Allocation Procedure for Emissions of Food Products and Ingredients

A Guidance Document Aligned with ISO 14044 Methodology

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1. Introduction

The distribution of environmental burdens is an essential step in product carbon footprints (PCFs) and carbon accounting of purchased goods (scope 3.1). When a single process generates multiple outputs, and a fair distribution of impacts is needed, an allocation procedure is performed to attribute the share of the total environmental impacts of the production system among the generated outputs (Schau et al. 2008). This is applied to quantitative metrics such as land management GHG emissions, land occupation, blue water consumption and land use change emissions and plays a critical role in ensuring transparency and comparability in product-level assessments.

While multiple allocation approaches can be applied depending on the selected attribute, the procedure relies on proper mass flows across the system, ensuring completeness in the inventory, in line with recommendations of ISO 14044:2006/Amd 2:2020 standard, and enables the distribution of impacts from commodities to ingredients, aggregated to final products. Put simply, if you're producing orange juice concentrate, allocation accounts for the multiple kg of input (oranges) required to make 1 kg of orange juice concentrate, and allocates impacts to the juice and by-products such as orange oil made from the peel.

International standards such as ISO 14044 are industry agnostic and recognize multiple allocation approaches. Biophysical allocation considers physical attributes such as mass weights, nutritional or dry matter content; when mass is used, burdens are distributed in proportion to the mass share of each co-product. Economic allocation, in contrast, assigns burdens according to the relative market value of each co-product.

Adopting different approaches can lead to significantly different results and interpretations, influencing the outcomes of comparative studies, labeling schemes, and environmental claims. Therefore, choosing an appropriate allocation and documenting it clearly is essential to maintain the credibility and usefulness of product carbon footprint (PCF) or life cycle assessment (LCA) results (Ijassi et al. 2021).

Particular attention in the food, beverage and agri-food industries is given to the economic allocation method. HowGood uses allocation factors and guidance specified in recognized industry standards like the EU's Product Environmental Footprint (PEF) general guidance or category rules (PEFCRs), typically specifying economic allocation, but may differ like the dairy PEFCR based on dry matter content, or industry publications like the World Cocoa Foundation's GHG Accounting Manual For Cocoa (also using economic allocation). We are aligned with the merits of applying economic allocation, when appropriate (noting the dairy exception) and data are available. Given the breadth of HowGood's library of 5,000+ unique ingredients, existing industry standard guidance on economic allocation factors for food and beverage product ingredients covers a limited portion of our ingredients database.

In this context, we propose a specific allocation approach based on a market-value assessment to systematically classify outputs as co-products, by-products and waste according to a specific criteria and use proxy factors when no actual economic values are available. We introduce the term here because in agricultural LCAs, it is common to find what can be described as proxy-economic allocation. This occurs when studies and reports implicitly reflect an economic hierarchy of products, even though no explicit economic data are used. For example, in studies of maize, when corn stover is not considered a co-product (Li, 2021; Holka et al., 2017) and all impacts are attributed to maize grain, the distribution of burdens is implicitly determined by system framing rather than by an explicitly defined allocation procedure. By doing so, the assessment implicitly assumes that the grain is the main product of economic value, thereby applying a market-based logic without presenting supporting price or revenue information. This practice, while widespread, effectively prioritizes the material(s) of principal commercial interest, in this example the maize grain, over co-products or by-products, which may also have uses or values.

We use this principle to apply a structured market-based value classification of the outputs and assign a proxy value from a similar commodity/output when no standard factors are available. This approach allows consistent and scalable application across a wide range of co-product systems. When economic allocation factors are unavailable, HowGood systematically applied this proxy-economic allocation approach to our large internal database of food ingredients and products sold by food retailers, distributors, food service companies, CPGs and ingredient suppliers operating across the globe. We developed this approach because published allocation data is typically limited to the first or second level of processing for a given commodity, and with our ingredient library representing the entire food system, this approach allows us to fill the gaps by estimating impacts for ingredients not represented in allocation guidance that couldn't be calculated using published allocation ratios/factors alone.

The purpose of this document is to define the allocation methodology used for food and beverage systems, including upstream agricultural impacts. It includes practical guidance on performing the allocation procedure for materials spanning the food and beverage industry. Section 2 clarifies the scope and purpose, and Section 3 lists definitions. Section 4 outlines the allocation hierarchy, Section 5 specifies when to apply each allocation method, followed by a demonstration of worked examples in Section 6. Section 7 offers comparative analysis of the proxy-economic, economic, and physical allocation approaches. Section 8 proposes recommended next steps to refine the process and on steps to further align the agri-food life cycle assessment and carbon accounting communities on how to scale the allocation of impacts when industry standard data are unavailable or incomplete.

2. Scope and Purpose

This methodology document establishes the allocation procedure at the post harvesting processing stage, focusing on allocation of land management, transportation and land use change (LUC) in addition to water consumption and land use from a single commodity transferred to derived product(s). This approach is consistent with ISO 14044 principles and is intended to ensure clarity and consistency in life cycle assessment (LCA) and product carbon footprint (PCF) studies.

3. Definitions

Allocation: Allocation is defined as "partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems. (ISO 14044:2006/Amd 2:2020). The selection of a specific allocation approach depends on the purpose and intention of the assessment and includes economic, physical, energy, among others.

Allocation procedure: The process of allocation determines how to account for the impact of a single product when multiple outputs are produced via the same process.

Allocation ratio (AR): Also referred to in this document as AR. It is a multiplier used to distribute the environmental burdens (such as GHG emissions, land occupation, water use, etc.) from the raw commodity among the outputs of a production system. It reflects the proportion of total impacts assigned to a particular product or ingredient per unit of mass.

Allocation factor (AF): Also referred to in this document as AF. It is a percentage representing the share of total environmental impacts (e.g., GHG emissions, land use, water use) assigned to a specific output in a production system. It indicates the portion of the total burden allocated to that product and is expressed as a fraction of 1 (or 100%). Typically, the allocation factor is derived from physical relationships (mass, energy content, biophysical causality), economic relationships (market value), or other justified allocation approach.

Economic allocation: Economic allocation is a method applied when a shared process generates co-products, in which environmental burdens are distributed according to each product's share of the total economic value of all outputs.

Proxy-economic allocation: Method that uses a market based value assessment to systematically classify products when standard economic factors are not available or are missing. This method implies the use of consistent proxy allocation factors to ensure environmental burdens reflect market relevance.

Biophysical allocation: is a method used when a single process produces multiple co-products. It distributes environmental burdens according to the underlying physical relationships that determine how each output is generated. It includes for example, mass weight, dry solids, protein content, or any other physical attribute.

Market-based value assessment: An assessment method used to determine allocation factors for ingredients or outputs when standard economic allocation data is not available. The market-based value assessment considers the role and significance of each product in the market - to identify and classify whether it is a co-product, by-product, or waste. The classification of outputs is qualitative, and based on this categorization, a quantitative allocation is assigned. This qualitative-to-quantitative step informs the adjusted allocation factors applied in multi-stage processing systems (see the Appendix).

Commodity tree: A commodity tree is a symbolic representation of how a primary commodity is transformed into a product (Output) through multiple processing lines. It includes the mass fraction that links inputs to outputs (Food and Agriculture Organization of the United Nations. (2011). *Technical conversion factors for agricultural commodities*. FAO.

Functional unit: The functional unit is the measurable reference used in a life cycle assessment and carbon footprint to define the function of a product system. It allows all environmental inputs and outputs to be consistently compared. For example, the functional unit could be "1 kg of maize grain," or "1 liter of milk," depending on the system being assessed.

Outputs (products): These are the results generated within a specific production process. Any product generated by a processing line, measurable in mass, volume, or other units, which may be used as input for further processing or as a final product. Outputs are classified as co-product, by-product, or waste.

Co-products: This is the reference product of the system. Typically the highest value or intended product. According to the ISO-14044 this means any of two or more products derived from the same processing line (see definition below) or product system (ISO-14044, 2006/Amd 2:2020) and are physically or chemically linked to the main product. For instance, the products of wheat flour, wheat bran and wheat germ derived from the unit process of wheat grain. *Important:* Outputs from different, independent processing lines are **not** co-products of each other.

By-products: This term is not defined in the ISO-14044 but used in practice LCAs. It can be defined as outputs that are co-produced together with the reference product but would not justify performing a process for their own sake. For example, straw is produced together with wheat grain, which is the reference product. By-products are distinguished from the waste since waste does not have an economic or market-based value, whereas by-products do have a value on the market (ecoinvent, 2023). Examples include but are not limited to offals, blood, hides, hulls, husk.

Waste: This is defined in the ISO-14044 as substances or objects which the holder intends or is required to dispose of (ISO-14044, 2006/Amd 2:2020) and will not be further processed or utilized. When waste materials are intended for further processing such as drying for use as animal feed they are no longer classified as waste but are instead reclassified as by-products, given their continued functional and economic or market-based value within the system. Examples of waste include peels and scraps of fruits and vegetables that are not used for animal feed; leaves and stems in flowers or herbs that are discarded.

Processing line: The processing line indicates the type of transformations a material undergoes from a primary commodity to one or more outputs. It involves physical, chemical, or biochemical transformations, where each co-product can be processed into new materials. Processing lines can be organized hierarchically:

> **Level 1:** It usually refers to the initial processing of the raw material immediately after it leaves the farm.
>
> **Level 2:** It represents transformation of outputs from level 1 lines.
>
> **Level 3 and beyond:** They are subsequent transformations of outputs from previous levels. Each processing line is independent, even if multiple lines exist at the same hierarchical level.

Mass fraction (%): It quantifies the proportion of mass assigned to each output derived from the primary commodity material and is important for calculating allocation ratios, regardless of allocation approach applied. Example: primary commodity: Banana, 100%; outputs: banana puree, 70%; banana peel, 30%.

Primary commodity (raw material): The primary commodity represents the raw material or agricultural product at the beginning of the supply chain, typically defined at the farm gate. This is the point from which GHG emissions are allocated across all downstream products. It is important to confirm that the functional unit used for the primary commodity (e.g., 1 kg of harvested crop) is consistent with the unit used throughout the mass distribution in the commodity tree.

4. Allocation hierarchy

This allocation procedure follows ISO 14044:2006/Amd 2:2020 standard guidelines, interpreted from the ISO allocation hierarchy (Table 1) for application of scalable allocation approach in food and agricultural systems and prioritized as follows:

Table 1. Adapted allocation hierarchy based on ISO-14040/44

Step	*Procedure*
1	Avoid allocation, if possible
2	Align with legislative requirements (often economic)[a]
3	Align with sectoral recommendations (often economic)[a]
4	Consider biophysical allocation (e.g., based on mass, volume, energy content, chemical composition, number of units, etc. of co-products)
5	Consider economic (e.g., based on the market value of co-products) or other allocation (e.g., based on the land area-time needed to produce co-products)

[a]Steps 2 and 3 have been added to this hierarchy to include legislative and sectoral recommendations, considered the industry standard for allocation.
Source: Adapted from ISO-14040/44 and GHG Protocol Product Standard

We follow this hierarchy by avoiding allocation whenever possible. When allocation cannot be avoided, we align to legislative requirements (for example, the Dairy PEFCR applying dry matter content), or sectoral recommendations, such as World Cocoa Foundation using an economic approach that provides economic allocation factors (AFs). While relevant for certain commodities, we have found sectoral recommendations insufficient for covering the entirety of the food system. For the overwhelming majority of ingredients in our database, allocation cannot be avoided and the last two steps of the hierarchy must be considered.

The ISO standard is not-industry specific. In HowGood's experience, the next option in the hierarchy, biophysical allocation, is not well accepted in the agri-food industry primarily because mass can be misaligned with market value (see Section 7 for more details). In cases where economic AFs are not available or reliable, we use the ISO guidance to build our own approach, specifically in line with the final step of the hierarchy ("consider economic or other allocation"), that consist in applying our market-based value assessment approach to classify commodity outputs. This allows us to assign proxy-economic allocation factors using consistent proxy allocation values for outputs considered by-products and distribute the remaining emissions to co-products. This situation often arises because economic data is typically limited to primary commodities or the first level of processing, while data for downstream by-products or intermediate ingredients is either not publicly accessible, poorly documented, or highly variable across regions.

For example, palm fiber (mesocarp) is considered a waste in some industries due to the absence of a well established market. However, it is rich in dietary fiber and phenolic compounds, which could be extracted to create added value. Because this methodology considers customer usage whether the output is utilized by our customers or their suppliers as a valuable input, we classify such materials as a by-product rather than a waste, even without specific economic factors, to the authors knowledge, for palm fiber; nevertheless, its characteristics are comparable to analogous materials such as soy hulls and cocoa shells, which are frequently classified as by-products in other studies and guidances.

The approach has proven especially useful in complex supply chains or commodities with limited economic data, where direct pricing is unavailable. For example, peels and scraps of fruits and vegetables, seeds that are not used in animal feed often lack an established market value. The strength of this method lies in its ability to recognise materials that may be discarded within one part of the value chain but they retain value for another. Further details of this approach can be found in the following section.

5. Methodological approach: Allocation decision tree

The decision tree in Figure 1 addresses how to allocate emissions as described above when a raw material results in multiple products.

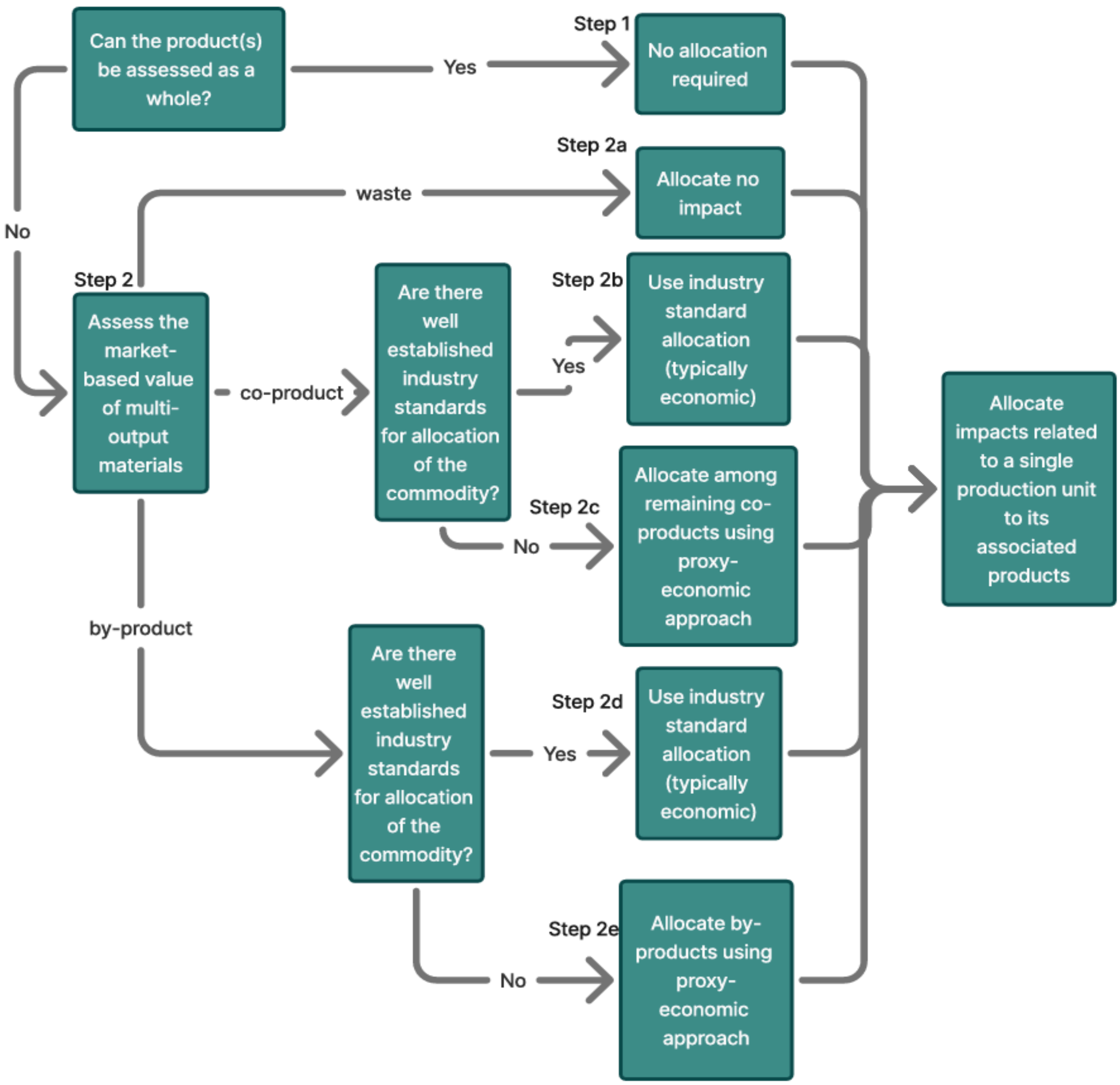

Figure 1. Decision tree for allocating impacts to waste, co-products and by-products using industry standard or proxy-economic approaches (Source: HowGood).

In Figure 1, the branches of the decision tree illustrate the sequence of decision points and criteria used to determine the allocation pathway.

Step 1. Identify products within the commodity tree that can be assessed as a single functional system. This means broadening the basis of comparison to include all co-products of a system, so impacts are assessed per expanded functional unit which also means these are expressed per all outputs produced together in the system, therefore avoiding the need for allocation. For example, if a wheat processing facility produces both wheat flour and wheat bran, the functional unit can be expanded from reporting only per 1 kg of wheat flour to include both outputs (one system unit containing 1 kg wheat flour and 0.36 kg of wheat bran). Thus, the overall environmental impact is reflected for the entire system.

Step 2. If the production system cannot be subdivided or allocation cannot be avoided, step 2 involves a market-based value classification to determine the functionality of these outputs whether they contribute to human consumption or animal feed, while also considering their market-based value. This classification is based on a structured set of criteria including *production intentionality, market, value, functional use, and processing cost*. By analyzing market-based value and the functionality of the outputs, we ensure that those are appropriately classified as co-products, by-products and waste, assessing their economic significance and functional relevance which refers to the primary function of a specific output within the production system based on its intended function, demand or role in the supply chain. Further details on market-based classification can be found in the Appendix.

An example can be useful to further clarify these first steps 1 and 2:

Soybean is a crop grown to produce multiple high value products that are used widely in the food industry (See Figure 2) such as soy protein isolate (an ingredient commonly used to increase the protein content of processed foods) and soybean oil (a widely used cooking oil). In extracting the high value products, there are also low value products that are obtained during processing (sometimes unintentional) such as soybean hulls that are a by-product of soybean production not typically eaten directly in the human food system but used in ways that benefit human systems (for example use in animal feed). In this example, soy protein isolate and soy oil are classified as co-products due to their high market value and production intentionality as both are deliberated targets of the production process. On the other hand, soy hulls are classified as a by-product because of its relatively low market value and its primary use in the animal feed industry.

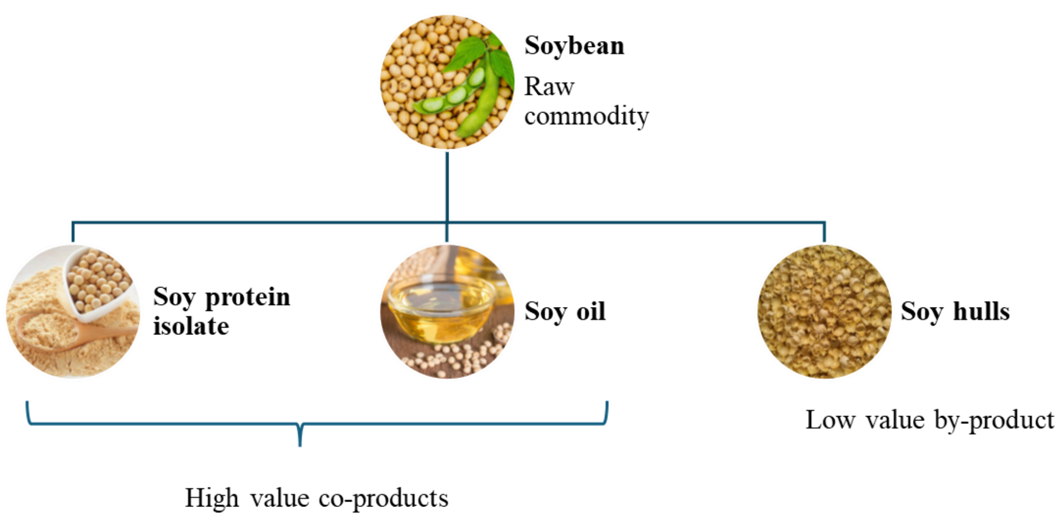

Figure 2. Market-based classification of soy products (Source: HowGood)

The classification of the commodity outputs should be consistently applied across all levels of processing within the commodity tree, from primary materials to final products. The classification criteria are outlined in the Appendix, which serves as a reference for distinguishing between main products/co-products, and low value by-products. In cases where the available guidance does not fully address a specific situation, any assumptions or interpretations used to classify products must be transparently documented and supported by a clear rationale. This ensures consistency, traceability, and alignment with methodological best practices throughout the assessment.

After classification, allocation is applied by following steps below (supported by examples in the next section):

Step 2a: For substances or objects classified as waste, which the holder intends, or is required, to dispose of and will not be further processed or utilized, no impact is allocated as recommended in ISO-14040/44. Standard documents providing economic allocation factors implicitly redistribute impacts from waste to co-products and by-products via mass fraction included in the AF (FAO 2016). Similarly, in cases where economic allocation factors are not available, this redistribution is made as part of the estimated AF.

Step 2b: For outputs classified as co-products, we evaluate the availability of existing industry standard allocation factors (see examples below) to determine the respective emissions. These standards may be well recognized documents as the EU's Product Environmental Footprint Category Rules (PEFCR), which are rulesets describing how to calculate the environmental footprint of a specific set of products (such as dairy or pet food, in addition to general category rule guidelines). In this type of document allocation factors are provided or the allocation approach is already established. Step 2b includes products with available data where allocation factors are widely considered the industry standard. An economic allocation approach is typically, but not always applied (i.e., based on the relative market-based value of each co-product). Examples of these documents are:

- FAO Livestock Environmental Assessment and Performance Partnership (LEAP) guidelines (2015)
- GHG accounting Manual for Cocoa from World Cocoa Foundation (Quantis, & World Cocoa Foundation, 2025).
- Technical supporting document on Soy conversion factors (Round Table on Responsible Soy Association, 2020).
- Product Environmental Footprint Category Rules general guidance (PEFCR; European Commission, 2021)
- PEFCR for dairy products (2025)
- PEFCR feed for food producing animals (2024)

Step 2c. For outputs classified as co-products where no available allocation factors in industry standards or sectoral guidance are published, further interpretation of the ISO 14040/44 guidelines for scalability in the food and agricultural system is presented here where emissions are allocated with the proxy-economic allocation approach using both market based value assessment and biophysical attributes. Biophysical allocation precedes economic for two reasons: alignment with both the GHG Protocol Product Standard allocation requirements and the ISO hierarchy in Table 1, and because a market-based value classification was performed in step 2. This classification of market-based value based is an essential step to avoid known weaknesses of biophysical allocation performed in isolation of economic context. By aligning biophysical allocation with the market-based value, the method offers a more representative distribution of the impacts, and allows for broader coverage of co-products used in industry.

Step 2d. The allocation of impacts to by-products first requires the identification of existing industry standards having relevant allocation factors. Examples of these are the PEFCR documents, such as the PEFCR general guidance (European commission, 2021) in which by-products for different types of meats (beef, pork and sheep) are allocated in a range between 0.5-3.5%, based on economic allocation. In those cases, standard factors are used.

Step 2e. When no available allocation factors for by-products are published as industry standard data, these are assigned a small portion of the total impact allocation (i.e., 0.5% - 5%) as part of the proxy-economic allocation. This range has been considered according to research specific to similar products in other commodities for instance: for fiber-rich products such as hulls, shells, we use 3% as an average value that is consistent with public data for soy hulls based on economic allocation (FAO 2016).

We have performed a literature review and identified some ranges for certain ingredients that can be grouped:

1. Low value agri by-products
   Examples: rice husk, wheat bran, wheat germ, wheat gluten feed, wheat gluten meal
   The typical proxy range is around 0.5%-5% (LEAP 2016)
2. Root and Tuber by-products
   Examples:potato pulp, tapioca starch, cassava pomace
   The typical proxy range is around 2%-12% (Blonk, 2015)
3. Animal by-products
   Examples:bones, fat, hides, cat. 3 slaughter by-product
   The typical proxy range is around 0.5%-3.5% (European Commission 2021)
4. Fish by-products
   Examples: Head, bones, skin, blood.
   The typical proxy range is around 3.4%-12% (Marine Fish PEFCR: Screening and recommendations, 2016 and PEFCR pet food)

In cases where multiple by-products are generated from the same processing stream and economic factors are not available, the minor share of impact associated with this stream is allocated proportionally by mass, whereby each by-product receives a share corresponding to its mass relative to the primary commodity.

For example, during cassava processing, two by-products (peels and pomace) are generated. Both are classified under the by-products category. If 7% of the total environmental impact is allocated to this by-product stream as a small portion, that percentage must then be divided between the individual by-products according to their mass.

This approach ensures a consistent distribution of allocated impacts across multiple by-products, grounded in their share of the original input stream. And as you'll see in the next section, economic data can be used (when available) and combined with the market-based value approach introduced in this paper.

6. Allocation ratio – applied examples

The allocation ratio (AR) is a multiplier applied to HowGood quantitative metrics of a materials' land management GHG emissions, land occupation, blue water consumption, and land use change (LUC) emissions. It takes into account the allocation factors assigned in step 2 and sub-steps of the allocation methodology to each ingredient (see Figure 1) divided by the mass fraction of the product/ingredient. Please note that in these examples allocation cannot be avoided, hence no detailing of step 1. Allocation ratios are used to distribute environmental burdens across co-products generated within the same system.

AR = Allocation factor (%) / Mass fraction (%)

Allocation example 1 - Palm System

This section presents our methodological approach used to determine allocation ratios (ARs) for palm outputs: palm oil, palm kernel, and palm fiber. We also compare it with mass and economic allocation factors in section 7.

Allocation Step 2: Assess market-based value of commodity outputs

Following ISO 14044 definitions and a market-based classification, each output from the palm fruit processing system is categorized as follows:

The functional unit for the palm system is the fresh fruit bunch (FFB). After harvest, FFB is separated into multiple outputs. Palm empty bunch having no commercial value is classified as waste while primary outputs from the FFB are palm oil and palm kernel that are both categorized as co-products based on the market-value assessment detailed in Table 2. Finally the palm fiber or mesocarp which is the fibrous pulp surrounding the palm kernel is classified as a by-product.

Table 2. Market-based value classification of multi outputs within the palm system.

Palm system outputs	*Market-based value classification*	*Rationale*
Palm oil	Co-product	It shares economic value with other outputs and is intentionally produced within the palm system. This reinforces the validity and viability of a market-based assessment approach, even if it's not applied in this case due to the availability of economic allocation factors.
Palm kernel	Co-product	This product also has commercial value and is deliberately produced because of its oil content.
Palm fiber	By-product	Palm fiber is treated as a by-product, because of its low economic value. This is consistent with analogous materials such as soy hulls and cocoa shells, which are frequently considered by-products in LCA studies.
Palm empty bunch	Waste	No commercial value

Allocation Steps 2a and 2b: Use industry standard allocation factors

Table 3 summarizes the mass weights and economic allocation factors of the outputs over the functional unit (FFB). Using our approach, Step 2a assigns no impact to the palm empty bunch which is classified as waste. Step 2b applied standard economic allocation factors for the palm outputs classified as co-products using standard allocation factors reported by FAO (2016). Finally, palm fiber lacks a documented allocation factor in the literature, requiring a separate analysis.

Table 3. Mass weight and economic allocation factors available for palm outputs.

Output	*Market-based value classification*	*Mass weight**	*Economic allocation factor (Std)*	*Source*
Palm oil	Co-product	12.5%	86.3%	FAO, 2016
Palm kernel	Co-product	3.9%	13.7%	FAO, 2016
Palm fiber	By-product	49.1%	Not available	Not available
Palm empty bunch	Waste	34.55%	0	Not available

**Weight over fresh fruit bunch*

Note: While FAO yields are reported per palm fruit, here values are converted to fractions of fresh fruit bunch using 65.5% palm fruit and 34.5% empty bunch. While we acknowledge that LEAP is primarily tailored to animal feed and may not be fully representative of palm oil products intended for human consumption, it remains a reliable reference, offering default factors that support consistency and transparency in our assessment.

Default economic allocation factors from industry standard documents can be applied to the palm co-products. However, palm fiber does not have any standard economic allocation factor provided by standard documents and it has multiple uses in industry because of its fiber content. Therefore, it should not be considered as waste and instead it should have small responsibility when producing palm fiber ingredients and be classified as a by-product. As no standard factors are available for palm fiber by-product (step 2d), this is treated in step 2e.

On the other hand, the palm empty bunch is also missing from the industry standard reference but with no commercial value, thus, it is assessed as waste and allocation of zero is assigned. See Steps 2c and 2e for how to fill these gaps.

Allocation Steps 2c and 2e. Estimation of allocation for by-products

To address the lack of economic allocation data for palm fiber, and using the internal market-based value classification, Steps 2c and 2e in Figure 1 are applied. In this approach, a small proportion of environmental burden is attributed to by-products, generally ranging from 1% to 5%, depending on functionality, industrial relevance, and nutritional content. For palm fiber, a value of 3% was assigned, based on its typical industrial use as a low-value material (see step 2e ranges).

The remaining 97% of the burden was then reallocated between palm oil and palm kernel according to their original economic proportions. The adjusted allocation percentages are presented in Table 4.

Table 4. Adjusted allocation percentages using Steps 2c and 2e

Output	*Market-based value classification*	*Mass weight*	*Economic AF (Std)*	*AF (adjusted*)*
Palm oil	Co-product	12.45%	86.3%	83.7%
Palm kernel	Co-product	3.9%	13.7%	13.3%
Palm fiber	By-product	49.1%	Not available	3%
Palm empty bunch	Waste	34.55%	0%	Not applicable

**Allocation factors (AF) adjusted to account for impact of palm fiber, by-product with no published allocation factors.*

The final allocation ratios were calculated using the formula:

AR = Adjusted Allocation factor (%) / Mass weight (%)

This step ensures consistency with the PEFCR guidance for economic allocation. Results are presented in Table 5.

Table 5. Final allocation ratios

Output	*Market-based value classification*	*Mass weight*	*AF (adjusted)*	*AR*
Palm oil	Co-product	12.45%	83.7%	6.73
Palm kernel	Co-product	3.9%	13.3%	3.38
Palm fiber	By-product	49.1%	3%	0.06
Palm empty bunch	Waste	34.55%	Not applicable	Not applicable

This allocation approach provides a transparent and replicable method to assign environmental burdens to palm oil system outputs, balancing economic value and physical flow. The method highlights the significance of co-product classification and the need for careful attribution in cases where standard allocation factors are unavailable. In particular, assigning a small share of environmental responsibility to palm fiber as a by-product aligns with its market relevance and supports more accurate carbon accounting in palm-derived ingredient LCA models.

Allocation example 2 - Soy system

For the soy system the initial functional unit has been defined as one unit of soybean. At the first-level, of processing, the main outputs are soy oil, defatted soy meal, and hulls. For this commodity, standard economic allocation factors (AFs) are available from the LEAP guidelines (please see the note in Step 2 of Allocation example 1 - palm system regarding the use of LEAP). In such cases, AFs and product mass weights are used directly to calculate the allocation ratios (ARs). Table 6 includes Steps 2 and 2b.

Table 6. Mass weight and economic AFs available for soy outputs

Output	*Market-based classification*	*Rationale*	*Mass weight*	*Economic AF (Std)*	*AR*
Soy oil	co-product	Intended product, high value in the market.	20%	42%	2.08
Defatted soy meal	co-product	Intended product, high value in the market.	72%	56%	0.77
Soy hull	by-product	Low value product in the market. Used in animal feed.	8%	3%	0.38

Source: Adapted from LEAP guidelines (FAO, 2016)

Oil and defatted meal are ingredients obtained from the primary processing of soybeans. These outputs, however, often serve as raw materials for a second level of processing, which yields additional ingredients such as soy protein isolate or soy lecithin. For these second-level ingredients, standard economic allocation factors are typically unavailable or not well-documented. In such cases, we apply a market-based value assessment as described above in Step 2 of the allocation approach to derive adjusted AFs. This involves using the allocation ratios (ARs) previously assigned to oil or defatted meal, followed by a new calculation based on the market value of the derived ingredient.

To calculate the final allocation ratio (AR) for the second-level ingredient, we multiply the AR of the input material (e.g., defatted meal) by the adjusted AF for the new ingredient, divided by its mass share. This is expressed as:

AR (second-level processing) = (AF adjusted / mass weight) × AR input (first-level processing)

For example, in the case of soy protein isolate (Table 7), it is derived from defatted soy meal with an AR of 0.77. The defatted soy meal AR is multiplied by the adjusted AF for soy protein isolate of 95% divided by the mass share of 33%, resulting in an AR of 2.22. The soy protein isolate AF of 95% was reached after looking at the three outputs from the process and applying AFs of 0% to waste, 5% to the by-product of soy carbohydrates, as referenced in Step 2e, and the remainder applied to the only co-product of soy protein isolate. Applying the formula:

0.77 × (0.95 / 0.33) = 2.22

This two-step approach ensures consistency and transparency in allocating environmental burdens across processing levels. Refer to Table 7 for detailed calculations.

Table 7. Mass weight and economic allocation factors available for soy outputs

Output	*Market-based classification*	*Rationale*	*Mass weight %*	*Economic AF (Std)*	*AF% (adjusted)*	*AR*
Soy protein isolate	co-product	Intended product, high value in the market.	33%	Not available*	95%	(95% ÷ 33%) × 0.77 = 2.22
Soy Carbohydrates	by-product	Used in animal feed or value-added bioproducts	25%	Not available	5% (Defined for carb-rich materials used for feed)	(5% ÷ 25%) × 0.77 = 0.15
Soy losses (From protein extraction)	waste	No identifiable market value.	42%	Not available	0	-

**Economic allocation factor not available for a second level.*

Note: The factor of 0.77 corresponds to the allocation ratio previously assigned to the defatted meal, based on first-level economic allocation in Table 6.

These adjusted allocation factors support a consistent and transparent application of allocation across multiple processing stages, particularly where direct economic allocation factors are partially available. By using market-based valuations in conjunction with prior ARs, we ensure that environmental burdens reflect both product value and processing hierarchy. This approach aligns with LCA best practices when extending system boundaries to cover multi-stage ingredient production.

Allocation example 3 - Cocoa system

When dry cocoa beans are processed, they are first separated between shells and liquor (paste). The first step of allocation involves estimating the allocation ratios for cocoa paste and cocoa shell. Standard allocation ratios at first level of processing are already provided in the standard report from Quantis, & World Cocoa Foundation, 2025. Since cocoa butter and cocoa powder are the primary outputs derived from cocoa paste, the AR of cocoa paste must be incorporated into the calculation. In the second level of processing, cocoa butter and cocoa powder are produced from paste and both materials have published allocation factors (Table 8) and do not require further adjustments.

Table 8. Allocation ratios for cocoa paste system

Output	*Market-based value classification*	*Rationale*	*AR from cocoa paste*	*Mass weight*	*Economic AF (Std)*	*AR*
Cocoa butter	co-product	Intended product, high value in the	1.19	47% of paste	65%	1.64

		market.				
Cocoa powder	co-product	Intended product, high value in the market.	1.19	53% of paste	35%	0.78

The cocoa shell has been allocated using economic allocation factors from standard, however, other outputs derived from cocoa, like cocoa shell extract and cocoa shell biomass, created from the same processing step, do not have published allocation factors, and therefore require an adjustment according to the approach in Step 2.c.

Table 9. Allocation ratios for cocoa shell system.

Output	*Market-based classification*	*Rationale*	*Mass weight*	*AR from cocoa shell*	*Economic AF (Std)*	*AF% (adjusted)*	*AR*
Cocoa Shell extract	By-product	A by-product valued for its polyphenols, dietary fibers, and methylxanthines	7% of shells	0.25	Not available	100%	3.57
Cocoa shell (Spent)	Waste	No value in the market.	93% of shells	0.25	Not available	0	0

The ARs are calculated following the equation stated above and multiplying by the previously determined AR of the cocoa shell from standard (0.25). This approach ensures that the allocation is consistent through the processing chain within the commodity tree.

7. Comparative allocation approaches

A comparative analysis was conducted to assess how land management emissions (and land use change) compare when applying the market-based allocation (proxy-economic allocation), standard economic allocation (Std), and mass approaches for soy and cassava processing outputs. The standard economic allocation factors for soy protein isolate and soy okara, have been retrieved from the Agrifootprint 6.0 report while cassava factors from Agrifootprint 2.0 report (most recent version containing cassava data). GHG emissions and land use change values were sourced from HowGood database.

Figure 3. Shows the results of the land management emissions of the soy processing into soy protein isolate and okara under different allocation approaches. These outputs accounted for the land management and land use change emissions (LUC).

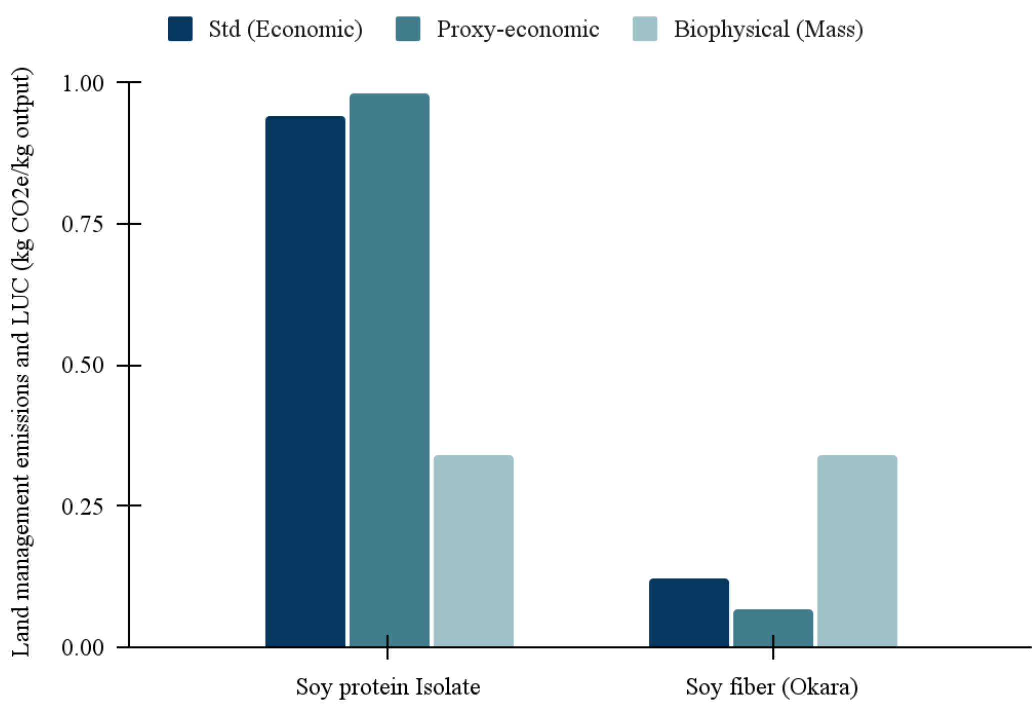

Figure 3. Comparative analysis of land management emissions of soy products using different allocation approaches. (Source: HowGood)

Results show that both standard (economic) and proxy-economic approaches attributed most of the soy emissions to the protein isolate. This is because that product has a high market value in the food and feed industry. The elevated market price reflects the protein isolate's functional and economic significance, justifying its dominance in the allocation of upstream impacts compared to other co-products such as soy okara. This allocation approach aligns with

ISO - 14044 guidelines, ensuring that environmental impacts are distributed according to the relative economic value of outputs within the system boundary.

On the other hand, emissions of soy protein isolate are very similar under proxy-allocation approach (0.98 kg CO_2e/kg) compared to Std, economic (0.94 kg CO_2e/kg), representing a relatively small, 4%, increase. For soy fiber (okara), emissions assigned under proxy-allocation approach resulted in 0.07 kg CO_2e/kg, which is lower than the 0.12 kg CO_2e/kg assigned by Std (economic), indicating that proxy-economic approach places less economic importance on this co-product. Even with this difference, both methods reflect the lower economic relevance of okara within the soy product system. Waste streams such as soy losses receive negligible emissions under all allocation approaches in accordance with ISO 14044 guidance, therefore it is not displayed in the figure.

As seen before, both methods Std (economic) and proxy-economic, prioritize soy protein isolate as the main economic driver, assigning it the majority of emissions consistent with market-based allocation principles. This alignment underscores a key strength of the proxy-economic assessment introduced in this paper: despite relying on implicit market relevance rather than explicit price data, it produces results that are broadly consistent with standard economic allocation.

For comparison, mass-based allocation distributes emissions more evenly among outputs, assigning approximately 0.58 kg CO_2e/kg to both soy protein isolate and okara which ignores the clear value hierarchy between a high-value ingredient like protein isolate and a low-value by-product such as okara.

The results presented above demonstrate that allocation choice significantly influences impact distribution, underscoring the importance of transparent reporting and sensitivity testing when assessing product-level environmental performance.

Another example of allocation comparison is shown in Figure 4. For cassava processing, the main outputs are cassava starch, peels and pomace/pulp. Under the std economic allocation, starch is assigned a high economic share while peel and pomace with low economic share. Similarly, the proxy-economic approach classifies starch as the main co-product because of its characteristics and presence in the market, while pomace and peel are classified as by-products.

Figure 4 shows land management emissions (including LUC) of cassava products under different allocation approaches.

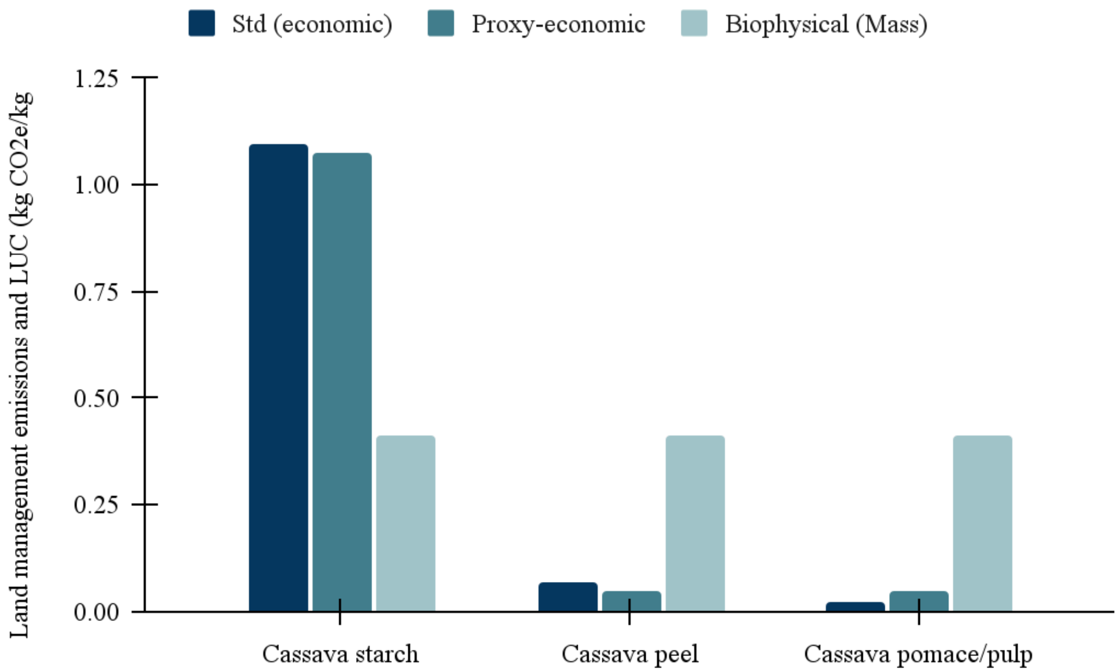

Figure 4. Land management emissions of cassava starch and by-products using different allocation approaches. (source: HowGood)

Under Std (economic) and proxy-economic allocations, emissions are heavily concentrated on the main product, cassava starch, which reflects the reality of its economic importance as the primary driver of cassava cultivation. Both methods yield similar results, with cassava starch bearing nearly the entire environmental burden (~1.07 kg CO_2e/kg), and by-products receiving minimal allocation (<0.1 kg CO_2e/kg).

In contrast, the mass-based allocation distributes emissions based on the physical mass of each product relative to the total cassava input. This leads to a dramatic shift: cassava peels and pomace/pulp each receive considerably higher emissions (~0.4 kg CO_2e/kg), while the burden on cassava starch is effectively reduced or excluded in this specific representation. This outcome reflects the substantial physical quantities of these by-products, despite their low or zero economic value.

Biophysical allocation can be inaccurate if applied strictly by mass as in the example above. Conversely, the economic allocation presents two main limitations: data scarcity and impact underestimation. Data scarcity arises because reliable market pricing and allocation factors are often unavailable for co-products transformed beyond second-level processing of a commodity or for low volume commodities. In addition, to mitigate market fluctuations and ensure consistency, data is recommended to be collected from a long-term average of market price data (for instance LEAP recommends market price data from 5 years back). On the other hand, the most significant drawback is the impact underestimation: co-products with low economic value often receive zero allocation since they are treated as waste but they are subsequently used in other valuable goods (e.g. fruit and vegetables trimmings used for pectic or colorant extraction). This failure to assign some responsibility to the usable by-products unfairly minimizes the true impact of the main commodity.

The comparative analysis presented before reinforces that allocation is a critical decision point in carbon footprint methodology. The results show that economic and proxy-economic allocation methods produce similar outcomes, especially for high-value main products like cassava starch or soy protein. To be clear, when economic allocation data are available, HowGood uses it to perform the allocation procedure, and only relies on proxy-economic allocation when industry standard economic allocation factors are unavailable.

8. Recommendations

The comparative analysis in the previous section suggests that proxy-economic allocation is a suitable and robust alternative when detailed economic data is unavailable or incomplete.

At events and calls we've attended with other practitioners at food & beverage companies, consultancies, NGOs, academia, and other service providers, the lack of alignment on how to allocate impacts has been clear. We see this lack of alignment as a sign of maturation in carbon accounting, and are motivated to contribute our approach and findings to the community, and learn best practices presented by others.

In conversations with respected consultancies specializing in life cycle assessment (LCA) and carbon accounting, there is a stated preference to use economic allocation. We collaborate with some of these thought leaders that contributed significantly to this space in recent decades with clear voices and resources guiding the community. We appreciate their perspective and contributions and agree with them that applying physical allocation alone is incorrect, as evidenced in Figure 3 and elaborated upon in the previous section.

We're publishing this report to take another step towards aligning the LCA and carbon accounting community by sharing some of our data-driven results from scaling the provision of product carbon footprints (PCFs) and scope 3 purchased goods emissions (scope 3 Category 1 or 3.1) to some of the largest retailers, CPGs, food distributors, and food service operations in the world. Accommodating the breadth of product portfolios carried by retailers, distributors and food service providers means we had to design for scalability, which presented a unique set of requirements and constraints. Because our platform was initially launched to serve product formulators, we built our database of crops and ingredients to cater to all ingredients in product formulations, and therefore were not able to apply the cutoff rule often used in carbon accounting for the bottom 5% of ingredients within a formulation. That bottom 5% often contains highly concentrated ingredients that can have a notable impact on a PCF. We applied this approach of measuring the impact of all ingredients to all customer types noted above. The scale required to provide granular, accurate PCFs and 3.1 emissions to these customers and their wide variety of products and ingredients necessitated the design of the proxy-economic method introduced in this document.

We believe the long-term shared goal for the LCA and carbon accounting community should be a shared resource of economic data that spans the entirety of the agri-food system, making the proxy-economic allocation approach obsolete. And we're interested in partnering with the community on making that vision a reality. Until that vision is realized, we offer this alternative method to the community to pursue methodological alignment when published, industry standard allocation factors are unavailable. If you're interested in learning more about this topic via a webinar or have an interest in collaborating for the benefit of the community, please send an email describing your interest to contact@howgood.com.

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About HowGood

HowGood is an independent research company and SaaS Sustainability Intelligence platform with the world's largest database on food product sustainability. With more than 90,000 agricultural emissions factors, HowGood helps leading brands, suppliers, retailers and restaurants to measure, reduce, and communicate their environmental and social impact. Through in-depth, ingredient-level insights into factors like greenhouse gas emissions, biodiversity, labor risk, animal welfare, and other key impacts, HowGood's data power strategic decision-making for the sourcing, manufacturing, merchandising, and marketing of sustainable products. For more information, visit www.howgood.com.

Appendix: Classification of co-products, by-products, and waste

This section presents the structured approach for classifying outputs from processing systems into co-products, low-value co-products (by-products), or waste. Accurate classification is essential for appropriate environmental burden allocation in carbon emissions.
While Market-based classification incorporates market considerations, it does not rely solely on subjective judgment. Instead, it follows systematic criteria grounded in industry standards, specific research, and expert consultation.

Step 1: Understand the Commodity Tree

A commodity tree is a hierarchical representation illustrating how a primary product is processed into secondary and tertiary outputs. Understanding this structure is essential for identifying the relationships between products.

Step 2: Identify Product Relationships

For each branch of the commodity tree, determine the nature of the output relationship based on definitions for:

Co-products: Outputs produced intentionally and simultaneously from the same process, typically of comparable economic importance.

By-products (Low-value co-products): Outputs that are incidental or secondary, often residuals with lower economic or functional value.

Waste: Outputs with no intended use, requiring disposal.

Additionally, consider whether the crop or input was cultivated or processed specifically for the product in question. Products targeted by cultivation or processing are classified as main products or co-products; otherwise, they are typically by-products.

Step 3: Apply Classification Criteria

The classification informs how environmental burdens are allocated in LCA. The following criteria guide the distinction between co-products and low-value by-products:

Criterion	*Definition*	*Co-product*	*Low-value By-product*
Intentionality	Whether the output is a deliberate target of production.	Intentionally produced as a primary or equally important goal of the process.	Generated incidentally or as a secondary consequence of producing another product.
Market value	Relative economic worth of the output compared to other outputs from the same process, based on prevailing market prices.	Significant market value comparable to main product(s); contributes materially to overall revenue.	Minimal economic value; limited influence on process economics.
Functionality	The practical or nutritional role of the output in intended applications (e.g., food, feed, industrial use).	Intended for sale or use due to functional or nutritional attributes (e.g., fat, protein, carbohydrates, industrial properties).	Limited functional or nutritional value; not a primary driver of production.
Processing cost	The additional effort and economic justification required to make the output market-ready.	Requires further processing that is economically viable and justified by the product's value.	Requires minimal or no further processing; often sold or used in residual form.