelling or Clune et al. data[3].
Stage Breakdown	Emissions should be broken down per life cycle stage.	Emissions from stages not reported separately are estimated using Klimato's modelling or data from Clune et al.
Land Use Change (LUC)	Studies should include direct or statistical LUC but exclude indirect LUC. If indirect LUC is included, it must be reported separately.	If direct or statistical LUC is provided and reported separately in the study, the source value is used. If direct or statistical LUC is included or mentioned but not reported separately, the LUC model is used to estimate the LUC emissions. If LUC is not mentioned, it is assumed that no direct or statistical LUC is involved. If indirect LUC is included and reported separately, the emissions from it are excluded from the final value used in the database. If indirect LUC is included but not reported separately, the study is excluded.
Carbon Sequestration	If included in the study, it must be clearly reported as a separate value.	Carbon sequestration emissions are removed when they can be separated; if not separable, the study is excluded.
Allocation Method	Studies applying physical and economic allocation are preferred, as the Klimato database only accepts attributional LCA	If a study uses system expansion, and it is the only available data source that otherwise meets the attributional

[3] Clune, S., Crossin, E. and Verghese, K., 2017. Systematic review of greenhouse gas emissions for different fresh food categories. Journal of Cleaner Production, 140, pp.766-783

Criterion	Requirement	Action if Not Met
	studies, and system expansion can bring in consequential thinking.	LCA requirement, it is accepted for inclusion. In all cases, regardless of the allocation method applied in the study, the allocation method is mentioned in the metadata of the Klimato database.
GHG Scope	Must include all Kyoto Protocol (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, NF_3) gases.	Excluded if the data cannot be corrected or supplemented to include all Kyoto Protocol gases.
Consistency with Literature	The study's results should generally align with the findings of similar LCAs in scientific literature.	If the study's emission values deviate significantly from similar LCAs in scientific literature, this deviation must be acknowledged and well-justified within the study itself. If such justification is absent or deemed insufficient, the study is excluded.
Date of Publication	Data sources should be published between 2009 and 2025. More recent studies (≤ 6 years) are preferred for dynamic or fast-evolving sectors (e.g., alternative proteins), while older data may be accepted for stable and consolidated processes (e.g., conventional dairy, cereal crops).	Studies published outside this temporal range are excluded unless no alternative data exist and the available study meets the representativeness criteria.
Representativeness	The study should reflect the dominant or typical production systems used in the region or country, such as national or regional averages. Studies focusing on experimental, pilot-scale, or highly innovative systems that are not yet widely adopted should be deprioritised unless no other data exists.	Flagged for potential lack of generalizability.
Comparative Studies	All else being equal, studies that compare conventional and organic systems under the same methodological conditions are preferred.	If no suitable comparative study exists, use separate studies that individually meet Klimato's criteria. If no organic-specific data is available, assume emissions for organic are equal to conventional, and clearly document the assumption in the database.
Review or Harmonized Studies	All else being equal, review studies or comprehensive datasets that provide harmonized emissions data across ingredient categories using consistent methods are preferred.	/

3.1.2. Preference Hierarchy When Multiple Studies Are Available

When multiple data sources are available for the same ingredient in a given country or region (e.g., several studies on milk production in Sweden), and all meet the core quality criteria, the following hierarchy is used to select the most appropriate source:

1. **Representativeness** of the system for the country/region: the selected source should reflect the most representative national or regionally dominant production systems. For example, if one study covers intensive beef production and another covers extensive farming, but the majority of beef consumed in the country is produced through intensive systems, the study on intensive production is preferred. If no information is available on the dominant production system in the country or region, studies are compared based on other criteria in this hierarchy.
2. **Recency**: Most recent (up-to-date) study. Data must reflect current practices.
3. **Methodological transparency**: Highest level of methodological transparency and data clarity to ensure results can be trusted and understood.
4. **Granularity:** Most detailed breakdown of life cycle stages.

Sometimes, a selected study includes multiple production methods. In such cases, if one method clearly dominates national production (e.g., most of the meat consumed is produced intensively), we use the value corresponding to that method. If no information is available on the dominant method and production volumes are similar (i.e., within 25% of each other), we use an average. If production volumes differ significantly, we use the value corresponding to the method with the higher production share. This approach is consistently applied across all products with multiple production methods, including meat, vegetables, and fruits.

3.2. Functional Unit

CF values in the database are expressed in kilograms of CO_2e per kilogram of food product as the functional unit. For meat and fish products, values are reported per kilogram of bone-free meat (BFM), with conversion factors from live weight or carcass weight to BFM based on Clune et al. (2017).

3.3. System Boundaries and Life Cycle Definitions

The CF values in the Klimato database encompass emissions from multiple stages of the food product's life cycle, including the agricultural stage, processing, and packaging. Emissions associated with food losses are also taken into account.

The definitions of each stage, along with a detailed breakdown of what is included, are provided in the following sections.

3.3.1. Agriculture & Land Use Change

This component accounts for the share of the CF resulting from the agricultural stage, including emissions from LUC.

Agriculture
This value can be sourced directly from literature (including calculations derived from published data), estimated through Klimato's internal models, or approximated using proxy data. For more details on how proxy data and models are applied, please refer to Section 3.5.1. and Section 3.5.2., respectively.

Land Use Change
For information on how LUC is incorporated into Klimato's assessments, please refer to Section 2.3.1.1.

3.3.2. Processing

This stage represents the share of the CF attributed to the processing stage of the ingredient, if any. This value can be sourced from the literature, derived from a model, or estimated. When a specific model is not available or considered unnecessary, default parameters based on the ingredient type are applied.

3.3.3. Packaging

The packaging stage represents the share of the CF attributed to the packaging of the ingredient, if any. The value can either come from the literature paper, or be estimated. In this case we use a default parameter depending on the type of ingredient and packaging.

3.3.4. Food losses

At Klimato, we follow the definition of food losses and food waste provided by FAO (2011). According to this definition, food losses and waste refer to the quantities of edible food intended for human consumption that are lost or discarded along the food supply chain. This excludes food used for animal feed or inedible parts of food products. The key distinction between the two lies in where they occur: food losses occur during production (including harvest and pre-harvest operations), post-harvest handling, and processing, while food waste takes place at the end of the food chain (retail and final consumption), mainly due to retailers' and consumers' behavior.

The carbon footprints of food products in Klimato's database account for the impact of food losses. Following Poore and Nemecek (2018), we include losses from postharvest handling and storage, as well as processing and packaging. Losses occurring before or during harvest are excluded. This approach is consistent with FAO's methodologies for developing food balances (FAO, 2023) and monitoring the SDG Target 12.3.1 Global Food Loss Index (FAO, 2018).

To incorporate food losses into Klimato's carbon footprints, weight percentages of losses for each food category are used to estimate the additional quantity of food required to deliver one

kilogram of product. Loss percentages for postharvest handling and storage, and for processing and packaging, are primarily sourced from FAO (2011; Annex 4, p.26–27). For food categories not covered by FAO (e.g., coffee and spices), data from Waite et al. (2019), as provided in the Coolfood Calculator, are used.

Since FAO (2011) reports regional loss values, we calculated global weighted averages for each category using regional domestic supply data from FAO's food balances (FAO, 2021). Based on these loss percentages, carbon footprints are then calculated to include the additional GHG emissions associated with producing the extra food needed to compensate for losses.

3.4 Allocation

Ingredient-level CF estimates in the Klimato database adopt the allocation methods used in the original data sources.

Studies applying physical or economic allocation are preferred, as the Klimato database only accepts attributional LCA studies. System expansion is generally avoided because it introduces elements of consequential thinking. However, if system expansion is used in a study that otherwise meets the attributional LCA criteria and is the only available data source, it may be accepted. In all cases, the allocation method applied in each study is documented in the metadata of the Klimato database.

3.5. Dealing with lack of data

In cases where specific literature values are absent, Klimato resorts to **proxy data** or **internal models**. Proxy data involves attributing the CF of a similar food product based on shared characteristics like food category, cultivation methods, and country similarities (climate, soil, energy mix). Internal models are proprietary estimation models applied for data gaps or when existing sources do not cover all life cycle stages, built using data from peer-reviewed sources (e.g., for Land Use Change, Processing, and Packaging).

3.5.1. Proxy data

During a literature review, it is possible to encounter a lack of data regarding certain food types or production countries, resulting in unknown food CF values. In these cases Klimato makes some assumptions.

Klimato attributes to a food product the same CF of another when:

- two countries have similar climate, soil, food production methods and energy mix (e.g., the known value for potatoes produced in Sweden is assigned to potatoes produced in Norway whose CF is unknown).
- the food belongs to the same food category (e.g., equivalent to fruit must be another fruit), and

- the food has the same cultivation and/or production methods (e.g., equivalent to a vegetable grown in a greenhouse must be another vegetable also grown in a greenhouse).

3.5.2. Models

In the absence of specific CF data for certain ingredients, or when available sources do not cover all life cycle stages within Klimato's system boundaries, estimation models may be applied as a secondary option. These models are built using data from peer-reviewed sources, including conversion ratios, processing yields, energy consumption figures, or other relevant parameters, depending on the type of ingredient. Their purpose is to derive reasonable estimates for the Agriculture and/or Processing stages of ingredients not directly covered in the literature.

These models currently support a range of ingredients and food categories, such as:

- Meat conversions (e.g., live weight to boneless meat)
- Processed meat and fish products
- Beef to veal ratio
- Bakery products (e.g., bread, flour, bran)
- Pulses and legumes
- Dairy products
- Brewed beverages (e.g., tea, coffee)
- Chocolate and cocoa derivatives
- Fried and dried products (e.g., chips, crisps, vegetables)
- Cooked and canned goods
- Cakes and baked goods
- Egg components (e.g., yolk, white)

Example: **Beef Sausage Produced in Finland**

Here it is reported how Klimato calculates the climate impact of beef sausage produced in Finland as an example of our models. Klimato uses the baseline value from the Klimato database for unprocessed products (i.e., beef produced in Finland). The value is extracted from Hietala et al., 2021.

Model development: According to Scholz (2013), most sausages have an average meat content of 60%, and the non-meat portion has a negligible influence on the total CF of the product. The same study also provides information on the energy required to process beef meat into sausages. Using this data, Klimato estimates the CF of the Processing stage by applying the reported energy consumption (in kWh), the country-specific energy emission factor for Finland, and the 60% meat content assumption.

The country-specific emission factors are sourced from OurWorldinData (2022) and represent the production mix (i.e., the average carbon intensity of electricity produced in each country). Klimato uses the production mix rather than the residual mix because the database is designed to reflect average food products, not specific supply chains or producers, an approach more appropriate for generalized LCA modelling.

3.6 Internal Data Handling and Governance

3.6.1. Database Roles, Responsibilities, and Update Procedure

Klimato's database is continually updated to account for new studies and scientific knowledge, ensuring that its CF values remain accurate and up-to-date.

The Klimato database is centrally maintained by the Klimato Science Team, with updates managed at the role level rather than individual responsibility to ensure transparency and continuity.

- The primary responsibility for updating, expanding, and maintaining emission factors and underlying methodology lies with the LCA Specialist.
- When adding new values to the database the review check list in Table 1 is applied as a standard to select the most representative studies. In case of any potential uncertainties a second LCA specialist is involved to review the selecting process.
- Database updates include the addition of new ingredients, packaging materials, transport modes, and methodology refinements (e.g., allocation rules, food loss application).

Update process:

- New data is identified and evaluated for quality and source validity (see database quality screening procedure).
- Data is harmonized into Klimato’s internal structure, with consideration of region, production method, and functional unit (typically kg of food).
- Each entry is documented with metadata on source, publication year, system boundaries, and any adaptations made.
- Changes are logged in the internal changelog and flagged for peer review.
- Upon successful review, updates are merged into the working version and deployed into the operational database used by the Food Producer Tool and procurement modules.

Regular update cadence:

- **Annual updates** (typically Q1).
- **Ad-hoc updates** may be conducted when critical new datasets become available or if a methodological revision requires immediate implementation.

3.6.2. Review Trigger for Significant Changes

To ensure that the critical review remains valid between regular 2-year review cycles, Klimato commits to initiating a re-review if:

- **More than 15%** of total product emission factors are modified, OR
- A methodological change significantly alters the results (e.g., switch in LCA scope or IPCC source).

In such cases:

- The affected database version is flagged for review.
- A notification is sent to all internal teams and relevant clients if their product values are impacted.
- The re-review is conducted by the same or an equivalent independent third party (e.g., Bureau Veritas).

Klimato

For more information,
contact Klimato at klimato.com/contact

Figures and Tables

References

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Appendix
A. Assurance

Critical review

Klimato AB

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This critical review concerns the product carbon footprint calculation tool and methodology for product greenhouse gas emissions quantification in accordance with the requirements of GHG Protocol Product Life Cycle Accounting and Reporting Standard (2011), and ISO 14067:2018.

Object

The critical review has been made on the following documents: ''Product carbon footprint report'', ''Product carbon footprint methodology'', ''Klimato database methodology'', ''Product carbon footprint calculation'', ''Product carbon footprint calculation - Multiple plants''.
Version: 11. August 2025
The reporting, modelling, relevant certificates, and other relevant documentation have been reviewed in relation to the listed standards.
Important Note: These documents collectively represent the comprehensive methodology and reporting framework for carbon footprint calculation across various production scenarios. The current review validates only the methodological approach and calculation framework, not the individual product carbon footprint calculations that may be generated using this tool.

Declaration

The review has been completed as a critical review with limited assurance by an external panel of reviewers. We hereby confirm that nothing has come to the reviewers' attention which would lead to conclude that the methodology does not provide an accurate depiction or is not completed in accordance with the requirements of GHG Protocol Product Life Cycle Accounting and Reporting Standard, and ISO 14067:2018, in the above-referenced documents.

Ref.: Critical Review_Klimato AB_CF Calculation System and Methodology_ 20250811

Date for certificate: 11-08-2025
Expire date: 11-08-2027

Validated by:

Edvinas Damukaitis – Reviewer, LCA & EPD Consultant

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B. Klimato's LUC Model

LUC emissions can be categorized into two types:

- **Direct LUC (dLUC):** refer to the emissions directly resulting from land conversion in the specific area where the change occurred.
- **Statistical LUC (sLUC):** refer to emissions that are calculated for a broader area, such as a country or region, using aggregated statistical data (WRI & WBCSD, 2022).

Calculating direct land use change (dLUC) emissions requires detailed, location-specific data on previous land use—information that is often unavailable. For this reason, a more practical approach is to estimate simplified land use change (sLUC) emissions using national and regional land use statistics. To enable this, Klimato has developed a global sLUC emissions model that provides country- and region-specific LUC estimates.

Klimato's LUC model follows the PAS 2050-1 methodology (BSI, 2012), using parameters from the IPCC alongside national land use, crop, and yield data from the FAO. The model covers both crop and animal-based products. For animal products, it applies a feed basket approach, estimating emissions based on the crop-level LUC emissions of feed ingredients, weighted by their share in the animal's diet, in line with SBTi (2022) guidance.

LUC allocation is carried out using a weighted average method. Emissions are proportionally assigned based on the share of land converted from each previous land category (e.g., forest, grassland, cropland) into the expanding crop area. The model first assesses the extent of crop expansion within a country, then determines how much of that expansion replaced each land category.

In addition to country-specific LUC results, the model generates global and regional average LUC emission factors for each crop and animal-based product. These averages are calculated using weighted averages—based on crop yields (for crops) and production quantities (for animal products) per country from FAOSTAT (FAO, 2024)—covering the three most recent years prior to the assessment year (2022). These global and regional averages act as default values when country-specific data is unavailable, complementing detailed crop- and country-level estimates derived from land use change dynamics.

To account for the temporal distribution of emissions, the model applies a 20-year amortization period using a linear approach, ensuring emissions from a LUC event are proportionally allocated to the years following the event.

There are two approaches to amortization:

- **Equal amortization:** assumes that emissions are the same for each year throughout the entire amortization period, starting from the year of the LUC event.
- **Linear amortization:** assumes that emissions gradually decrease over time, with emissions approaching zero by the end of the amortization period. In essence, with the linear approach emissions from recent years receive more weight compared with earlier years.

The selection of the linear amortization approach in the Klimato database ensures that recent land use changes are weighted more heavily and aligns with both the GHG Protocol Land Sector Guidance and Science-Based Targets initiative (SBTi).

LUC emissions are allocated using a **weighted average method**. This means that emissions are proportionally assigned based on the share of land converted from different previous land categories (e.g., forest, grassland, or cropland) into the expanding crop area. The model starts by assessing the area of crop expansion within a country and determines how much of this expansion replaced each land category.

C. Domestic transport

European countries

The methodology is based on Valsasina (2016), originally developed for Switzerland in the Ecoinvent database. To estimate domestic transport emission factors for each region, the following steps were used.

The first step was to estimate **weighted average transport distances** for all European countries using Eurostat data from the period 2017–2022. Specifically, two key metrics were extracted for each mode of transport (**road**, **railway**, and **inland waterways**) from the relevant Eurostat datasets (Eurostat 2023a; 2023b; 2023c):

- The total quantity of freight transported (in thousand tonnes), and
- The total transport performance (in million tonne-kilometres or tkm).

These data were extracted for the following NST (Nomenclature uniforme des marchandises pour les Statistiques de Transport) 2007 groups:

1. *Products of agriculture, hunting, and forestry; fish and other fishing products*
2. *Food products, beverages, and tobacco*

For each transport mode and NST category, the **average distance** was calculated by dividing the total payload-distance (tkm) by the total freight amount (tonnes). Then, the average distance across the two categories was computed to represent the typical transport distance for food-related goods.

Next, the **modal shares** were calculated as the proportion of goods transported by each mode (road, rail, and inland waterways) in relation to the total, based on mass (tonnes). These modal shares were then combined with the mode-specific average distances to compute a **weighted average transport distance** for food products in each country.

Finally, these weighted average distances were used to estimate the CF of domestic food transport, using emission factors from **Mobitool 3.0** (Sacchi and Bauer, 2023).

US and Canada

The methodology to estimate the CF of domestic transport for the US is the same as the one used for European countries. The datasets used were extracted from Freight Analysis Framework (National Transportation Research Center, 2023) for the US and from the Canadian Freight Analysis Framework (Statistics Canada, 2023).

United Arab Emirates (UAE)

The CF of domestic food transport in the UAE is estimated under the assumption that all transport is done by road. This is because the country's recently developed rail network is primarily designed for passengers and industrial goods (e.g., granulated sulfur), rather than food products (Arabian Business, 2023).

To estimate average transport distances, a sample of 14 key farm areas was identified using land use maps from Sherif et al. (2018). The road distances from these farms to the main urban centers (Dubai and Abu Dhabi) were measured using Google Maps, and the average was calculated.

The CF was then estimated using emission factors from Mobitool 3.0 (Sacchi & Bauer, 2023).

Hong Kong

The CF of domestic transport for food products in Hong Kong was calculated assuming that all the transportation is done via road, as the distances from the agricultural areas and fishponds are small (approx. 30 km). The average distance was estimated using the land use map from Wang et al. (2018). The EFs were taken from Mobitool 3.0 (Sacchi and Bauer, 2023).

D. Data Quality Questionnaire

Table 11: Questions for quantitative data quality assessment of activity data used to quantify GHG emissions per life cycle stage (TE: technological representativeness, TI: time representativeness, GE: geographical representativeness, CO: completeness, RE: reliability, DQR: data quality rating; scored from 1 = very good, 2 = good, 3 = fair, 4 = poor).

Quality factor	Customer question	Answer options	Scores
MATERIAL ACQUISITION & PRE-PROCESSING			
TE	Does your data reflect the actual production method (conventional or organic) of the ingredients?	Data represents the exact production method (conventional or organic) for all ingredients.	Very good
		Data represents the production method (conventional or organic) for at least 50% of the ingredients.	Good
		Data represents the production method (conventional or organic) for less than 50% of the ingredients.	Fair

Quality factor	Customer question	Answer options	Scores
		No data on the production method (conventional or organic) is provided for the ingredients.	Poor
TI	How recent is your data?	Less than 3 years old	Very good
		3-5 years old	Good
		6-10 years old	Fair
		More than 10 years old	Poor
CO	How complete is your data regarding raw ingredients?	All raw ingredients and their quantities are provided, and the country of origin is known for each ingredient.	Very good
		All raw ingredients and their quantities are provided, and the country of origin is known for most ingredients (more than 50%).	Good
		The list of raw ingredients and quantities is provided, but the country of origin is missing for more than 50% of them.	Fair
		Gaps exist in the list of raw ingredients and/or the quantities provided (i.e. key ingredients or large quantities are missing)	Poor
GE	How representative is your data regarding the origin of the raw ingredients?	The exact country of origin is provided for all raw ingredients, with no regions left unspecified.	Very good
		The exact country of origin is provided for most ingredients (more than 50%), and for the remaining, a broad region (e.g., Europe, Asia) is provided.	Good
		Country of origin is provided for some ingredients (less than 50%), but many are missing or only specified by a broad region.	Fair
		Country of origin is unknown or unspecified for all raw ingredients.	Poor
RE	How reliable is your data?	Data based on measurement or observation	Very good
		Data partly based on measurement and partly on modeling/calculations.	Good
		Data based on assumptions or qualified estimates (e.g. by a sector expert)	Fair
		Non-qualified estimate	Poor
MATERIAL TRANSPORT*			
TE	Does your data reflect the actual technology (transport mode) used?	Data on the transport mode is provided for all the ingredients.	Very good
		Data on the transport mode is provided for at least 50% of the ingredients.	Good

Quality factor	Customer question	Answer options	Scores
		Data on the transport mode is provided for less than 50% of the ingredients.	Fair
		No data on transport mode is provided for the ingredients.	Poor
TI	How recent is your data?	Less than 3 years old	Very good
		3-6 years old	Good
		6-10 years old	Fair
		More than 10 years old	Poor
CO	What level of transport data do you provide?	Distance data is provided for all ingredients.	Very good
		Distance data is provided for at least 50% of the ingredients.	Good
		Distance data is provided for less than 50% of the ingredients.	Fair
		No distance data is provided for the ingredients	Poor
RE	How reliable is your data?	Actual transport distances obtained from transportation providers.	Very good
		Estimated distances (e.g., calculated based on exact start and end points).	Good
		Estimated distances (e.g., calculated based on approximate start and end points).	Fair
		No distance data is provided for the ingredients	Poor
PRODUCTION			
TE	Does your data reflect the actual technology and production processes used?	Data reflects the exact production method and technology used (specific equipment-level data is provided).	Very good
		Data reflects a similar but slightly different production process (equipment-level approach used with close approximations).	Good
		Data reflects a different production process (equipment-level approach used but with significant differences in technology).	Fair
		Technology is unknown ("at the factory approach" selected)	Poor
TI	How recent is your data?	Less than 3 years old	Very good
		3-6 years old	Good
		6-10 years old	Fair
		More than 10 years old	Poor

Quality factor	Customer question	Answer options	Scores
GE	At what geographic level does your data represent your production process?	Specific facility/production site(s)	Very good
		Country level	Good
		Regional level	Fair
		Global average value	Poor
CO	How comprehensive is your data in covering all relevant aspects of production?	Data provided for all relevant processes measured over an adequate time period (i.e. a period that includes multiple production cycles to adequately represent the production process).	Very good
		Data provided for all relevant processes over an adequate time period, but some minor data gaps exist (e.g. no electricity supplier-specific carbon intensity provided)	Good
		Data provided for all relevant processes over a shorter time period (i.e. single production cycle or limited timeframe).	Fair
		No data available for relevant processes ("At the factory approach" selected)	Poor
RE	How reliable is your data?	Data based on measurement or observation	Very good
		Data partly based on measurement and partly on modeling/calculations.	Good
		Data based on assumptions or qualified estimates (e.g. by a sector expert)	Fair
		Non-qualified estimates	Poor
PACKAGING MATERIAL**			
TI	How recent is your data?	Less than 3 years old	Very good
		3-6 years old	Good
		6-10 years old	Fair
		More than 10 years old	Poor
CO	How comprehensive is your packaging data?	All packaging materials and their quantities are provided, and the country of origin is known for each material.	Very good
		All packaging materials and their quantities are provided, and the country of origin is known for at least 50% of materials	Good
		All packaging materials and their quantities are provided, but the country of origin is known for less than 50% of materials	Fair
		Gaps exist in the list of packaging materials and/or the quantities provided (i.e., key materials or large quantities are missing).	Poor

Quality factor	Customer question	Answer options	Scores
GE	How detailed is your data regarding the origin of the packaging materials?	The country of origin is provided for all packaging materials, with no regions left unspecified.	Very good
		The country of origin is provided for at least 50% of packaging materials, and for the remaining, a broad region (e.g., Europe, Asia) is provided.	Good
		The country of origin is provided for less than 50% of packaging materials.	Fair
		The country of origin is unknown or unspecified for all packaging materials.	Poor
RE	How reliable is your data?	Data based on measurement or observation	Very good
		Data partly based on measurement and partly on modeling/calculations.	Good
		Data based on assumptions or qualified estimates (e.g. by a sector expert)	Fair
		Non-qualified estimate	Poor
PACKAGING MATERIAL TRANSPORT*			
TE	Does your data reflect the actual technology (transport mode) used?	Data on the transport mode is provided for all packaging materials.	Very good
		Data on the transport mode is provided for at least 50% of the packaging materials.	Good
		Data on the transport mode is provided for less than 50% of the packaging materials.	Fair
		No data on transport mode is provided for the packaging materials.	Poor
TI	How recent is your data?	Less than 3 years old	Very good
		3-6 years old	Good
		6-10 years old	Fair
		More than 10 years old	Poor
CO	How comprehensive is your packaging transport data?	Distance data is provided for all packaging materials.	Very good
		Distance data is provided for at least 50% of the packaging materials.	Good
		Distance data is provided for less than 50% of the packaging materials.	Fair
		No distance data is provided for the packaging materials.	Poor
RE	How reliable is your data?	Actual transport distances obtained from transportation providers.	Very good

Quality factor	Customer question	Answer options	Scores
		Estimated distances (e.g., calculated based on exact start and end points).	Good
		Estimated distances (e.g., calculated based on approximate start and end points).	Fair
		No distance data is provided for the ingredients	Poor
DISTRIBUTION*			
TI	How recent is your data?	Less than 3 years old	Very good
		3-6 years old	Good
		6-10 years old	Fair
		More than 10 years old	Poor
RE	How reliable is your data?	Actual transport distances obtained from distribution providers.	Very good
		Estimated distances (e.g., calculated based on exact start and end points).	Good
		Estimated distances (e.g., calculated based on approximate start and end points).	Fair
		Average transport distances for distribution of products	Poor

*Geographical representativeness is excluded as a quality indicator for transport data because the geographical context is already captured through other indicators, particularly technological representativeness and completeness. Specifically, the level of geographical accuracy in the data, such as how precisely the origin, destination, and route are reflected, is inherently tied to the level of detail provided on transport mode and distance. As a result, geographical representativeness is a direct consequence of these factors, and including it as a separate indicator would be redundant and unlikely to improve the overall assessment of transport data quality. To better understand how these aspects are evaluated, refer to the transport data quality questionnaire provided in the appendix.

**Technological representativeness was excluded as a quality indicator for packaging data because the data collected pertains only to the type and quantity of packaging materials used (e.g., PET, cardboard), not the specific manufacturing technologies (e.g., injection molding, thermoforming). Furthermore, Klimato applies LCI datasets that already incorporate representative industry-average technologies for packaging materials. Since the technological representativeness of these datasets is evaluated as part of the emission factor quality assessment, including it again in the assessment of the activity data would be redundant and would not improve overall data quality. Introducing it at this level could also lead to unnecessary complexity.

For the distribution stage, the quality indicators for technological representativeness and completeness are not included in the questionnaire because providing data on transport mode and distance is mandatory for the client. Therefore, these categories are assigned a default score of “Very good” for all distributed products, reflecting the assumption that this data is complete and accurately represents the actual technology and distances used.

E. Biogenic Sensitivity Analysis

Table 12: Sensitivity analysis of the assessment's applied biogenic emission shares from Agribalyse against data by HESTIA (2025) and various literature sources.

		Agribalyse		Hestia				Literature			
Ingredient	**Klimato CF**	**Biogenic share (%)**	**Origin**	**Biogenic share (%)**	**Source**	**Origin**	**Deviation from Agribalyse**	**Biogenic share (%)**	**Origin**	**Source**	**Deviation from Agribalyse**
Soy protein	6.09	0.03%	France	3.07%	Hestia (2025) - Soybean, seed	Brazil	3.04%	/	/	/	/
Rice all types	2.61	58.55%		72.98%	Hestia (2025) - Rice, grain (in husk), flooded	China	14.43%	/	/	/	0.72%
Courgette	0.32	0.16%		6.80%	Hestia (2025) - Courgette, fruit	France	6.64%	/	/	/	/
Apple	0.26	1.51%		2.94%	Hestia (2025) - Apple, fruit	Iran	1.43%	1.02%	Italy	EPD-IES-0000369:005 (S-P-00369)	-0.49%
Tomato	0.5	0.18%		8.52%	Hestia (2025) - Tomato, fruit	Ivory Coast	8.34%	1.60%		EPD-IES-0005451:002 (S-P-05451)	1.42%
Chicken	6.09	2.83%		/		/	/	24.24%		Berton, M.et al. (2025)	20.03%
Pork	7.48	34.58%		/		/	/	48.28%			13.70%
Beef	31.47	73.70%		/		/	/	72.99%			-0.71%