Life Cycle Assessment | Beyond Meat, Inc.

A Comparative Cradle-to-Distribution Study of Beyond Steak® Plant-Based Seared Tips and Beef-based Steak Tips

POSITIVE SCENARIOS CONSULTING, LLC

Project Information

Project Title	A Comparative Cradle-to-Distribution Study of Beyond Steak® Plant-Based Seared Tips and Beef-based Steak Tips
Contracting organization	Beyond Meat, Inc.
Practitioner organization	Positive Scenarios Consulting, LLC
Liability statement	Positive Scenarios Consulting, LLC (PSC) prepared the attached report only for Beyond Meat, Inc. (the Client) pursuant to an agreement solely between PSC and the Client. PSC did not perform its services on behalf of or to serve the needs of any other person or entity. Accordingly, PSC expressly disclaims any duties or obligations to any other person or entity based on its use of the attached report report, other than an indemnified party as defined in the Client's contract. Any other person or entity must perform its own due diligence inquiries and procedures for all purposes, including, but not limited to, satisfying itself as to the financial condition and control environment of the Client, as well as the appropriateness of the accounting for any particular situation addressed by the report.
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Executive Summary

This study is a life cycle assessment (LCA) commissioned by Beyond Meat, comparing the Beyond Steak® Plant-Based Seared Tips to pre-cooked beef-based steak tips. The scope of the study is cradle-to-distribution; as such, the boundary of the systems studied will include activities necessary to produce the Beyond Meat and animal-based meat in retail-ready form and deliver it to the customer. Primary data were provided by Beyond Meat on product formulation, packaging specifications, processing inputs, intermediate and final transportation distances and methods, as well as locations for intermediate and finished good cold storage. Secondary data were used for modeling the impacts of Beyond Steak® material and energy inputs, transportation, and cold storage. The comparison product, pre-cooked beef-based steak tips, was modeled through a composition analysis and secondary data from the United States Department of Agriculture (USDA) and the *World Food LCA Database* (*WFLDB*), a comprehensive LCA database and data collection initiative led by Quantis in partnership with leaders in the agri-food sector (Quantis, 2024).

Table ES.1 summarizes the results by impact category for the two products, including the percent reduction associated with Beyond Steak® compared to the beef-based steak tips. The following impact categories were considered and assessed in this study: global warming, terrestrial acidification, freshwater and marine eutrophication, land use, fossil resource scarcity, and water consumption. These impact categories are modeled with the characterization method from *ReCiPe 2016* and default midpoint indicators (*Midpoint (H)*). These impact indicators were selected based on their high relevance to the product systems and according to guidance from the Good Food Institute (GFI).

Table ES.1: Summary of results for Beyond Steak® and beef-based steak tips.

Impact category	unit	Beyond Steak®	Beef-based steak tips	Percent reduction (Beef-based steak tips → Beyond Steak®)
Global warming	kg CO_2 equivalent	0.52	3.27	**84%**
Terrestrial acidification	kg SO_2 equivalent	0.0015	0.023	**94%**
Freshwater eutrophication	kg P equivalent	0.00014	0.00064	**77%**
Marine eutrophication	kg N equivalent	0.00029	0.0063	**95%**
Land use	m^2a crop equivalent	0.55	4.49	**88%**
Fossil resource scarcity	kg oil equivalent	0.13	0.35	**65%**
Water consumption	m^3 water consumption	0.0042	0.058	**93%**

Based on the comparative assessment of the Beyond Steak® production system with beef-based steak tips (modeled using *WFLDB*), the Beyond Steak® generates 84% less global warming impact (or GHG emissions), and requires 88% less land use, 65% less fossil resources, and 93% less water consumption. The biggest gap is present in terrestrial acidification and marine eutrophication, where the impact of Beyond Steak® is 94% and 95% less than that of the beef-based steak tips. Additionally, freshwater eutrophication is 77% lower than the beef-based steak tips in the Beyond Steak® system.

The quality of the data was found to be in alignment with the goal and scope of the study through a data quality assessment process. Based on these data quality indicators and uncertainty in background datasets, overall uncertainty in the results is calculated and represented via error bars in impact category-specific results figures. These uncertainties do not impact the study finding that Beyond Steak® has lower impact than beef-based steak tips across all impact categories. A comparative Monte Carlo simulation demonstrates that, for all impact categories, the impact of beef-based steak tips is higher than Beyond Steak® in 100% of the simulations.

The study has been critically reviewed by a panel of three external reviewers and is conducted following guidance from the International Standards Organization (ISO 14040 / 14044). This type of critical review is recommended for comparative studies intended to be disclosed to the public.

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A Comparative Cradle-to-Distribution Study of Beyond Steak® Plant-Based Seared Tips and Beef-based Steak Tips

1.0 Introduction

This document summarizes the approach and methodology of a comparative life cycle assessment (LCA) performed by Positive Scenarios Consulting, LLC (herein, "PSC") at the request of Beyond Meat, Inc. (herein, "Beyond Meat"). PSC was contracted by Beyond Meat in the fall of 2023 to compare the Beyond Steak® Plant-Based Seared Tips to pre-cooked beef-based steak tips, from cradle-to-distribution. The overarching goal of the assessment is to provide a data-based comparison of the environmental impacts of Beyond Meat's products relative to animal-based meat. Past LCAs commissioned by Beyond Meat have focused on their flagship product, Beyond Burger®, the most recent of which was conducted on Beyond Burger® 3.0 and published in December 2023 (Heller et al., 2023). This study aims to expand the portfolio of Beyond Meat products that have product specific, comparative LCA data, supporting the company in evaluating and communicating its mission to "create delicious, nutritious, sustainable protein" (Beyond Meat, n.d.).

The company was founded in 2009 with the belief that the positive choices we all make, no matter how small, can have a great impact on our personal health and the health of our planet. The company advocates shifting from animal-based meat to plant-based protein to positively impact four growing global issues: human health, climate change, constraints on natural resources and animal welfare (Beyond Meat, n.d.).

Plant-based and alternative proteins are gaining traction in the global market. In 2022, the global plant-based meat market size was valued at USD 4.40 billion and is expected to continue to grow in the coming years (Grand View Research, 2023). Plant-based protein manufacturers seek to offer a solution to lower the impact of the protein production system, while still offering products that satisfy customer demand for protein and are comparable in taste and texture to their animal-based counterparts.

To date, comparative studies to evaluate the environmental impacts of plant-based proteins have primarily been conducted at the industry level. The Good Food Institute (GFI) offers a high-level summary of these studies' findings:

> *Such studies demonstrate that plant-based meat can be produced with up to 98% fewer emissions, 93% less land, and 99% less water than conventional meat and that cultivated meat can be produced with up to 92% fewer emissions, 95% less land, and 78% less water than conventional meat.* (Chapman & Murray, 2023)

This study seeks to contribute and add to the discussion of the environmental impacts of plant-based meat, using representative processes and supporting data, and following a robust third-party critical review process to lend credibility to results.

Life cycle assessments (LCAs) are a useful and standardized approach for evaluating the potential environmental impacts from a product system(s) throughout its life cycle. Each LCA defines and assesses a set of relevant impact categories to develop an environmental profile for the system. LCAs are intended to provide a comprehensive and repeatable study by following established guidelines such as those published by the International Organization for Standardization (ISO). LCAs may focus on part of the product system (e.g., cradle-to-gate) or the full product system (cradle-to-grave) assessments.

This report is structured for both ease of use by Beyond Meat and ease of review by the panel of critical reviewers. To supplement this full report, PSC has also developed a summary document for appropriate use within the organization and externally. In the future, should LCA results be placed on the main body of the product or its packaging, additional documentation and evaluation may need to occur.

2.0 Methods

This LCA is attributional and conducted in accordance with the ISO standards:

- ISO 14040:2006, *Environmental management — Life cycle assessment — Principles and framework* (ISO, 2006a);
- ISO 14044:2006, *Environmental management – Life cycle assessment – Requirements and guidelines* (ISO, 2006b).

As this LCA is also being communicated outside of the client organization, the following additional standards were adhered to:

- ISO 14026:2017, *Environmental labels and declarations – Principles, requirements and guidelines for communication of footprint information* (ISO, 2017a);
- ISO/TS 14071:2014, *Environmental management – Life cycle assessment – Critical review process and reviewer competencies* (ISO, 2014).

In accordance with ISO 14044, this LCA report's results, data, methods, assumptions, limitations, and the life cycle interpretation are presented in sufficient detail to allow the reader to comprehend the complexities and trade-offs inherent in the study. Attributional LCA is used so that specific aspects of each product can be traced back to its contributing unit process. The report is organized in a manner that follows the study approach of goal and scope definition, life cycle inventorying, impact assessment, and interpretation. This approach and report organization is in line with the LCA method steps according to the ISO standards. This report documents the LCA results and conclusions transparently and without bias and allows results and life cycle interpretation to be used in a manner consistent with the goals of the LCA study. Report findings are intended to be used for comparative assertions, and thus have undergone review by a critical review panel.

This study draws on ISO-aligned guidance developed by The Good Food Institute (GFI), a nonprofit think tank seen as a leading voice in the industry for advancing alternative proteins. The GFI public guide establishes best practices for alternative protein companies interested in conducting LCAs (Chapman & Murray, 2023).

The LCA model was created using SimaPro v.9 software and Microsoft Excel. The main life cycle impact assessment (LCIA) method to be used and accessed via SimaPro is *ReCiPe 2016 Midpoint (H)*. The LCIA method was selected for its coverage of the impact categories of focus in this study, which are presented and discussed in the *Impact Categories* section. *IPCC 2021 GWP100* and *IPCC 2021 GWP20* were also used to provide additional insights. The following life cycle inventory (LCI) databases were accessed via SimaPro and used to build out the system products and processes: *World Food LCA Database (WFLDB), Agrifootprint-6*, *ecoinvent v3.9.1,* and *AGRIBALYSE v3.1*. Use of these databases enabled this study to best represent the complexity of the product systems and the breadth of ingredients. Additionally, externally published LCA reports or resources may be referenced to support modeling of specific parameters in the beef-based comparison products.

2.1 Goal

Beyond Meat seeks to offer a nutritious and tasty alternative to animal-based meat that reduces the generation of greenhouse gas emissions and provides additional environmental benefits. As a leader in plant-based meat, Beyond Meat aims to add to and expand evidence-based claims in support of its products when compared to animal-based meats.

Beyond Meat has previously assessed and communicated the environmental benefits of Beyond Burger®, its flagship product (Heller & Keoleian, 2018; Heller et al., 2023). In this study, Beyond Meat has commissioned PSC to assess Beyond Steak® Plant-Based Seared Tips, with the goal of communicating its potential environmental impact when compared to animal-based meat alternatives. A secondary goal of this study is to inform the organization's greater sustainability and ESG (environmental, social and governance) efforts.

The intended application of this study is to support product-level communications to external audiences as appropriate. The intended audiences for this report are internal stakeholders at Beyond Meat who will use results and conclusions to evaluate and communicate the environmental impacts of its products compared to animal-based meat. This study will also be made directly available to external audiences, such as customers. Results from this study will be comparative assertions, publicly disclosed on Beyond Meat's website, in sales, and in ESG reporting. Any comparative assertions made apply to product made and distributed in the United States. Beyond Meat also expects peer organizations, supporters, non-governmental organizations (NGOs), and the animal-meat industry to take an interest in the results of this study.

Given that comparative assertions will be an outcome of this study, the full LCA report will be publicly available. However, proprietary information, such as specific ingredient details, formulations, and quantities, and supplier information, will not be public, as they are considered highly confidential and a trade secret. The critical review panel had access to confidential information during the review process.

2.2 Scope

The Beyond Meat product system in this study are pre-cooked Beyond Steak® Plant-Based Seared Tips. The product is assessed in its finished good form with retail store packaging, and against a comparable, animal-based meat of pre-cooked beef-based steak tips in their finished good, retail-ready form. Beyond Meat products sold to foodservice customers are not included in the scope of this study.

The study represents a cradle-to-distribution assessment of the Beyond Steak® Plant-Based Seared Tips product chain. As such, the boundary of the systems studied will include activities necessary to produce the Beyond Meat and animal-based meat in retail-ready form and deliver it to the customer. Retail, use and end-of-life stages are excluded from the study as these are not expected to differ significantly between the two systems. More details are provided in the *System Boundaries* section of this report.

Although both the plant-based and animal-based product systems can be found globally, the geographic scope of this study applies to finished goods manufactured and sold in the United States market. Justification for narrowing the geographic scope to the U.S. is threefold:

1) *Regional agricultural systems*: Practices in upstream agricultural systems can vary significantly by region. Narrowing focus on U.S.-based beef production enables a clearer and more defined comparison of products and more focused results and discussion.

2) *Regional product variations*: Beyond Meat product ingredient composition, product formulation and retail packaging vary slightly by region. Similarly, manufacturing locations and upstream suppliers can vary by region. Narrowing the scope to the U.S. enables a more streamlined data collection process and a more defined comparison to animal-based meat.
3) *Regional applicability*: While both the plant-based and animal-based product systems in this study can be found in a global market, a key segment of Beyond Meat's customer base is in the U.S. This study is targeted to U.S. consumers, with the product SKU under study only being sold in the U.S. Therefore, narrowing the scope to be regionally relevant to the U.S. was deemed appropriate. In future studies, other regions may be assessed to cover other regional audiences.

Results presented in this LCA are representative of Beyond Meat product performance since the launch of the current version of Beyond Steak® Plant-Based Seared Tips, shown in Table 1.

Table 1: Temporal representativeness of this study for Beyond Steak® Plant-Based Seared Tips.

Product System	Product Name	SKU	Current version	Market Launch Date
Beyond Steak® Plant-Based Seared Tips	Original	2B52-001	1.0	October 2022

Where possible, calendar year 2023 (CY2023) data were used as the baseline for data collection. As data collection is ongoing, exceptions to this baseline year will be addressed. This LCA should be relevant until substantive changes to product formulation or process flow are made. The significance of those future changes on this scope and study results cannot yet be evaluated.

This LCA report has been critically reviewed in accordance with ISO/TS 14071 by a panel of three reviewers. Further detail of the critical review can be found in the *Critical Review* section of this report and appendices (Appendix A).

Roland Geyer was engaged to review the goal & scope of this LCA prior to study completion, which included a review of the study's approach, limitations, and assumptions. Once alignment was reached and the study was completed, Roland Geyer and his panel of reviewers also reviewed the final report to determine if:

- the methods used to carry out the LCA are consistent with ISO 14040 and 14044;
- the methods used to carry out the LCA are scientifically and technically valid;
- the data used are appropriate and reasonable in relation to the goal of the study;
- the interpretations reflect the limitations identified and the goal of the study; and
- the study report is transparent and consistent.

The review statement from the critical review panel stating conformance with ISO 14040 and 14044 is provided in Appendix A.

2.2.1 Function and Functional Unit

The primary function of Beyond Steak® Plant-Based Seared Tips and its animal-based meat, pre-cooked beef-based steak tips, is the same: to supply human nutrition. Both product systems also provide secondary, non-nutritional functions, such as pleasure, emotional and psychological value, and cultural identity, which are considered equivalent in this study. Given that Beyond Meat's products are designed to mimic both the flavor and texture profiles of animal-based meat, the equivalency of the product system's primary and secondary functions was deemed appropriate.

Careful consideration was given to the functional unit of this study. PSC referenced the decision tree provided by United Nations Food and Agriculture Organization (FAO) for functional unit selection, shown in Appendix C (McLaren et al., 2021). This decision tree offers several options for functional unit selection, including comparison based on a single nutrient, mass, or standard serving size. Based on the decision tree, this study will focus primarily on a mass-based functional unit. The key objective of this LCA aligns with the FAO decision tree to study alternative foods in a meal (i.e., substituting animal-based meats for plant-based) with some focus on nutritional or health impacts, but without explicitly comparing nutritional quality of the product in the functional unit (McLaren et al., 2021). Using a mass-based functional unit is also in alignment with GFI recommendations (Chapman & Murray, 2023).

Table 2 summarizes the functional unit and reference flow for the products in this study. The functional unit is the mass-equivalent to one serving size of Beyond Steak® Plant-Based Seared Tips. The animal-based meat, pre-cooked beef-based steak tips, was scaled to the equivalent mass. Although mass is the main reference flow based on the functional unit, the table also includes reference flows for caloric value and protein content to support later sensitivity analysis.

Table 2: Functional unit and reference flow.

			Reference Flows for 88 grams, cooked		
Comparison Group	Product	Functional Unit	Mass (g)	Calories (kcal)	Protein (g)
Steak tips	Beyond Steak® Seared Tips	88 grams cooked	88	170	21
	Beef-based Steak Tips		88	126	18

Though many of the product performance or nutritional profile attributes are similar across plant-based and animal-based meat, there is some variation. To account for this variation, this study follows the recommendation of GFI to use multi-issue functional units to evaluate how results are affected using alternative functional units (Chapman & Murray, 2023):

- *Calorie equivalence*: scaling results of both products to match a shared caloric value;
- *Protein equivalence*: scaling results of both products to match a shared protein mass.

The results with these alternative functional units are included in the sensitivity analysis.

Table 3 offers a more detailed look at the product performance or nutritional profile of Beyond Steak® Plant-Based Seared Tips and its animal-based meat comparison product, pre-cooked beef-based steak tips.

Table 3: Nutritional profile for pre-cooked steak tips comparison group.

Nutritional profile attributes	Beyond Steak® Seared Tips	Beef-based Steak Tips
Calories per gram (kcal)	1.93	1.43
Protein per gram (g)	0.24	0.20
Total fat per gram (g)	0.07	0.04
Saturated fat per gram (g)	0.01	0.01
Cholesterol per gram (mg)	0.00	0.60
Sodium per gram (mg)	3.41	4.76
Iron per gram (mg)	0.02	0.02

This assessment seeks to compare the Beyond Meat product to a hypothetical and generic animal-based meat product rather than to any specific competitor on the market. However, actual competitor product on the market was referenced (e.g., nutritional profile, ingredient label, composition analysis) in order to create the model for the beef-based steak tips. Further detail on modeling can be found in the *Beef-based Steak Tips Overview* section.

2.2.2 System Boundaries

This study is a cradle-to-distribution assessment, including impacts associated with raw material production and manufacturing, finished good production, and product distribution for both the plant-based and animal-based product systems. The system boundary of this assessment ends after distribution to the customer (whether distributor, wholesaler, or retailer), at the customer's first point of receipt (whether in warehouse or in store). All life cycle stages after distribution of the finished product to the customer (e.g., retail, use phase, end of life) are excluded. According to GFI, this type of cradle-to-distribution scope "is the most common system boundary applied to food product LCAs […] and is recommended as the standard approach for alternative protein manufacturers" (Chapman & Murray, 2023). Figure 1 offers a summary diagram of the general system boundary of cradle-to-distribution studies relative to other scope types.

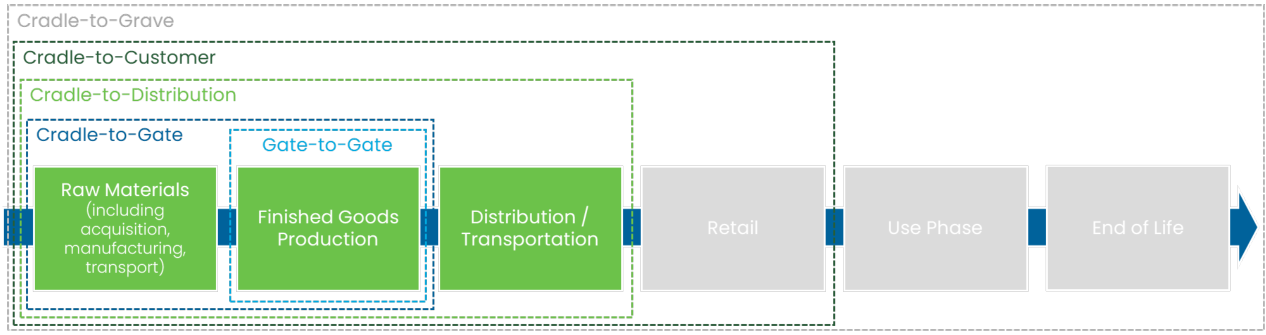

Figure 1: Cradle-to-distribution scope of the study.

A cradle-to-distribution system boundary was deemed appropriate based on the identified goals of this study. Generally, the highest environmental burdens for food products occur during earlier stages of the product life cycle (Chapman & Murray, 2023). By limiting the boundary to these life cycle stages, this study enables the following:

- deeper focus and discussion on key areas of impact;
- enhanced comparability across products within the alternative protein industry and the broader food system (Chapman & Murray, 2023);
- enhanced data quality of the overall assessment given the ability to collect more primary data for raw material, manufacturing, and distribution phases, compared to downstream phases (i.e., retail, use phase, end of life) where data is likely to be based more on assumptions.

Additionally, as described in the *Goal* section, Beyond Meat seeks to gain understanding of the environmental impacts of its product and operations. Given the company's lesser ability to control downstream impacts at the retail and consumer levels, a focus on its managed operations and upstream value chain, where it has more substantive control, is appropriate.

Further justification for the cradle-to-distribution scope, in addition to the recommendation from GFI, is provided below for each downstream life cycle stage that would be considered beyond the distribution gate or out of scope:

- *Retail* – An animal-based meat product similar in size and storage requirements to the Beyond Steak® Plant-Based Seared Tips was selected for comparison. It is likely that storage space and methods (e.g., refrigerated, frozen) at retail locations are similar for both the plant- and animal-based meat product systems, and therefore may not be significant in a study with the retail stage in scope.
- *Use Phase* – An animal-based meat product in a similar state of preparation to the Beyond Steak® Plant-Based Seared Tips was selected for comparison. Both plant- and

animal-based steak tips are pre-cooked by the manufacturer. While consumer cooking instructions may vary slightly between the plant- and animal-based products and use phase impacts may be material over the course of each product's life cycle (Quantis, 2016), consumer preferences on cooking duration (e.g., medium vs. well-done) and cooking method (e.g., grill vs. oven vs. stovetop) vary significantly. Use phase assumptions would be applied with a high degree of uncertainty and variability for both product systems, and therefore the results are less useful or reliable.

- *End of Life* – Similar to the use phase, end of life product impacts can also be material, particularly given the pervasive issue of food waste in the U.S. (Buzby et al., 2014). However, for both product systems, primary data at the retail- or consumer-level is unavailable. End-of-life assumptions for life cycle assessments are traditionally unreliable, requiring scenario and sensitivity analysis to show potential impact deviations.

To ensure a robust comparison to support external claims, careful consideration was given to representing and modeling of the comparative product. Where possible, product system attributes within the system boundary were consistent across both product systems. Similarly, attempts to select products with equivalent system attributes outside the system boundary were also prioritized to further justify the exclusion of downstream life cycle stages after distribution. A summary is shown in Table 4.

Table 4: Product system attributes of steak tips comparative products.

Attributes	Beyond Steak® Plant-Based Seared Tips	Beef-based Steak Tips
Storage (before distribution)	Frozen	Frozen
Storage (during distribution)	Frozen	Frozen
Storage (at retailer)	Frozen	Refrigerated or Frozen
Pre-cooked?	Yes	Yes
Retail packaging*	Plastic pouch with zipper	Plastic pouch with zipper

*Given the variation in retail packaging across animal-based meat products in the market, this study has assumed the same materials (composition and mass per functional unit) are used to package the animal-based meat product as the Beyond Meat products. By doing this, we eliminate how variation in packaging of animal-based products across the market affects the results.

The activities included in this study within each life cycle stage are provided in Table 5. No major activities within the raw materials, preparation / manufacturing, and distribution stages were excluded from the study. For both product systems, minor exclusions were made and are detailed in Table 5. As all unit processes that were excluded would be based on equivalent activity and assumptions between the two products, the exclusion of these materials and processes is in alignment with the goal of the study and does not significantly impact the overall study conclusion or comparison between the two systems. Additionally, this study sought to have system boundary continuity with previous Beyond Meat LCAs.

Table 5: Processes included and excluded in this study, by life cycle stage.

	Included	Excluded
Raw Materials	Raw material manufacturing	Raw material packaging
	Product loss during WIP* preparation	WIP* packaging (bags, crates)
	Water inputs (including ice and tap water)	Tertiary packaging (pallets)
	Retail (primary) packaging materials	Raw material loss at supplier level
	Case (secondary) packing materials	Disposal of manuf. product loss
		Losses from inventory shrink
Logistics	Inbound transportation of raw materials	Forklift operation within facilities
	Cold storage of intermediate WIP*	Capital goods, other overhead
	Transport of WIP* ingredients to finished goods manufacturing	Additional transport undertaken by customer after first delivery
	Transport of finished product to intermediate cold storage	
	Cold storage of finished product	Refrigerant usage
	Distribution of product from intermediate cold storage to customers	
Manufacturing	Utility inputs for warehousing & manufacturing	Capital goods, other overhead
		Refrigerant usage

*WIP refers to work in progress or raw materials that undergo some form of preparation and assembly into dry or wet blends before heading into finished goods manufacturing. Preparation of WIP ingredients specific to this product occurs at a different facility than finished goods manufacturing and packaging of finished goods.

The system boundary is applied consistently across the Beyond Steak® Plant-Based Seared Tips and pre-cooked beef-based steak tips. However, there are differences in some of the specific methods and data sources used for each stage within the system boundary. A comparison between the plant- and animal-based meat system boundaries, data sources, and assumptions applied during the life cycle inventory can be found in the *Product Systems Overview and Comparison* section.

A high-level overview of the product process flow is provided in Figure 2. Both product systems follow this general process flow. A more detailed process flow diagram is in the *Product Systems Overview and Comparison* section of this report. Inbound transport is not temperature controlled (ambient), while intra- and outbound transport are refrigerated.

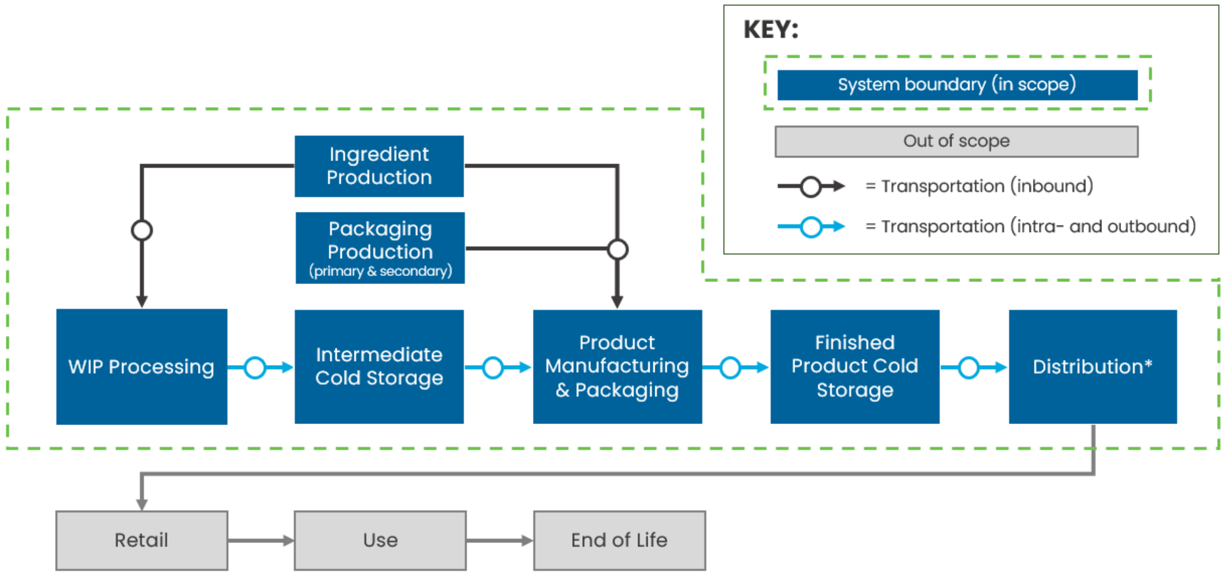

Figure 2: High-level process flow for both plant-based and meat-based product systems.
*Distribution is considered as the customer (whether distributor, wholesaler, or retailer), at the customer's first point of receipt (whether in warehouse or in store).

No specific cut-off rules were applied by PSC when assessing material and energy flows of the product systems. In some cases, a proxy approach was applied for material flows without a matching life cycle inventory dataset. All proxy usage is indicated in the relevant LCI sections.

2.2.3 Allocation

Allocation of impacts for raw materials with co- or by-products followed the allocation method of the LCI database. The *ecoinvent*, *Agrifootprint*, *WFLDB*, and *AGRIBALYSE* databases rely on mostly economic allocation, with only a few exceptions, none of which are relevant to the product systems in this study. This is a common allocation method for agricultural products. No modifications were made to the allocation methods embedded in the datasets.

Allocation of facility-wide energy inputs was done using a mass-based approach, wherein the total facility impacts were divided by the total throughput over that time. These per-mass energy flows were then allocated to the mass of our functional unit passing through the respective facility. Allocation of cold storage requirements was done using space utilization per day.

2.2.4 Impact Categories

The following impact categories were considered and assessed in this study: global warming, terrestrial acidification, freshwater and marine eutrophication, land use, fossil resource scarcity, and water consumption. These impact categories are modeled with the characterization method from *ReCiPe 2016* and default midpoint indicators (*Midpoint (H)*) to reduce the uncertainty associated with modeling endpoint indicators. *(H)* within the name of the midpoint method stands for *(Hierarchist)*, representing a consensus model common in scientific models and is the default model for *ReCiPe 2016 Midpoint* (Pré Sustainability, 2016). The full suite of impact categories available for the chosen characterization model, including their midpoint indicators and characterization factors, is shown in Appendix D.

These impact areas were selected based on high relevancy, as aligned with GFI guidance for priority impact categories for alternative protein manufacturers (Chapman & Murray, 2023); however, this does not proclaim to provide a complete set of environmental metrics of the product. Table 6 provides a summary of the categories in scope, along with characterization models used and the justification for their inclusion in this assessment.

In selecting impact categories relevant to this study, value choices and assumptions were minimized to reduce bias. Guidance from GFI on high priority categories was considered as a baseline (Chapman & Murray, 2023). To align with previous studies, energy use was included and modeled using the fossil resource scarcity category. In previous studies conducted on the Beyond Burger®, energy use or fossil resource scarcity was one of the categories with less demonstrated benefit relative to animal-based meats (Heller & Keoleian, 2018). Further, pre-existing and internationally-accepted impact categories and models were selected – no new categories, indicators, or models were defined through this LCA study.

Characterization models selected are scientifically and technically valid, as well as based upon a distinct identifiable environmental mechanism and reproducible empirical observation. Results for these in-scope impact categories are reported by impact category with no normalization, grouping or weighting.

Table 6: Impact categories in scope and the justification.

Impact Category	Definition	Unit	Characterization Model*	Justification
Global warming	Alteration of global average surface temperature caused by greenhouse gases	kg CO_2 equivalent	ReCiPe 2016 Midpoint (H), based on IPCC 2013 AR5†	GFI recommended for alternative protein manufacturers. Climate action is a core impact area of focus for Beyond Meat.
Acidification (terrestrial)	Change in soil acidity	kg SO_2 equivalent	ReCiPe 2016 Midpoint (H)	GFI recommended for alternative protein manufacturers. Feed for cattle could be a differentiator for land & water systems.
Eutrophication (freshwater)	Accumulation of nutrients in aquatic systems	kg P equivalent	ReCiPe 2016 Midpoint (H)	GFI recommended for alternative protein manufacturers. Feed for cattle could be a differentiator for water systems.
Eutrophication (marine)		kg N equivalent		
Land use	Characterized land use at the midpoint level based on relative species loss per land use type	m^2a crop equivalent	ReCiPe 2016 Midpoint (H)	GFI recommended for alternative protein manufacturers. Plant-based meat is often discussed as having more efficient use of land resources in delivering nutrition. Legumes & cereals grown together tend to have better yield and be less land intensive. Cattle can be land-intensive for feed and rangelands. Further data on this category would be helpful for future planning / scenario analysis and seeking opportunities for improvement.
Fossil resource scarcity	Fossil energy use	kg oil equivalent	ReCiPe 2016 Midpoint (H)	GFI lists 'resource use' as a lower priority category. However, assessing fossil resource use would support identification of operational opportunities for improvement (or hotspots, efficiencies, etc.). This category has also been included in previous Beyond Meat LCAs.
Water consumption	Consumptive water use, or the amount of water used that is not eventually returned to the system	m^3 water consumption	ReCiPe 2016 Midpoint (H)	GFI recommended for alternative protein manufacturers. Plant-based meat is often discussed as having water benefits (especially depending on region). Further data on this category would be helpful for future planning / scenario analysis and seeking opportunities for improvement.

*Details of the *ReCiPe 2016 Midpoint (H)* characterization model taken from Huijbregts et al., 2017.

† Sensitivity analysis is performed using *IPCC 2021 AR6*, the most recent publication and method from the Intergovernmental Panel on Climate Change (IPCC), which is yet to be incorporated into a *ReCiPe* model update.

2.2.5 Data Requirements and Collection

Data Requirements

Where feasible, primary data were collected for all life cycle stages. When primary data collection was not feasible or impactful, secondary data sources were used. This use of secondary data is particularly relevant for the data collection in the animal-based meat comparison products. Secondary data were also used when primary data could not be validated. A description of both primary and secondary data sources is provided in this section of the report.

Where possible, primary data were collected over the course of at least a 1-year period to ensure representativeness, unless otherwise stated. For utility inputs in Beyond Meat facilities, data for the final month of the year was not available for all facilities. For these exceptions, extrapolation was used and documented in the LCI.

This study aimed to achieve at least *good* data quality, prioritizing data with high temporal, geographical, and technological representativeness. Data quality was assessed through a standardized data quality assessment, detailed in this section of the report.

Data Collection

Beyond Steak® Plant-Based Seared Tips Product System

Primary and secondary data were collected and used to study this product system. The primary data were collected from Beyond Meat and their supply chain partners. Where primary data were unavailable (due to feasibility of collection or failure to meet data requirements), external data were used from credible industry sources.

The impact categories in scope for this study were also considered throughout the data collection process. Where applicable, extra attention was given to collecting inventory data relevant to specific impact categories, such as water consumption.

Data gathered from each source is shown in Table 7 along with a description of the data, the source, and other details about the data (e.g., measured, calculated, or estimated; timeframe; geography) to be used for the following data quality assessment.

Table 7: Summary of data collected (primary and secondary).

Stage	Data	Description	Source & Data Approach	Timeframe	Geography
Raw Material Ingredients	Product ingredient components and mass	Bill of materials (BOM) by stock keeping unit (SKU) of ingredient components and mass	Beyond Meat, measured	2023	Site-specific
Raw Material Ingredients	Product ingredient component yields	BOM lists estimates for ingredient loss based on product and BOM level	Beyond Meat, estimated	2023	Site-specific
Raw Material Ingredients	Water weights per product	% of water in final product	PSC, calculated (Beyond Meat verified)	2023	Site-specific
Packaging	Packaging mass	Internal database lists net and gross packaging weights	Beyond Meat, measured	2023	Country-specific
Packaging	Packaging materials	BOM lists description of material packaging	Beyond Meat, measured	2023	Country-specific
Raw Material Ingredients	Ingredient country of origin	Country of origin of main ingredient components	Beyond Meat & suppliers	2023	Country-specific
Transport (Inbound)	Upstream raw material ingredient transport	Supplier shipments to Beyond Meat (BYND), based on country of origin of main ingredient components	PSC, estimated	2023	Country-specific
Transport (Intra)	WIP ingredient transport	Trucking of WIP ingredients between Columbia, MO (COMO) facilities and to finished goods manufacturing facility	PSC, calculated	2023	Site-specific
Manufacturing	Electricity usage at BYND facilities	Facility-wide electricity usage at BYND facilities, for manufacturing and short-term ambient storage	Beyond Meat, measured	2023	Site-specific
Manufacturing	Natural gas consumption at BYND facilities	Facility-wide natural gas consumption at BYND facilities, for manufacturing and short-term ambient storage	Beyond Meat, measured	2023	Site-specific
Manufacturing	Electricity usage at co-manufacturing facility	Average electricity usage per day of production of BYND products at co-manufacturer	Co-manufacturer, calculated	2023	Site-specific

Manufacturing	Natural gas consumption at co-manufacturing facility	Average natural gas consumption per day of production of BYND products at co-manufacturer	Co-manufacturer, calculated	2023	Site-specific
Manufacturing	Throughput at COMO (WIP facilities)	Total lb of WIP blends at COMO (WIP) facilities	Beyond Meat, measured	2023	Site-specific
Manufacturing	Throughput at finished goods manufacturing facility	Total lb of finished goods at manufacturing facility	Co-manufacturer, measured	2023	Site-specific
Cold storage	Electricity usage at cold storage facilities	Proxy value for electricity usage per pallet per day at intermediate and final product cold storage facilities	PSC, estimated	2022	Country-specific
Cold storage	Volume occupation at cold storage facilities	Volume occupied by WIP and final products at intermediate and final product cold storage facilities, respectively	PSC, calculated	2023	Site-specific
Cold storage	Days on hand at cold storage facilities	Days of inventory held of WIP and final products at intermediate and final product cold storage facilities, respectively	Beyond Meat, estimated	2023	Site-specific
Transport (Outbound)	Final product transport from finished goods manufacturing facility to cold storage facilities	Trucking of final product between manufacturing facility, cold storage warehouse, and regional cold storage fulfillment centers	Beyond Meat & PSC, calculated	2023	Site-specific
Transport (Outbound)	Final product transport (delivery) from fulfillment centers to customers	BYND-managed trucking of final product from cold storage fulfillment centers to first point of customer delivery, based on sales data	Beyond Meat, measured	2023	Site-specific
Transport (Outbound)	Final product transport (will call) from fulfillment centers to customers	Customer-managed ("will call") trucking of final product from cold storage fulfillment centers to first point of customer delivery, based on sales data	PSC, estimated	2023	City-specific

Beef-based Steak Tips Product System

Secondary, or generic, data from credible industry sources were used to study the pre-cooked, beef-based steak tips product system. PSC leveraged the *WFLDB* (v3.5) rather than a previously conducted LCA study, enabling the modification of model parameters and subsequent performance of uncertainty analyses. By using the *WFLDB*, the analysis was also not limited by the types of impact categories that could be assessed.

The *WFLDB* beef model is considered to reasonably represent average U.S. beef production and has very good coverage of upstream ancillary processes. Previous Beyond Meat LCA reports used beef data from Putman, Rotz, and Thoma (2023). To ensure consistency and comparability of results, sensitivity analysis was performed using extrapolated results from Beyond Burger® 3.0 LCA (Heller et al., 2023).

In addition to *WFLDB*, *Agrifootprint-6*, *ecoinvent*, and other previously conducted LCA studies were considered. This included Putman, Rotz, and Thoma 2023 which was referenced in the previous Beyond Burger® 3.0 LCA study. Although Putman, Rotz, and Thoma 2023 reasonably represents U.S. baseline beef production and has a comprehensive suite of indicators, without the life cycle model, uncertainty analysis is not possible.

Additional details and description of the *WFLDB* beef dataset can be found in **Appendix E.**

Data Validation

During data collection, checks on data validity were conducted to ensure data requirements have been met. Due to the iterative nature of LCAs, data validation and data quality assessments were performed in conjunction with one another to determine the most reliable, complete, and representative data choice for the study.

PSC's data quality assessment characterizes the quality of data and ensures that data used is valid for the intended application. The data validation process focused on individual data points (e.g., do these data points fulfill our intended application?), whereas the final data quality assessment presented in this report focused on datasets post-validation (e.g., what is the quality of these aggregated datasets for our intended application?).

During the data validation process, several data checks were performed with the following guiding questions:

- Reliability – were the data points from a reliable source?
- Completeness – were the data points complete (i.e., no missing pieces/gaps)?
- Representative – do the data points seem representative when considering the technology, geography, and time-period?

- Accuracy – do the data points seem accurate based on what would be expected?
- Correctness – do the data points "add up;" are there any mathematical errors (e.g., mass or energy balances not adding to 100%)?
- Consistency – were assumptions, allocation rules, system boundary, etc. consistently applied to data points?

These checks were performed and documented as part of the data quality assessment (see Appendix F), the product system comparison (see Table 15), and the consistency check (see Table 29). For this assessment, all data used in the final analysis and data quality assessment passed data validation checks.

Data Quality Assessment

This LCA study prioritized the collection and use of the best quality data available, minimizing bias and uncertainty as far as practical. A qualitative assessment of data reliability, completeness, temporal relevance, geographic relevance, and technological relevance was used to evaluate the data quality. The assessment methodology was adapted from data quality pedigree matrices developed by EPA (Edelen, 2016) and Weidema et al. (Weidema et al., 2013).

Data quality ratings are assigned on a scale of 5 (*very poor*) to 1 (*very good*). Overall, based on the average mean score for each data type, data quality for this study is *good*. Furthermore, data sources that were most material to the results were all classified as *good* or *very good in* terms of data quality. Only data sources of low or medium importance to the results had data quality ratings of *fair* or *poor*. See Appendix F for the full data quality assessment of both products and Appendix G for the pedigree matrix descriptions of data quality scores by indicator – reliability, completeness, and temporal, geographic, and technological representativeness.

This data quality assessment was integrated into the SimaPro models to allow for uncertainty assessments to be conducted in the form of Monte Carlo simulations by the software program, producing both product-specific uncertainty results and comparative uncertainty results. The Monte Carlo simulation "takes a random value from the uncertainty distribution for each uncertain data input and calculates and stores the LCA results for this set of samples values. The procedure is repeated an enormous number of times. Every time, SimaPro selects random values from the uncertainty distribution per data input, calculates the LCA results and stores them" (PRé Sustainability, 2023). The stored LCA results of, in this case, 1,000 iterations form an uncertainty distribution for the final result. The uncertainty distributions for each data input come from two sources in SimaPro, both of which use empirical values for pedigree matrix uncertainty factors to create quantitative uncertainty in the form of probability distributions. The first source of the distributions are provided by the data source (e.g., *ecoinvent*) in reference LCI datasets. The second source of distributions are generated by SimaPro's *Pedigree Uncertainty Calculation* tool, a built-in tool where the results of this study's data quality assessment are inputted into SimaPro's pedigree matrix. The software then translates these factors into quantitative uncertainty using lognormal probability distributions. Each product-specific assessment and the comparative uncertainty assessment were conducted to a 95% confidence interval using Monte Carlo simulation with 1,000 runs.

For the impact category of water consumption, a different approach was taken. A key requirement of a meaningful Monte Carlo simulation is that the parameters are independent. However, at the inventory level, water withdrawn and water released are treated as two independent flows rather than correlated flows. A Monte Carlo simulation cannot meaningfully calculate water consumption uncertainty with the way that water inflows and outflows are set up in the inventory. With the guidance of LCA experts and the support team at PRé Sustainability (makers of SimaPro), the uncertainty for this specific impact category was instead calculated using the pedigree matrix with results of the data quality assessment and system-level, instead of unit-level, datasets to avoid a misrepresentation of uncertainty. Using system-level datasets means that uncertainty in the background datasets is not considered.

Gravity analysis of results was also used to help determine where sensitivity and uncertainty analysis should be performed and prioritized. Uncertainty analysis was performed for all data types of high importance to the study, regardless of data quality. In circumstances where the data type was of at least medium importance to the study, uncertainty analysis was performed if the input data also had at least one quality indicator that was rated below *fair*. Where input data was likely to be high in variability or significant assumptions were made, sensitivity and/or scenario analyses were performed as part of a sensitivity check. Additional scenario analyses were also run on significant areas to help inform conclusions. The results of these analyses can be found in the *Results and Discussion* section of this study.

Moreover, consistency checks were performed to ensure consistent application of functional unit, geographical and temporal factors, allocation rules, system boundaries, and impact assessment methods. The results of these checks can be found in the *Assessment Limitations and Future Improvements* section.

2.2.6 Assumptions

Assumptions were made throughout the course of this study to support assessment feasibility. In general, it was assumed that:

- Primary data provided by Beyond Meat, their co-manufacturing partners, and their suppliers are accurately representative of Beyond Steak® Plant-Based Seared Tips;

- Beyond Meat's current production practices are representative of all U.S. Beyond Steak® Plant-Based Seared Tips products;
- Impacts associated with U.S. beef production, as reported in the *WFLDB* and in the study conducted by Putman et al. (2023), accurately represent the comparative product, pre-cooked beef-based steak tips. Alternative practices in beef production that may result in reduced environmental impacts (rotational grazing, regenerative practices, etc.) were not considered as part of the baseline.

More detailed assumptions, where relevant, are provided in the life cycle inventory (LCI) section, by process stage.

2.2.7 Limitations

While LCAs aim to provide a more comprehensive environmental profile of a product or system compared to single-indicator assessments, they are still limited in their ability to provide an exhaustive assessment of all potential environmental impacts. Though this LCA study should help Beyond Meat to achieve the goal of providing data-based evidence for the environmental impacts of plant-based meat relative to animal-based meat, PSC recommends considering non-environmental impacts (e.g., social, health, safety, economic), as well as any other environmental impacts that are out of scope in this study in the future development and improvement of products.

Many environmental assessment techniques exist in addition to LCA (such as risk assessment, environmental performance evaluation, and environmental auditing) and LCA may not be the most appropriate technique to use in all situations. Furthermore, comparative LCA does not and should not provide the sole basis of a comparative assertion of overall environmental superiority or equivalence. Additional information would be necessary to overcome some of the inherent limitations (e.g., value-choices, exclusion of spatial and temporal factors) in the LCA to allow for this type of assertion. However, LCA is currently one of the best options available today to assess and compare the environmental performance of products and systems.

This LCA study is attributional, meaning that the assessed environmental impacts of the product assume a static market scenario.

This LCA assesses impact using categories that are both global (e.g., global warming potential) and more localized (e.g., water use, acidification, eutrophication). It is limited in its ability to model local-level impacts, especially for elementary flows where exact locations are uncertain or unknown.

As the comparisons made in this study involve products outside of the client organization, there is a difference in data representativeness between the two product systems. Given Beyond Meat's involvement in this study, some primary data were available and leveraged in completing the Beyond Steak® Plant-Based Seared Tips assessment. However, the assessment of the beef-based steak tips relied exclusively on secondary data, meaning that the results are not representative of any one specific product on the market. The Beyond Meat product is compared to a hypothetical and generic animal-based meat product rather than to any specific competitor on the market. For the sake of modeling, however, actual competitor product on the market was referenced (e.g., nutritional profile, ingredient label, composition analysis). High levels of care were used in establishing the scope of study and performing uncertainty analysis to manage this limitation.

In general, sensitivity and uncertainty analyses, as well as thorough discussion and interpretation of results, are used to counteract the main limitations of this study.

3.0 Product Systems Overview and Comparison

This cradle-to-distribution LCA study compares two pre-cooked steak products produced in the U.S., plant-based seared tips from Beyond Meat and beef-based steak tips. The following sections will summarize the two product systems and provide a side-by-side comparison by product stage.

3.1 Beyond Steak® Plant-Based Seared Tips Overview

3.1.1 Characteristics of Product System

Beyond Steak® is a plant-based seared tips product designed to look and taste just like real steak. The steak tips include no GMOs, no added soy, and are kosher (Beyond Meat, n.d.). They must be stored frozen and require approximately five minutes of cooking on a hot skillet or in an air fryer to reach a recommended internal temperature of 165°F. The Beyond Steak® packaging and a picture of the product is shown in Figure 3 (Beyond Meat, n.d.).

Figure 3: Visual of Beyond Meat's Beyond Steak® included in this study.

POSITIVE SCENARIOS
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3.1.2 Process Flow Diagram

Figure 4 shows a high-level process flow of product system activities included in this study. As mentioned in the methods section, this is a cradle-to-distribution study, meaning all processes downstream from distribution are excluded from the system boundary.

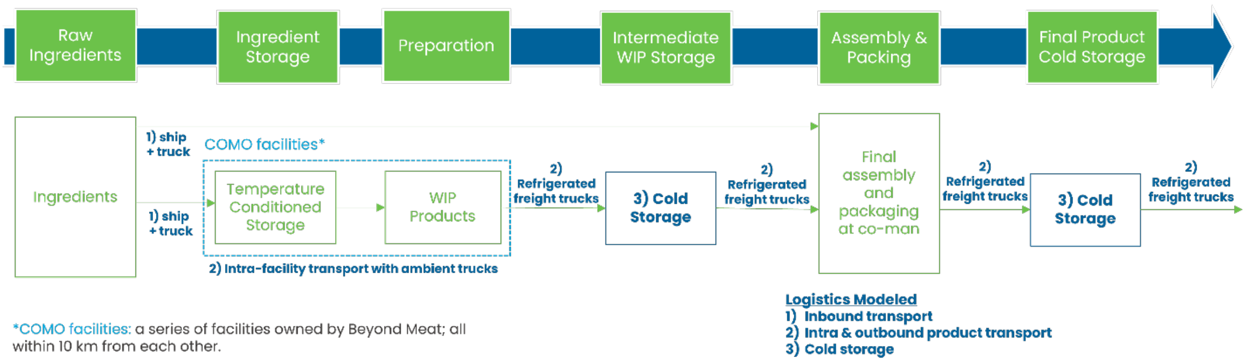

Figure 4: Process flow diagram for Beyond Steak® Plant-Based Seared Tips.

Raw materials are harvested, manufactured, and transported from various upstream ingredient suppliers. Ingredients are either transported directly to assembly at Beyond Meat's co-manufacturing location or are brought to an intermediate preparation step at Beyond Meat-operated facilities in Columbia, Missouri (COMO, for short) before continuing to assembly. Intermediary product components produced before finished goods manufacturing are referred to as WIP (work in progress) products.

For this specific product, ingredients going into WIP products are initially stored at a Beyond Meat COMO facility in ambient storage before being prepped, which may include processes such as mixing or extrusion. Allergen ingredients (such as wheat gluten) are stored and processed at different facilities than non-allergen ingredients. Once WIP products are prepped, they are then sent to a short-term cold-storage facility, owned by a third-party logistics (3PL) partner, prior to being transported to finished goods manufacturing via refrigerated trucks.

At the assembly stage, dry blends and water-soluble ingredients are mixed with water, and fat-soluble ingredients are mixed with oil. These products are combined and cooked in a steam oven, then frozen in the final product form. Frozen final products are then bagged, packed, and palletized to be shipped to separate facilities (a warehouse then regional fulfillment centers) for cold storage prior to distribution to customers. Distribution to customers (the last leg of transport in scope) is managed either by Beyond Meat or through customer pick-up (i.e., will call). The boundary of this study ends with the product being received by customers at the first point of delivery, whether in the warehouse of a distributor or retailer or directly in-store.

POSITIVE SCENARIOS
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3.1.3 Life Cycle Inventory

Raw Materials

Raw material ingredients included in the life cycle inventory (LCI) are provided in **Table 8.** This table includes the LCI datasets and sources used for modeling. Where possible, PSC selected or customized datasets based on country of origin (COO) provided by either the supplier or procurement team at Beyond Meat. The weight of raw material per functional unit is proprietary information that was given to PSC for the assessment and not included in this public report. All ingredients were included in this assessment. In lieu of applying mass-based cut-off criteria, some ingredients were assessed using a proxy approach. The use of technical and geographical (non-COO-specific datasets) proxies is accounted for in the uncertainty assessment conducted in SimaPro.

Table 8: Beyond Steak® Raw Material Life Cycle Inventory.

Ingredient	LCI dataset	Source	Proxy?
Water	Tap water {GLO}| market group for tap water | Cut-off, U	ecoinvent v3.9.1	Geographical
Wheat Gluten	Wheat gluten meal, at processing {RER} Economic, U	Agrifootprint-6	N
Faba Bean Protein	Pea protein-isolate, at processing {modified to CA} Economic, U*	Agrifootprint-6	Technical
Expeller-Pressed Canola Oil	Refined rapeseed oil (pressing), at processing {AU} Economic, U	Agrifootprint-6	N
	Refined rapeseed oil (pressing), at processing {CA} Economic, U	Agrifootprint-6	N
Natural Flavor	Chemical, organic {GLO}| market for chemical, organic | Cut-off, U	ecoinvent v3.9.1	Technical & geographical
Spices	Customized assembly: Spice Mix	AGRIBALYSE v3.1	Geographical
Formulation contains less than 1% of the following ingredients:			
Pomegranate concentrate	Customized assembly: Fruit and Vegetable Juice blend	AGRIBALYSE v3.1	Geographical
Salt	Sodium chloride, powder {GLO}| market for sodium chloride, powder | Cut-off, U	ecoinvent v3.9.1	Geographical
	Potassium chloride {RoW}| market for potassium chloride | Cut-off, U	ecoinvent v3.9.1	Geographical
Sunflower Lecithin	Sunflower lecithin, at oil mill (WFLDB)/GLO U	WFLDB v3.5	Geographical
Fruit and Vegetable Juice Color	Customized assembly: Fruit and Vegetable Juice blend	AGRIBALYSE v3.1	Geographical

*Modifications to dataset described below and documented in **Appendix H**.

Other key assessment notes and assumptions related to raw materials include:

- The bill of materials (BOM) provided by Beyond Meat, including the ingredient composition, associated mass, and water weights, were assumed to be complete and accurately representative of Beyond Steak® Plant-Based Seared Tips;
- Product loss at the manufacturing stages was not measured directly, but rather estimated based on the product- and ingredient-level data available;
- Temporary shifts in Beyond Steak® Plant-Based Seared Tips ingredient composition or sourcing due to lack of supply or pricing constraints, if present, were not considered. The BOM and ingredient COO were considered static throughout the assessment timeframe.

Wheat Gluten

Wheat gluten is one of the main components of the Beyond Steak® wet blend. The supplier provided details on country or region of origin (Europe) and confirmation of the by- and co-products of wheat gluten production: wheat bran, wheat starch, and liquid feed. The LCI dataset for wheat grain uses economic allocation to assign impacts to each by- and co-product, including wheat gluten. *Agrifootprint* relies on price information of the outputs to determine this allocation. The allocation method was not modified.

Faba Bean Protein

Faba bean protein is another main component of the Beyond Steak® wet blend. The faba bean protein supplied to Beyond Meat comes from North America. By- or co-products of the production of faba bean protein include hulls and starch.

No adequate datasets were found across leveraged LCI databases to specifically represent the faba bean protein used in Beyond Steak®. Therefore, an analysis was conducted to (1) select the best available proxy based on information from the ingredient supplier and key known parameters about each available protein-isolate proxy, and (2) assess the impact of each proxy choice compared to the beef-based steak tips. The methods for and results of this analysis can be found in the *Sensitivity Analysis* section.

For the baseline model, a pea protein-isolate dataset from *Agrifootprint* was selected as the proxy for the faba bean protein ingredient, based on key parameters such as regional applicability, protein-content, and field operations. In the pea protein-isolate dataset, starch and hulls from peas are similarly system by-products. Economic allocation is used in the dataset with the majority of impacts from pea production allocated to the pea meal that is eventually transformed into pea slurry and then protein isolate. As by-products, hulls and starch slurry receive a lower burden of the impact per kg of output. In order to model the proxy ingredient coming from the supplier-provided region of origin (North America) the pea protein-isolate dataset was modified to represent agriculture and processing in Canada.

Appendix H provides documentation for how the base *Agrifootprint* dataset was modified to align with product region of origin.

Expeller-Pressed Canola Oil

Canola oil, a modified version of rapeseed oil, comes from crude rapeseed oil extracted from rapeseed. According to the supplier, expeller-pressed canola oil is produced through a process that results in canola meal as a by-product. Through discussion with the supplier, it was identified that canola oil used in the product comes from Canada (80% of supply) and Australia (20%).

The LCI dataset for crude rapeseed oil shows rapeseed expeller, essentially canola meal, as the by-product of the pressing process. The dataset uses economic allocation to split the impacts of pressing rapeseeds between the extracted crude oil (31% of mass output but 60% of economic allocation) and the expeller meal (69% of mass output but 40% of economic allocation). *Agrifootprint* relies on price information of the outputs to determine this allocation.

Spice Mix

To account for a variety of spices and seasonings used in the product a customized assembly was modeled using garlic powder, basil, oregano, parsley, marjoram, rosemary, thyme, and paprika. This blend serves as a proxy for both the Beyond and meat-based steak products.

Fruit and Vegetable Juice Color

To account for a variety of fruit and vegetable juice colorants used in the product, a customized assembly was modeled using beetroot juice, carrot juice, and orange juice. This blend serves as a proxy for the actual juice colorants and concentrates in the product.

Packaging

Packaging materials included in the life cycle inventory (LCI) are provided in Table 9. The table also includes LCI datasets used for modeling, the dataset source, and notes, where applicable.

Table 9: Beyond Steak® Packaging Life Cycle Inventory.

Packaging Type	LCI dataset	Source	Note
Primary / retail packaging: Plastic pouch	Customized assembly: - Polyethylene terephthalate, granulate, amorphous {GLO}| market for polyethylene terephthalate, granulate, amorphous | Cut-off, U - Polyethylene, linear low density, granulate {GLO}| market for polyethylene, linear low density, granulate | Cut-off, U - Extrusion, plastic film {GLO}| market for extrusion, plastic film | Cut-off, U	ecoinvent v3.9.1	Assumed 50% PET and 50% LLDPE
Secondary / case packaging: Corrugated board box	Corrugated board box {US}| market for corrugated board box | Cut-off, U	ecoinvent v3.9.1	Assumed to only be a corrugated box, no other packaging materials included.

Logistics

As shown in Figure 4, the following core logistics activities are modeled in this study: (1) inbound transport, (2) intra and outbound transport, and (3) cold storage of WIP products and final product.

Inbound transport includes transport of raw ingredients from tier 1 suppliers to either WIP preparation or finished good manufacturing. In this study, upstream transportation associated with 89% of the mass of dry ingredients were modeled based on country or region of origin provided by suppliers and Beyond Meat procurement. The remaining 11% of dry ingredient mass was not modeled given the low contribution to product weight and lack of origin information.

Intra and outbound transport includes intra-facility transport of WIP ingredients between Beyond Meat's COMO facilities, transporting WIP products to cold storage (at a third-party facility) and then finished goods manufacturing (at a co-manufacturer), in addition to transporting final product from the co-manufacturer to cold storage (at a third-party warehouse and regional fulfillment centers) and then to the customer (at gate or first point of receipt).

Cold storage includes intermediate cold storage of WIP products after the preparation phase, prior to being transported to finished goods manufacturing, as well as cold storage of finished product after manufacturing and packing.

The system boundary ends upon delivery of the product to customer gates. Any further transport or warehousing managed by the customer is out of scope. Figure 4 shows the logistics activities modeled in the study.

Inbound Transport

Inbound transport activities included in the life cycle inventory (LCI) are provided in Table 10, in addition to the LCI datasets and sources used.

For this study, it was assumed that:

- Raw materials from tier 1 ingredient suppliers are shipped in ambient conditions from upstream suppliers, using sea freight for origins outside of North America and freight trucks for origins within North America;
- Raw materials sent via sea freight arrive in the U.S. port nearest its next destination;
- Ingredients that go into WIP assemblies are then trucked and temporarily stored in a COMO storage facility; and
- non-WIP ingredients are then trucked directly to co-manufacturing site for finished goods manufacturing.

Table 10: Beyond Steak® Inbound Transport Life Cycle Inventory.

Activity	LCI dataset	Source
Ship	Transport, freight, sea, container ship {GLO}| market for transport, freight, sea, container ship | Cut-off, U	ecoinvent v3.9.1
Freight Truck	Transport, freight, lorry >32 metric ton, EURO6 {RoW}| market for transport, freight, lorry >32 metric ton, EURO6 | Cut-off, U	ecoinvent v3.9.1

Intra & Outbound Product Transport

Transport activities associated with WIP ingredients, WIP products, and final product included in the life cycle inventory (LCI) are provided in Table 11.

For this study, it was assumed that:

- Intra-facility transportation at COMO facilities - such as transferring WIP ingredients from storage to preparation - was modeled using ambient box trucks;
- Finished WIP products are transported from COMO facilities by refrigerated freight trucks to a third-party cold storage facility, and from there, are transported to finished goods manufacturing at the co-manufacturer using the same transport mode;
- Final product is transported from the co-manufacturer by refrigerated freight trucks to another third-party cold storage warehouse (near the co-manufacturer);
- From the cold storage warehouse, final product is transported by refrigerated freight trucks to regional cold storage fulfillment centers;

- Final product is transported to customer gates by refrigerated freight trucks and is either managed by Beyond Meat or through customer pick-up.

Table 11: Beyond Steak® Transport Life Cycle Inventory.

Activity	LCI dataset	Source	Note / Reference
Box truck	Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {RoW}| market for transport, freight, lorry 3.5-7.5 metric ton, EURO6 | Cut-off, U	ecoinvent v3.9.1	Leased small box trucks used between BYND WIP facilities. 99% of transport is ambient.
Freight truck (refrigerated)	Transport, freight, lorry with refrigeration machine, cooling {GLO}| market for transport, freight, lorry with refrigeration machine, cooling | Cut-off, U	ecoinvent v3.9.1	Logistics providers use refrigerated freight trucks to move WIP materials to finished goods manufacturing facilities and then final product to customers, but exact details of trucks such as sizing and fuel type are unknown. This dataset includes combination of large lorries (16-32 mt and >32 mt) and both CO_2 and R134a refrigerants.

Cold Storage

Energy requirements for cold storage of WIP products before transport to finished goods manufacturing and of final product before transport to customers included in the life cycle inventory (LCI) are provided in Table 12.

For this study, it was assumed that:

- All electricity use is medium voltage, as this is typical for industry (ecoinvent, 2023);
- Electricity used for the intermediate cold storage facility is modeled using SERC region averages because it is located in this region;
- Electricity used for the final product cold storage warehouse (near the co-manufacturer) is modeled using SERC region averages because it is located in this region;
- Electricity used for the final product cold storage regional fulfillment centers is modeled using percent of product passing through those facilities in CY2023 and U.S. grid average datasets based on the region of the facility;
- Cold storage energy intensity is the same as what was calculated in the Beyond Burger® 3.0 study (0.65 kWh electricity/pallet/day) (Heller et al., 2023);
- Each lb of product requires equivalent energy intensity from cold storage regardless of product;
- Only electricity usage was included, any refrigerant or natural gas usage is excluded – this is consistent with the Beyond Burger® 3.0 LCA study (Heller et al., 2023);

- Weight per pallet is consistent with weight per pallet of final SKU;
- Pallets of WIP product are stored for an average of 28 days;
- Pallets of final product are stored for an average of 14 days in a cold storage warehouse near the co-manufacturer;
- Pallets of final product are stored for an average of 60 days in regional cold storage fulfillment centers.

Table 12: Beyond Steak® Cold Storage Life Cycle Inventory.

Activity	LCI dataset	Source	Note / Reference
Electricity (SERC)	Electricity, medium voltage {SERC}| market for electricity, medium voltage | Cut-off, U	ecoinvent v3.9.1	Intermediate cold storage facility is located in SERC region.
Electricity (SERC)	Electricity, medium voltage {SERC}| market for electricity, medium voltage | Cut-off, U	ecoinvent v3.9.1	Final product cold storage warehouse (near the co-manufacturer) is located in SERC region.
Electricity (TRE)	Electricity, medium voltage {TRE}| market for electricity, medium voltage | Cut-off, U	ecoinvent v3.9.1	Final product cold storage fulfillment center is located in TRE region.
Electricity (RFC)	Electricity, medium voltage {RFC}| market for electricity, medium voltage | Cut-off, U	ecoinvent v3.9.1	Final product cold storage fulfillment center is located in RFC region.
Electricity (WECC)	Electricity, medium voltage {WECC, US only}| market for electricity, medium voltage | Cut-off, U	ecoinvent v3.9.1	Final product cold storage fulfillment center is located in WECC region.
Electricity (RFC)	Electricity, medium voltage {RFC}| market for electricity, medium voltage | Cut-off, U	ecoinvent v3.9.1	Final product cold storage fulfillment center is located in RFC region.

Manufacturing

There are two phases of manufacturing managed by Beyond Meat, one with the support of a co-manufacturer. First, preparation of WIP ingredients (dry and wet blends) occurs at Beyond Meat facilities in Columbia, Missouri (COMO). Next, final production (mixing, marinating, cooking, forming, freezing) and assembly (bagging, case packing) of Beyond Steak® into its final packaging form occurs at a co-manufacturing site in Georgia.

Utility data on electricity (CY2023) and natural gas (11 months of CY2023) was collected from Beyond Meat for the relevant COMO sites and extrapolated to represent a full year of production where needed. The co-manufacturer provided average natural gas and electricity consumption per production day of Beyond Meat products in 2023, along with the number of production days in 2023 and total pounds produced during those days.

Manufacturing inputs included in the life cycle inventory (LCI) are provided in Table 13. The table also includes LCI datasets used for modeling and the dataset source. For this study, it was assumed that:

- Electricity and natural gas consumption used for the COMO facilities and steak co-manufacturers are modeled using SERC region averages because they are located in this region;
- Energy requirements for any temporary conditioned storage at WIP facility and assembly facilities are included in the allocation of facility-wide energy use, but cannot be separated out from general facility energy requirements and classified as cold storage; however, intermediate and final products are only held at these facilities for less than 48 hours before packaging and shipment to longer-term storage.

Table 13: Beyond Steak® Manufacturing Life Cycle Inventory.

Activity	LCI dataset	Source
Electricity (SERC)	Electricity, medium voltage {SERC}| market for electricity, medium voltage | Cut-off, U	ecoinvent v3.9.1
Natural Gas Combustion (SERC)	Heat, district or industrial, natural gas {SERC}| heat and power co-generation, natural gas, conventional power plant, 100MW electrical | Cut-off, U	ecoinvent v3.9.1

3.2 Beef-based Steak Tips Overview

3.2.1 Characteristics of Product System

The comparison product for this study is pre-cooked beef-based steak tips produced in the U.S. The beef-based steak tips used for comparison are pre-seasoned and gluten-free. The product is stored fresh or frozen and should be re-heated to an internal temperature of 160°F.

3.2.2 Process Flow Diagram

Figure 5 shows a high-level process flow of product system activities included in this study. As described in the methods section, all processes downstream from distribution are excluded from the system boundary.

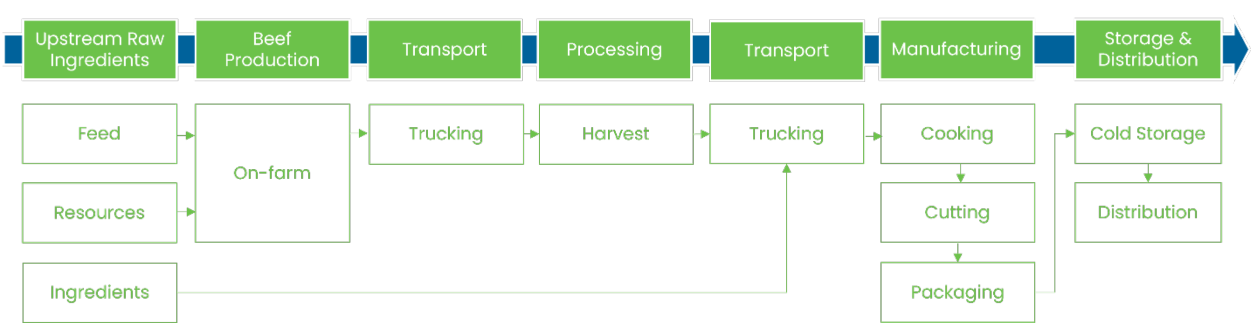

Figure 5: Process flow diagram for pre-cooked beef-based steak tips.

Raw materials are assumed to be harvested, processed, and transported from various upstream ingredient suppliers and shipped to the farm. On-farm activities include a range, feedlot, and finishing facility. The inventory includes the processes for beef cattle slaughtering, transport from the farm to the slaughterhouse, and slaughterhouse infrastructure. Meat is then shipped to final manufacturing where steak tips are seasoned, cooked, cut, and packaged. Final product is assumed to be transported to off-site cold storage facilities and then distributed to customers.

3.2.3 Life Cycle Inventory

Raw Materials

Raw material ingredients included in the life cycle inventory (LCI) are provided in Table 14. The table also includes LCI datasets used for modeling and the dataset source.

Internal teams at Beyond Meat tested for moisture, fat, and protein content in a beef-based representative comparative product to use as the baseline for this comparison. Moisture content was measured using CEM Smart 6, which removes moisture from samples and weighs the before and after to calculate total moisture content. CEM Oracle, a Nuclear Magnetic Resonance (NMR) machine that detects and quantifies fatty molecules, was used to calculate the amount of fat. Protein was calculated using a LECO Dumas machine that combusts the sample and measures nitrogen content derived from protein.

These calculations, combined with nutrition and ingredient labels on pack, were used to calculate the quantity of beef meat and water included in the product.

For this study, raw materials assumptions include:

- The results from comparative product testing provided by Beyond Meat are representative of a reasonable comparative product;
- Ingredient inputs were represented using *WFLDB, ecoinvent, and AGRIBALYSE* datasets;
- Beef production was assumed to occur in the U.S.;
- Meat cuts can vary in their moisture, protein, and fat content. The results of the composition analysis were compared with a USDA dataset for *Beef, flank, steak, separable lean only, trimmed to 0" fat, select, cooked, broiled* (USDA, 2019) to determine an estimate for the percent meat vs. percent added water in the product. This estimate was quality checked against the protein and fat content listed on the product packaging.
- Loss during preparation is assumed to be 5%, and shrinkage during cooking is 25%, based on an average taken from USDA-cited cooking yields of flank (81% yield) and brisket (69%) (USDA, 2014);

- Ingredients representing less than 2% of the product were modeled by assuming 1% salt and an even split of the remaining 1% of mass among other ingredients (spices, vinegar, potato starch, other natural flavors and additives).
- The same customized assembly spice mix was assumed for the Beyond Steak® and beef-based steak tips;
- The vinegar listed in the product ingredients was assumed to be diluted to 5%. This was modeled with a customized assembly of 95% tap water and 5% acetic acid.

Table 14: Beef-based steak tips Raw Material Life Cycle Inventory.

Ingredient	LCI dataset	Source	Mass per functional unit (g)
Beef	Beef, fresh meat, at slaughterhouse (WFLDB)/US U	WFLDB v3.5	90.6*
Water	Tap water {GLO}| market group for tap water | Cut-off, U	ecoinvent v3.9.1	17.2
According to product label, formulation contains less than 2% of the following ingredients:			
Sea Salt	Sodium chloride, powder {GLO}| market for sodium chloride, powder | Cut-off, U	ecoinvent v3.9.1	0.88
Spices	Customized assembly: Spice Mix	AGRIBALYSE v3.1	0.22
Vinegar	Customized assembly: Vinegar (diluted to 5%)	ecoinvent v3.9.1	0.22
Potato starch	Potato starch {GLO}| market for potato starch | Cut-off, U	ecoinvent v3.9.1	0.22
Other natural flavors and additives	PROXY: Chemical, organic {GLO} | market for chemical, organic | Cut-off, U	ecoinvent v3.9.1	0.22

* Final mass of beef meat in the finished product is 69 g but 90.6 g input modeled to account for 5% waste during processing and 25% shrinkage when cooked.

Packaging

Packaging for the beef-based steak tips was modeled as equivalent to Beyond Steak®. Given the variation in retail packaging across animal-based meat products in the market, this study has assumed that the same materials (composition and mass per functional unit) are used to package the animal-based meat product as the Beyond Meat products. By doing this, we eliminate impacts to the results based on variation in packaging of animal-based products across the market. Details behind the datasets used to model the packaging can be found in the Beyond Steak® *Life Cycle Inventory* section on packaging.

Logistics

The following core logistics activities are modeled in this study: inbound transport, farm to slaughterhouse transport, slaughterhouse to final processing transport, cold storage of final product, and outbound transport of final product from final processing to cold storage facilities and then to customer gates. This transportation covers the cradle-to-distribution scope.

Generic transport distances for raw materials and farm to slaughterhouse transport were used unmodified from the reference database. Slaughterhouse to final processing transport was assumed to be 150 km and modeled using a refrigerated freight truck (same LCI dataset as in **Table 11**). Other ingredients were also assumed to be transported 150 km and were modeled using an ambient freight truck (same LCI dataset as in **Table 10**). Sensitivity analysis was performed on this assumed distance to show that even with an assumption of 1,000 km, total product global warming impacts would only increase by 1%. Given the overall low contribution of this life cycle phase and distance assumption, deeper sensitivity analysis was not performed.

Storage and distribution of the final product was assumed to be the same as in the Beyond Steak® system as distribution impacts specific to the beef-based steak tips supply chain were not available and are not expected to deviate significantly from other processed foods, like Beyond Steak®. This approach is aligned with the previous Beyond Meat LCA report for Beyond Burger®. Details behind the datasets used to model the final product cold storage and distribution can be found in the Beyond Steak® *Life Cycle Inventory* section on logistics.

Manufacturing

For this study, final manufacturing, which includes the cooking, cutting, and packaging processes, was assumed to be equivalent between the two products. According to the website, the co-manufacturer used by Beyond Steak® also does processing (cutting and cooking) for beef-based steak in the same facility. Primary data provided by the co-manufacturer for Beyond Steak® was therefore assumed to be a good estimate for the beef-based steak tips. Manufacturing associated with WIP preparation at Beyond Meat facilities was not similarly applied to the animal-based meat system given that the WIP preparation happening at these facilities was considered to be unique to plant-based products.

3.3 Comparison and Summary

Throughout this study, results for Beyond Steak® and the beef-based steak tips were calculated separately. Given the shared functional unit, system boundary, and impact assessment methods, it is reasonable to make detailed comparisons between the two products.

Table 15 highlights a high-level comparison of the system boundaries, data sources, and different assumptions between Beyond Steak® and the beef-based steak tips. This comparison also serves as a completeness check and demonstration that all relevant information and data needed for the LCIA and interpretation are available and complete.

Table 15: Comparison of system boundary and data sources for Beyond Steak® Plant-Based Seared Tips vs. beef-based steak tips.

Stage / process component	Beyond Steak® Plant-Based Seared Tips	Pre-cooked beef-based steak tips
Raw material production and preparation	100% of product composition modeled using product BOM, ingredient datasets selected based on BOM descriptions	100% of product composition modeled using representative comparative product ingredient list, nutrition facts, and composition analysis
Product loss during processing	Yield % included in product BOM and final amounts needed to produce cooked 88 g	Assumption of 5% loss of meat during processing and 25% shrinkage of meat during cooking
Water inputs (including ice and tap water)	Ice included in product BOM and water inputs calculated based on dry vs. final weight of product	Moisture content included in ingredient data sets and water inputs calculated based on product composition analysis
Retail (primary) packaging materials	Plastic pouch, specifications provided and validated with measurement	Assumed to be the same as Beyond Steak®
Case (secondary) packing materials	Corrugated box, specifications provided	Assumed to be the same as Beyond Steak®
Inbound transportation of raw materials	Shipment from suppliers to Beyond Meat based on origin (89% of dry weight)	Shipment from suppliers to processing, included in ingredient datasets
Cold storage of intermediate WIP	Electricity usage in intermediate WIP storage facility	Not relevant
Transport of WIP ingredients to manufacturing	Refrigerated transport of WIP ingredients to manufacturing	Assumed transport of beef to manufacturing facility for cutting and cooking
Utility inputs for warehousing & manufacturing	Electricity and natural gas usage in Beyond Meat preparation and co-manufacturer facilities	Assumed to be the same as Beyond Steak® finished goods manufacturing (electricity and natural gas usage in co-manufacturer facility)
Transport of final product to cold storage (DC)	Refrigerated transport of final product from manufacturing to cold storage facilities (including regional fulfillment centers)	Assumed to be the same as Beyond Steak® transport
Intermediate cold storage of final product	Electricity usage in final product storage facilities	Assumed to be the same as Beyond Steak® cold storage
Distribution of final product from DC to customer gate	Refrigerated transport of final product from regional cold storage fulfillment center to customer gate	Assumed to be the same as Beyond Steak® distribution

4.0 Results and Discussion

This section includes the life cycle impact assessment (LCIA) and results of the life cycle assessment (LCA). The discussion summarizes significant issues identified, an evaluation that considers completeness, consistency, and sensitivity analysis of the results and a reflection of the assessment's limitations and opportunities for future improvement.

4.1 Life Cycle Impact Assessment

This comparative LCA study considered the impact categories of global warming, fossil resource scarcity, consumptive water use, land use, acidification, and eutrophication. Through the classification and characterization process, both product systems' inputs, process flows, and outputs have been translated from inventory data to impacts. These impact categories are modeled with midpoint indicators to reduce the uncertainty associated with modeling endpoint indicators. Table 6 in the *Methods* section provides a summary of the categories in scope, along with their respective indicators, and characterization models used, and the justification for their inclusion in this assessment. The system boundary and other methods employed during this study align with the necessary information needed to calculate the LCIA. As each impact category is measured in different units, detailed comparisons between the two products are made only by impact category. Table 16 shows the results by impact category for the two products, including the percent reduction associated with Beyond Steak® compared to the beef-based steak tips. Figure 6 shows a comparison of results for all impact categories by representing the impact of each product as a percentage, wherein the 100% bar corresponds to the highest impact between the products.

Table 16: Summary of results for Beyond Steak® and beef-based steak tips.

Impact category	unit	Beyond Steak®	Beef-based steak tips	Percent reduction (Beef-based steak tips → Beyond Steak®)
Global warming	kg CO_2 equivalent	0.52	3.27	**84%**
Terrestrial acidification	kg SO_2 equivalent	0.0015	0.023	**94%**
Freshwater eutrophication	kg P equivalent	0.00014	0.00064	**77%**
Marine eutrophication	kg N equivalent	0.00029	0.0063	**95%**
Land use	m^2a crop equivalent	0.55	4.49	**88%**
Fossil resource scarcity	kg oil equivalent	0.13	0.35	**65%**
Water consumption	m^3 water consumption	0.0042	0.058	**93%**

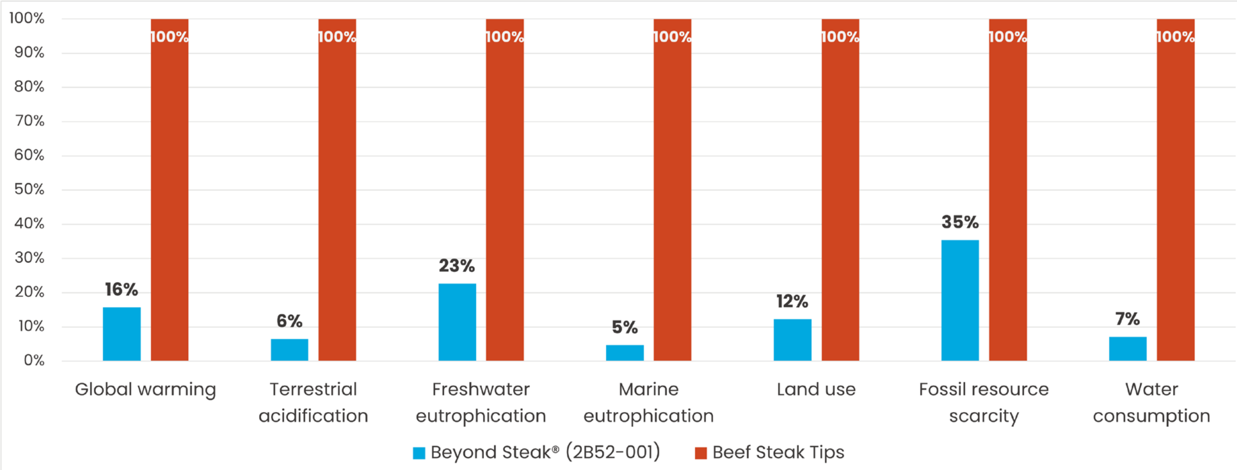

Figure 6: Comparison of results for Beyond Steak® and beef-based steak tips.

Based on the comparative assessment of the Beyond Steak® production system with beef-based steak tips (modeled using *WFLDB*), the Beyond Steak® generates 84% less global warming impact (or GHG emissions), and requires 88% less land use, 65% less fossil resources, and 93% less water consumption. The biggest gap is present in terrestrial acidification and marine eutrophication, where the impact of Beyond Steak® is 94% and 95% less than that of the beef-based steak tips. Additionally, freshwater eutrophication is 77% lower than the beef-based steak tips in the Beyond Steak® system.

The quality of the LCI and LCIA data was found to be in alignment with the goal and scope of the study through a data quality assessment process. Uncertainty in the calculations is represented via error bars in impact category-specific results figures. After results are presented in this section of the report, the *Uncertainty Analysis* section further details how uncertainty was managed, including methods, integration into findings, and any supplementary analyses performed.

The following LCIA does not provide a comprehensive set of environmental metrics of the product. The LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks. Normalization, grouping and weighting of the results are not employed in this study.

4.1.1 Global warming

Climate change is defined as “a change in the state of the climate that can be identified by [...] changes in the mean and/or the variability of its properties and that persist for an extended period, typically decades or longer” (IPCC, 2018). The impact category of global warming is one part of the human contribution to our complex climate system. The quantifiable representation of this impact category, or impact category indicator, is global warming potential (GWP) or greenhouse gas (GHG) emissions represented by carbon dioxide-equivalence (kg CO_2-eq). All relevant GHGs were considered in the calculation of CO_2-eq, including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). In the underlying method behind the *ReCiPe 2016 Midpoint (H)* impact category of global warming, GWP100, based on the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5), was used to quantify the global warming potential, meaning that GHG emissions are considered over a 100-year period.

Figure 7 shows the total results (kg CO_2-eq) per product for the functional unit of 88 grams. The error bars represent uncertainty to the 95% confidence interval resulting from the Monte Carlo simulation (see the *Data Quality Assessment* section for a description of this process). Figure 8 shows these results by product phase.

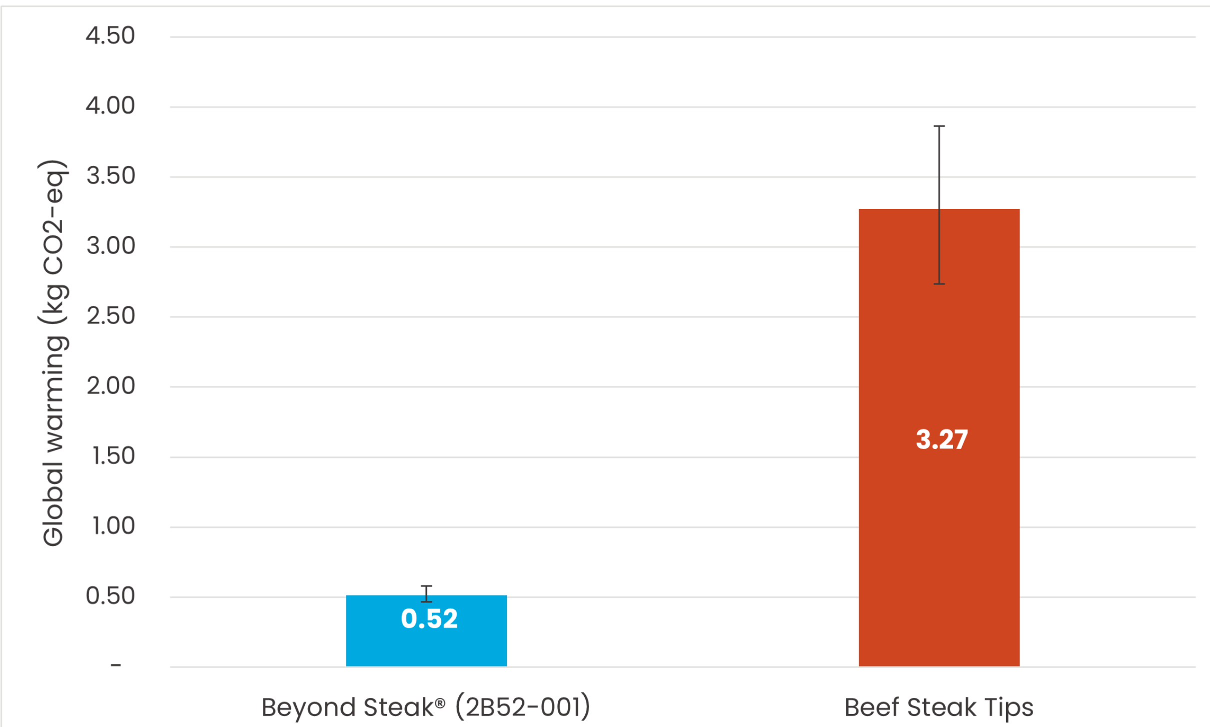

Figure 7: Comparison of global warming results for Beyond Steak® and beef-based steak tips.

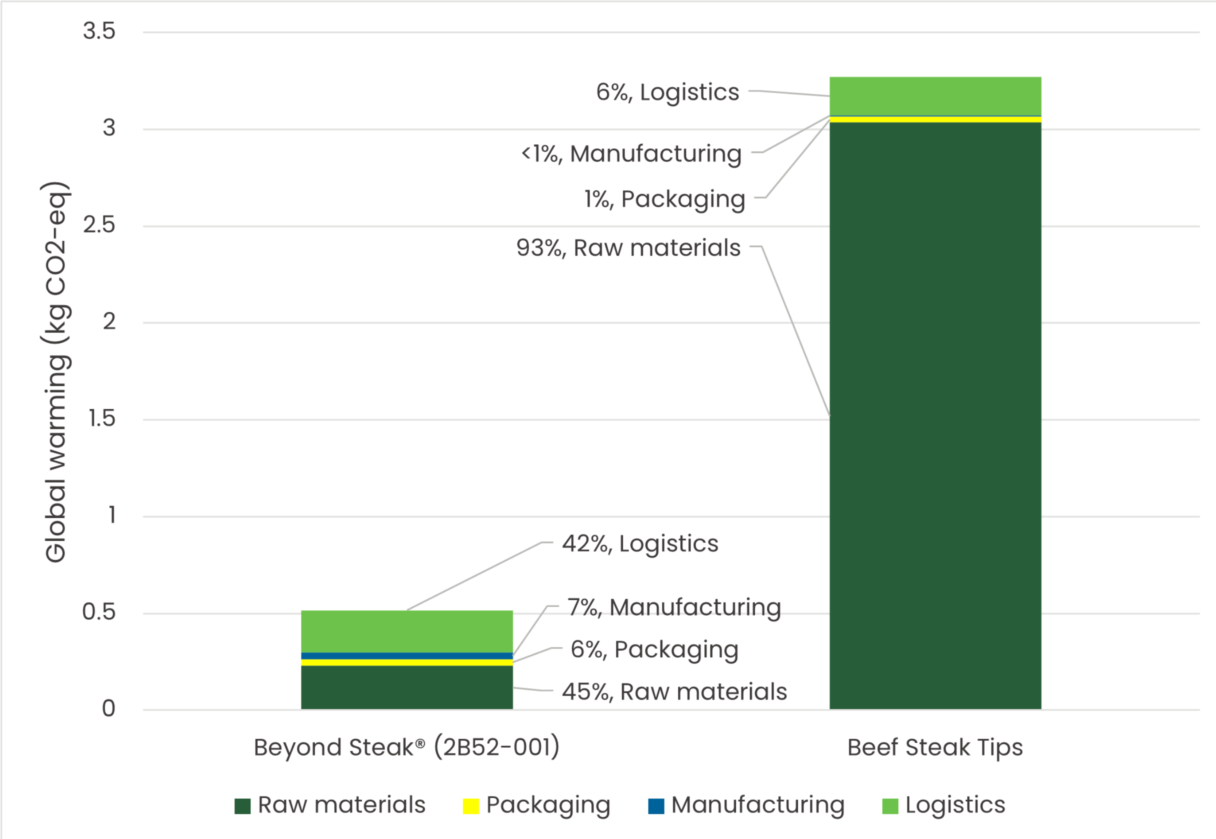

Figure 8: Comparison of global warming results for Beyond Steak® and beef-based steak tips by life cycle phase.

For both the Beyond Steak® and beef-based steak tips, raw materials were the highest contributor to global warming or GWP. Fresh beef contributed over 93% of the total GWP impact for the beef-based steak tips. For the Beyond Steak®, the faba bean protein wheat gluten and expeller-pressed canola oil contributed approximately 42% of the total GWP. Other major drivers for Beyond Steak® were distribution transport contributing a combined total of approximately 35%. Table 17 offers a breakdown of the top five contributors to the impact category for Beyond Steak®.

Table 17: Top five contributors to global warming results for Beyond Steak®

Inputs	Percent Contribution
Faba Bean Protein	19.0%
Outbound Transport (cold storage to intermediate DC)*	17.8%
Wheat Gluten	16.9%
Outbound Transport (intermediate DC to customer)*	16.8%
Expeller-Pressed Canola Oil	6.2%

*Assumed to be the same for Beyond Steak® and beef-based steak tips

4.1.2 Terrestrial acidification

The acidification impact category is defined as changes to soil acidity. The quantifiable representation of this impact category, or impact category indicator, is terrestrial acidification potential (AP) represented by sulfur dioxide-equivalence (kg SO_2-eq). Gases that cause acid deposition include ammonia (NH_3), nitrogen oxides (NOx), and sulfur oxides (SOx)(Huijbregts et al., 2017).

Figure 9 shows the total results (kg SO_2-eq) per product for the functional unit of 88 grams. The error bars represent uncertainty to the 95% confidence interval resulting from the Monte Carlo simulation (see the *Data Quality Assessment* section for a description of this process). Figure 10 shows these results by product phase.

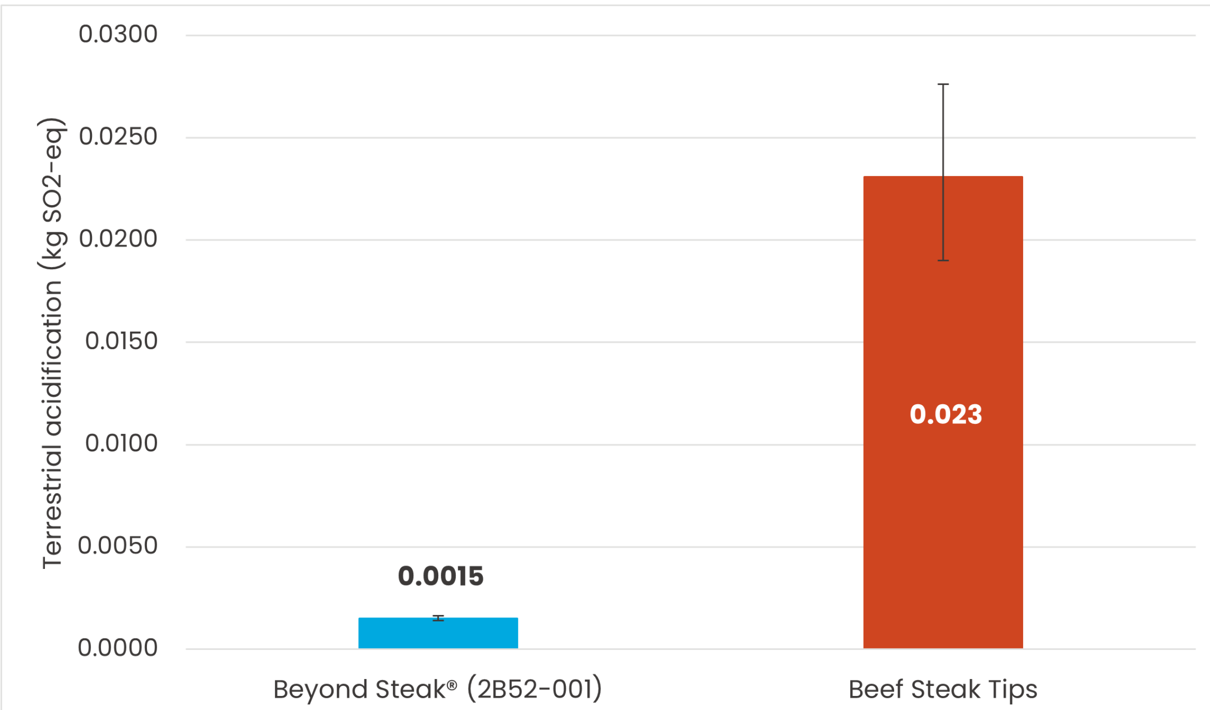

Figure 9: Comparison of terrestrial acidification results for Beyond Steak® and beef-based steak tips.

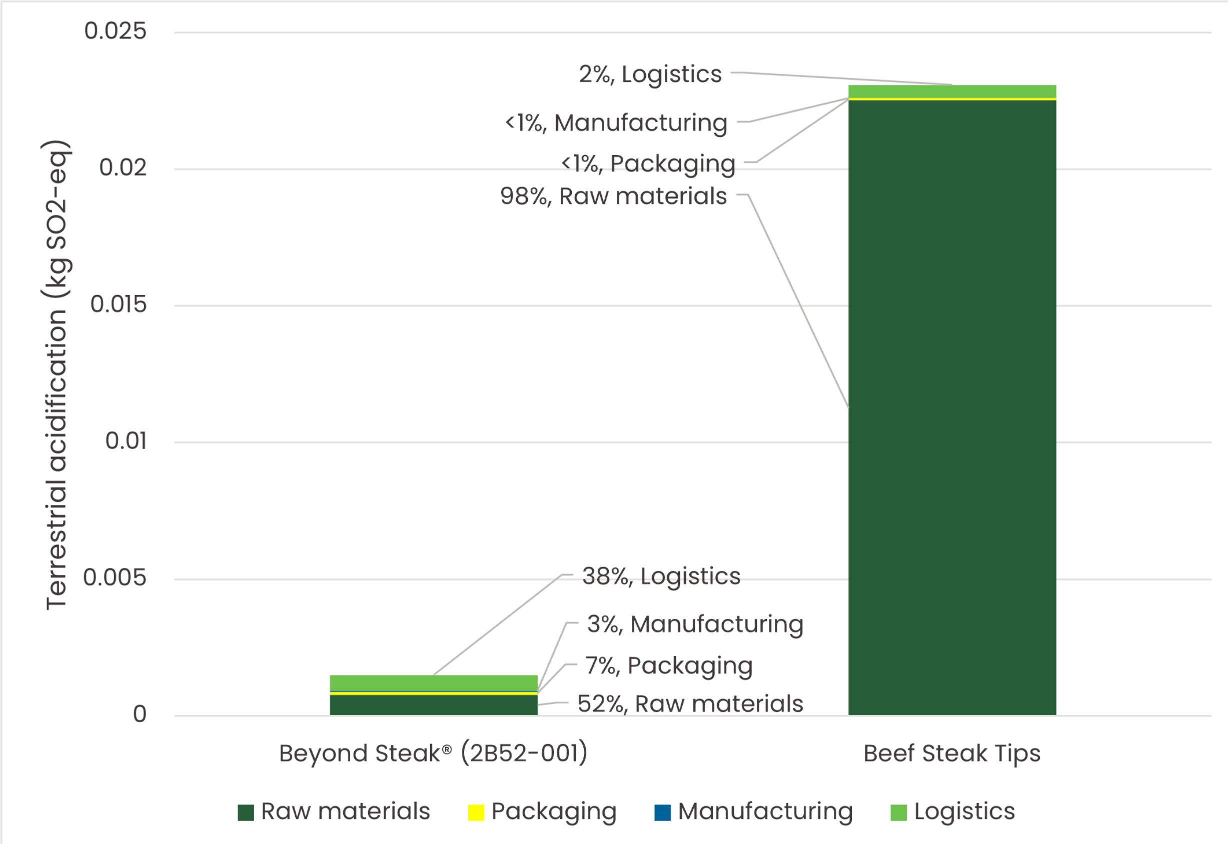

Figure 10: Comparison of terrestrial acidification results for Beyond Steak® and beef-based steak tips by life cycle phase.

For both the Beyond Steak® and beef-based steak tips, raw materials were the highest contributor to terrestrial acidification. Fresh beef contributed over 98% of the total category impact for the beef-based steak tips. For Beyond Steak®, wheat gluten, the faba bean protein, and expeller-pressed canola oil contributed approximately 46% of the total terrestrial acidification potential. Other major drivers for Beyond Steak® were distribution transport representing a combined 29% of the total category impact. Table 18 offers a breakdown of the top five contributors to the terrestrial acidification potential for Beyond Steak®.

Table 18: Top five contributors to terrestrial acidification results for Beyond Steak®.

Inputs	Percent Contribution
Wheat Gluten	26.8%
Outbound Transport (cold storage to intermediate DC)*	14.9%
Outbound Transport (intermediate DC to customer)*	14.1%
Faba Bean Protein	10.7%
Expeller-Pressed Canola Oil	8.7%

*Assumed to be the same for Beyond Steak® and beef-based steak tips

4.1.3 Freshwater eutrophication

The eutrophication impact category is defined as the accumulation of nutrients in aquatic systems (Acero et al., 2015). Freshwater eutrophication is driven by a phosphorus increase in freshwater (Huijbregts et al., 2017). The quantifiable representation of this impact category, or impact category indicator, is freshwater eutrophication potential (EP) represented by phosphorus (P) to freshwater-equivalence (kg P-eq). The characterization model assumes that, for emissions to agricultural soils, "typically 10% of all P is transported from agriculture soil to surface waters" (Huijbregts et al., 2017).

Figure 11 shows the total results (kg P-eq) per product for the functional unit of 88 grams. The error bars represent uncertainty to the 95% confidence interval resulting from the Monte Carlo simulation (see the *Data Quality Assessment* section for a description of this process). Figure 12 shows these results by product phase.

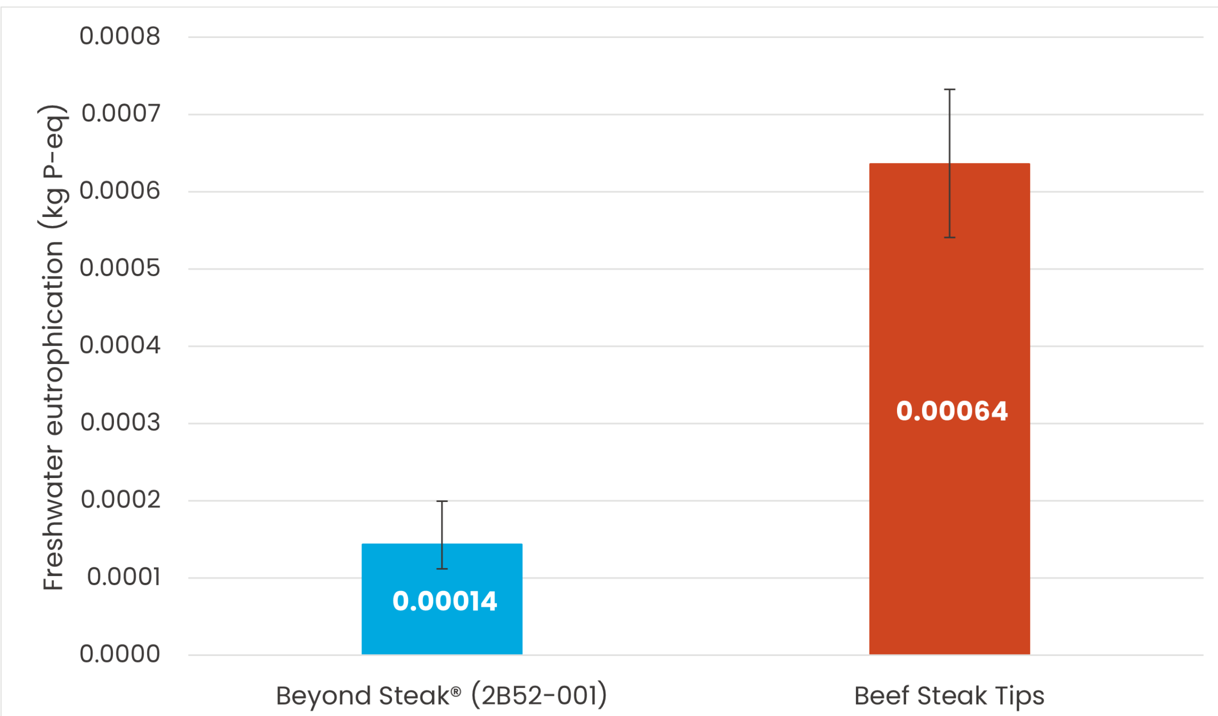

Figure 11: Comparison of freshwater eutrophication results for Beyond Steak® and beef-based steak tips.

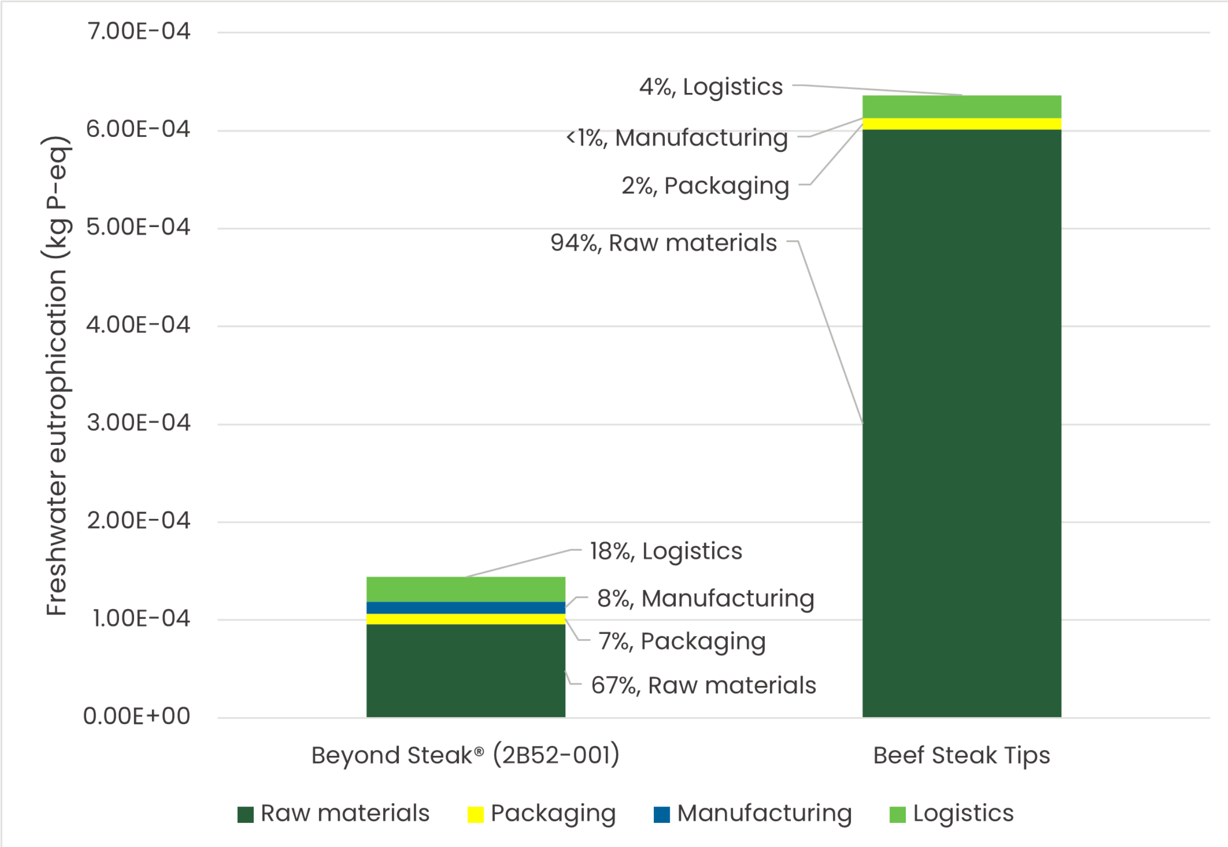

Figure 12: Comparison of freshwater eutrophication results for Beyond Steak® and beef-based steak tips by life cycle phase.

For both the Beyond Steak® and beef-based steak tips, raw materials were the highest contributor to freshwater eutrophication. Fresh beef contributed over 94% of the total category impact for the beef-based steak tips. For the Beyond Steak®, the faba bean protein, wheat gluten and expeller-pressed canola oil contributed approximately 64% of the total category impact. Other major drivers for Beyond Steak® were WIP manufacturing and distribution transport (to cold storage), which were responsible for approximately 8.3% and 5.7% of the total category impact respectively. Table 19 offers a breakdown of the top five contributors to the impact category for Beyond Steak®.

Table 19: Top five contributors to freshwater eutrophication results for Beyond Steak®

Inputs	Percent Contribution
Wheat Gluten	27.9%
Faba Bean Protein	26.5%
Expeller Pressed Canola-Oil	9.3%
WIP Manufacturing	8.3%
Outbound Transport (cold storage to intermediate DC)*	5.7%

*Assumed to be the same for Beyond Steak® and beef-based steak tips

4.1.4 Marine eutrophication

The eutrophication impact category is defined as the accumulation of nutrients in aquatic systems (Acero et al., 2015). Marine eutrophication is driven by an increase in dissolved inorganic nitrogen in marine water (Huijbregts et al., 2017). The quantifiable representation of this impact category, or impact category indicator, is marine eutrophication potential (EP) represented by nitrogen-equivalence (kg N-eq).

Figure 13 shows the total results (kg N-eq) per product for the functional unit of 88 grams. The error bars represent uncertainty to the 95% confidence interval resulting from the Monte Carlo simulation (see the *Data Quality Assessment* section for a description of this process). **Figure 14** shows these results by product phase.

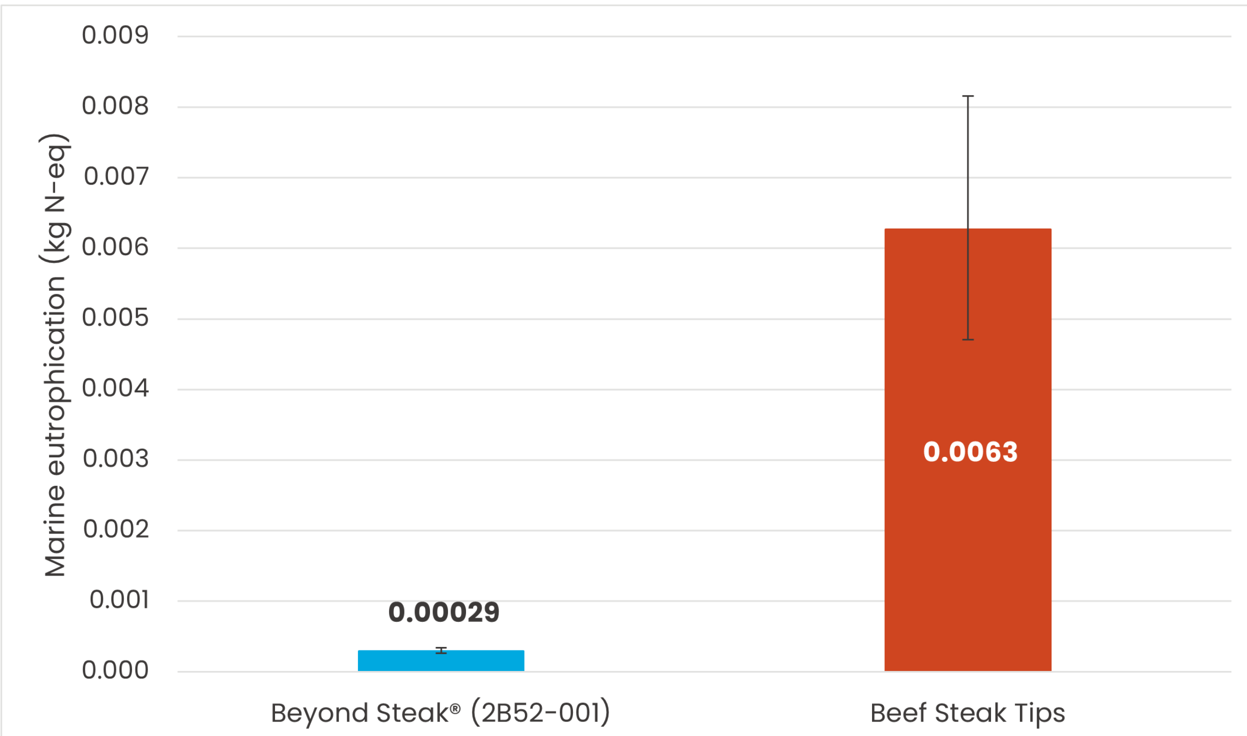

Figure 13: Comparison of marine eutrophication results for Beyond Steak® and beef-based steak tips.

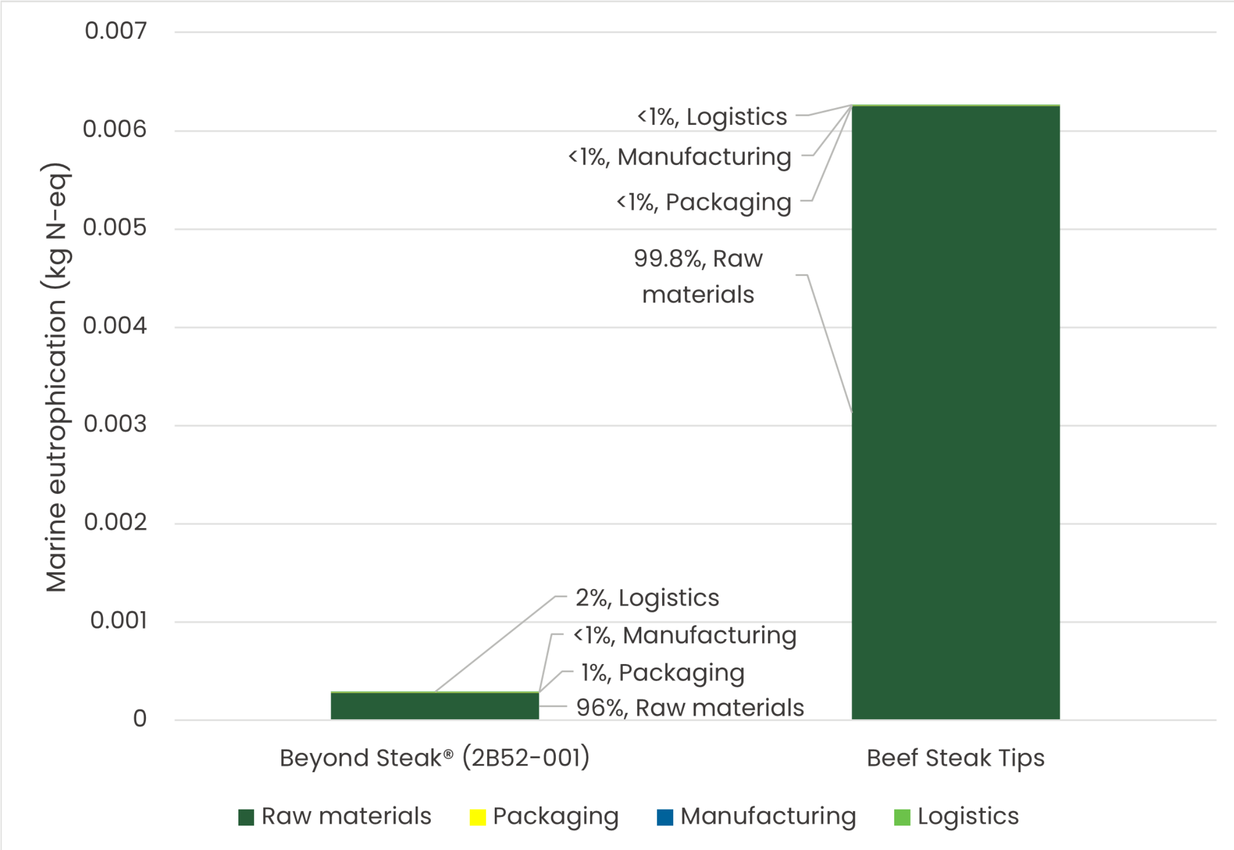

Figure 14: Comparison of marine eutrophication results for Beyond Steak® and beef-based steak tips by life cycle phase.

For both the Beyond Steak® and beef-based steak tips, raw materials were the highest contributor to marine eutrophication. Fresh beef contributed over 99% of the total category impact for the beef-based steak tips. For the Beyond Steak®, wheat gluten, the faba bean protein, and expeller-pressed canola oil contributed approximately 89% of the total category impact. Other major drivers for Beyond Steak® were spices and the corrugated case for secondary packaging, which were responsible for approximately 5.7% and 1.3% of the total category impact respectively. Table 20 offers a breakdown of the top five contributors to the impact category for Beyond Steak®.

Table 20: Top five contributors to marine eutrophication results for Beyond Steak®

Inputs	Percent Contribution
Wheat Gluten	48.8%
Faba Bean Protein	24.8%
Expeller-Pressed Canola Oil	15.7%
Spices	5.7%
Corrugated Case	1.3%

4.1.5 Land use

Land use can be reported at an inventory (i.e., absolute land use) or midpoint impact level (i.e., characterized land use). At the inventory level, LCI data is reported as is (e.g., acres of pasture, acres of urban land), without the application of any characterization factors (CF). At the midpoint level, the impact of land use is characterized with the use of characterization factors. For this study, *ReCiPe 2016 Midpoint* characterization factors are applied, which represent "relative species loss caused by specific land use type" (Huijbregts et al., 2017). In essence, *ReCiPe 2016 Midpoint* weights land cover types based on their species richness compared to annual cropping systems. Annual cropping systems have a CF of 1, and systems with more species richness have smaller CFs (e.g., perennial crops CF = 0.7 m^2 crop eq/m^2, pasture CF = 0.55, forest CF = 0.3)(Huijbregts et al., 2017). This means that perennial crops, pasture, and forest are all considered to have less land use impact than annual crops. For this impact category, results are presented in m^2 annual crop equivalence (m^2a crop eq). This midpoint land use indicator does not account for impact to the land, such as how soil health is affected.

Figure 15 shows the total results (m^2a crop eq) per product for the functional unit of 88 grams. The error bars represent uncertainty to the 95% confidence interval resulting from the Monte Carlo simulation (see the *Data Quality Assessment* section for a description of this process). Figure 16 shows these results by product phase.

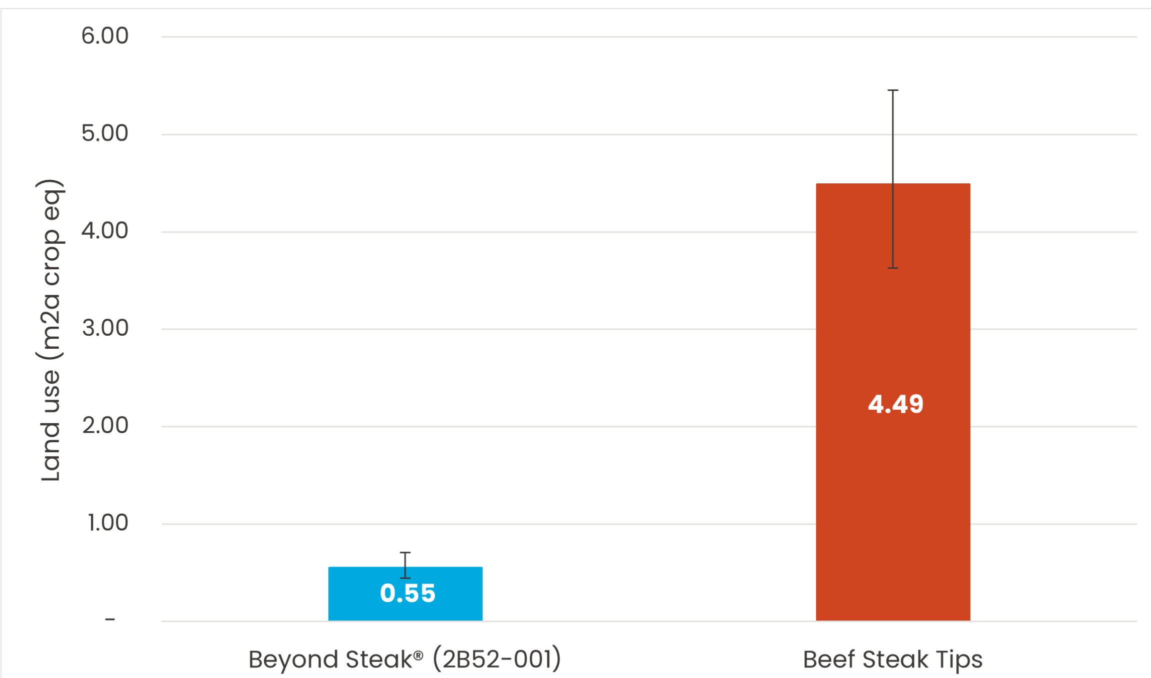

Figure 15: Comparison of land use results for Beyond Steak® and beef-based steak tips.

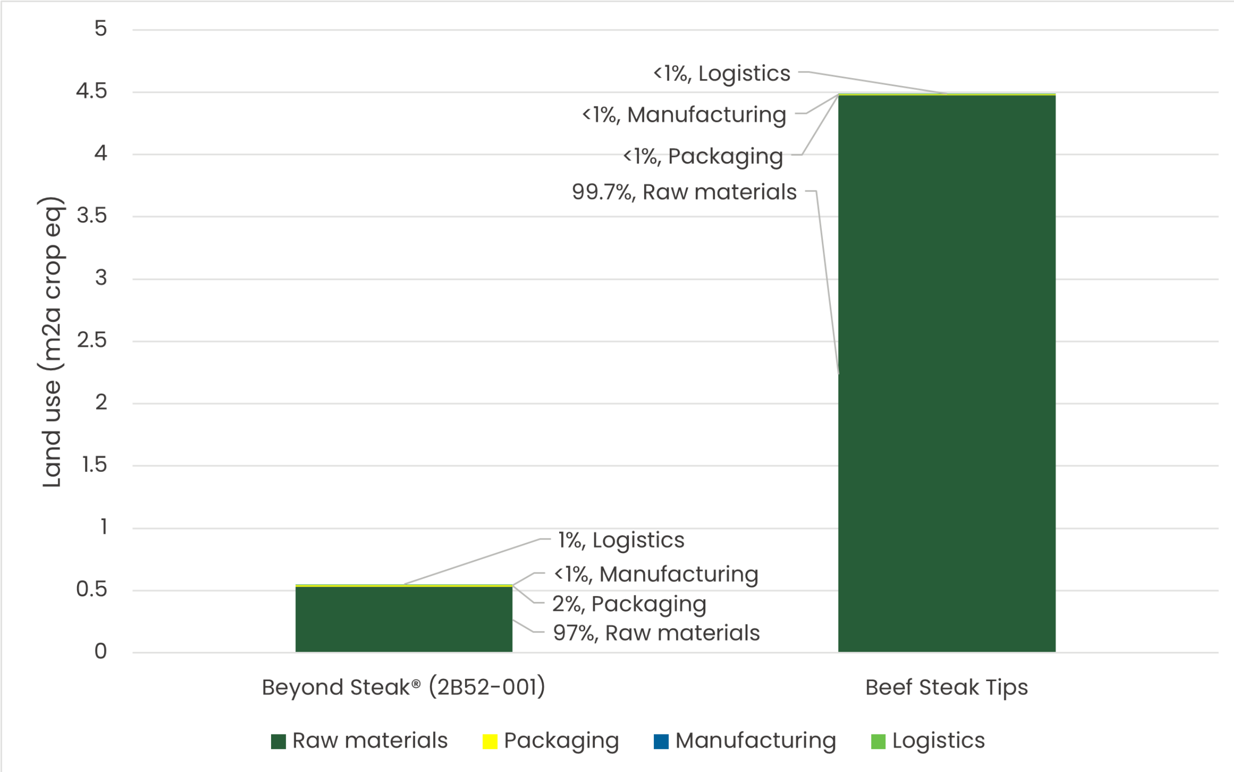

Figure 16: Comparison of land use results for Beyond Steak® and beef-based steak tips by life cycle phase.

For both the Beyond Steak® and beef-based steak tips, raw materials were the highest contributor to land use. Fresh beef contributed over 99% of the total category impact for the beef-based steak tips. For the Beyond Steak®, the faba bean protein, wheat gluten and expeller-pressed canola oil contributed approximately 95% of the total category impact. Other major drivers for Beyond Steak® were the corrugated case for secondary packaging and spices, which were responsible for approximately 2.1% and 1.7% of the total category impact respectively. Table 21 offers a breakdown of the top five contributors to the impact category for Beyond Steak®.

Table 21: Top five contributors to land use results for Beyond Steak®

Inputs	Percent Contribution
Faba Bean Protein	49.8%
Wheat Gluten	27.5%
Expeller-Pressed Canola Oil	17.3%
Corrugated Case	2.1%
Spices	1.7%

4.1.6 Fossil resource scarcity

Fossil resource scarcity is the impact category used by *ReCiPe 2016 Midpoint* to quantify the consumption of fossil fuels. This category can be referred to more generally as fossil energy use (Huijbregts et al., 2017). This impact category is characterized by using ratios of fossil resource heating values (energy content) to normalize to a single metric, crude oil equivalence (kg oil eq). *ReCiPe 2016 Midpoint* defines this characterization factor as the "fossil fuel potential" (FFP) (Huijbregts et al., 2017).

Figure 17 shows the total results (kg oil eq) per product for the functional unit of 88 grams. The error bars represent uncertainty to the 95% confidence interval resulting from the Monte Carlo simulation (see the *Data Quality Assessment* section for a description of this process). Figure 18 shows these results by product phase.

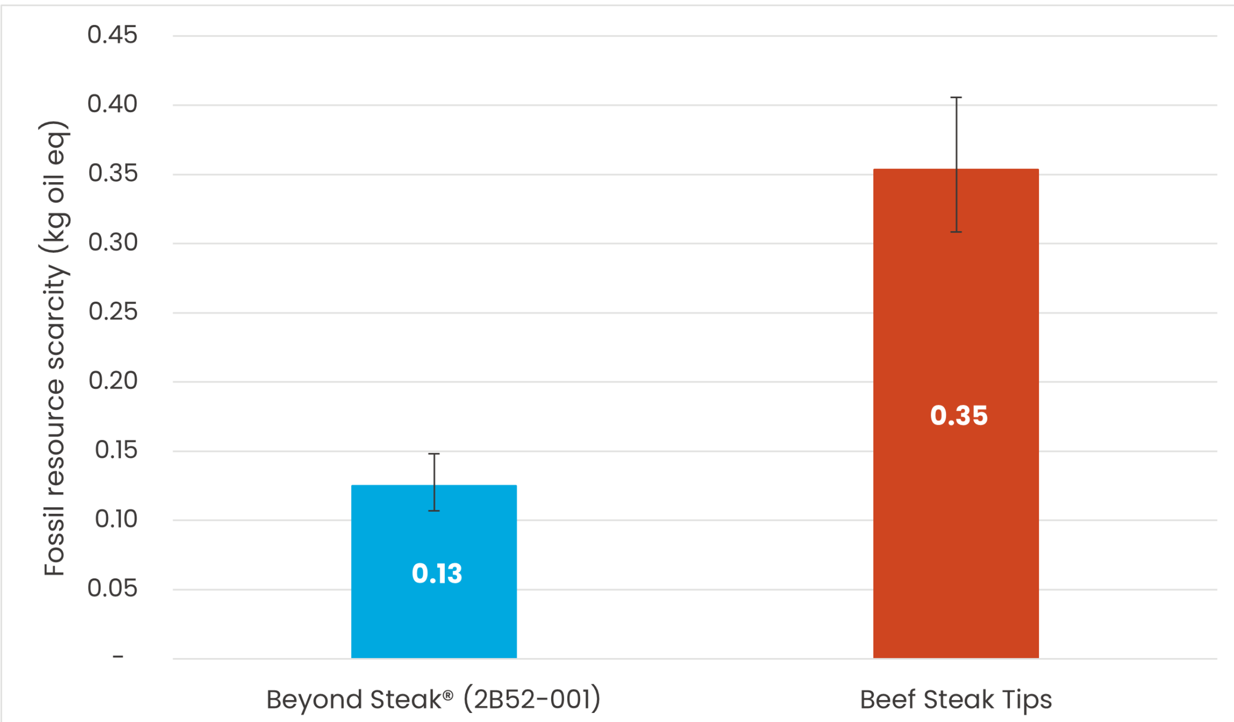

Figure 17: Comparison of fossil resource scarcity results for Beyond Steak® and beef-based steak tips.

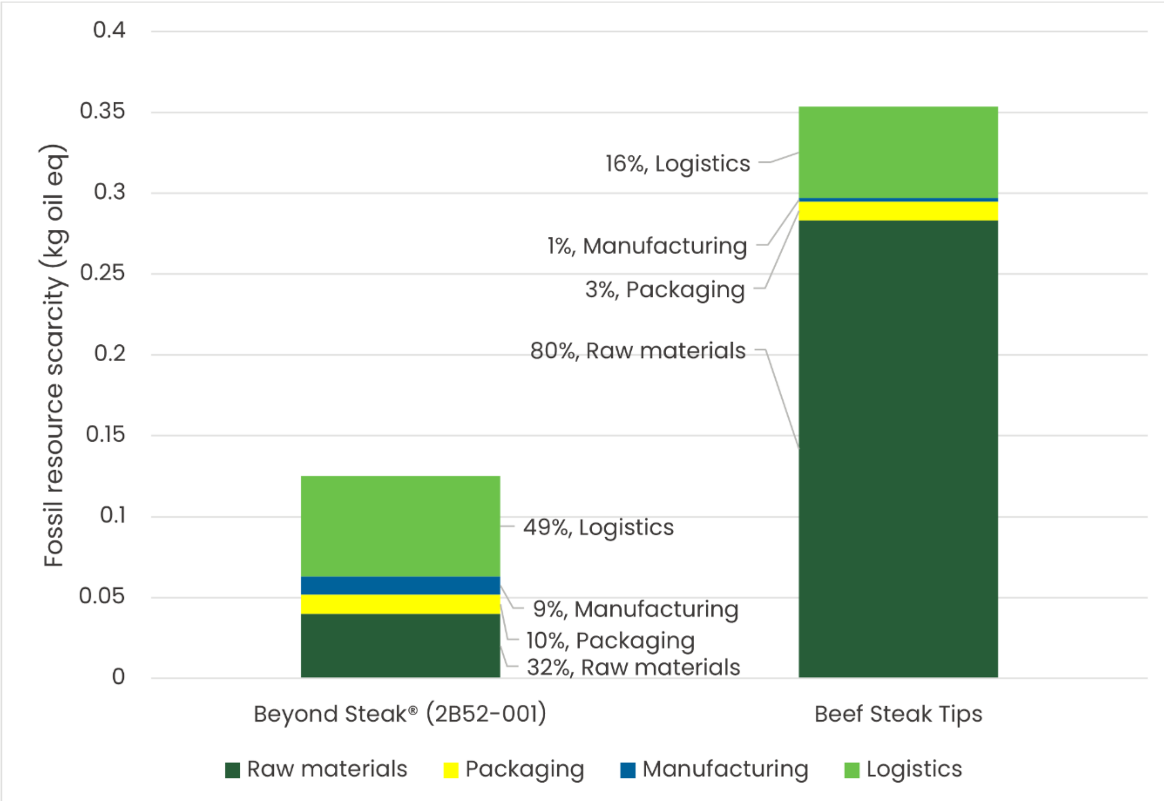

Figure 18: Comparison of fossil resource scarcity results for Beyond Steak® and beef-based steak tips by life cycle phase.

For the beef-based steak tips, raw materials were the highest contributor to fossil resource scarcity. Fresh beef contributed over 80% of the total category impact for the beef-based steak tips. This is to be expected given the fossil resource use happening on-farm for beef products.

For the Beyond Steak®, logistics (includes transport and cold storage) were the highest contributor to fossil resource scarcity, contributing 49% of the total category impact. Other major drivers for Beyond Steak® were wheat gluten, faba bean protein, and WIP manufacturing, which contributed approximately 33% of the total category impact. Table 22 offers a breakdown of the top five contributors to the impact category for Beyond Steak®.

Table 22: Top five contributors to fossil resource scarcity results for Beyond Steak®.

Inputs	Percent Contribution
Outbound Transport (cold storage to intermediate DC)*	20.7%
Outbound Transport (intermediate DC to customer)*	19.6%
Wheat Gluten	16.8%
Faba Bean Protein	8.8%
WIP Manufacturing	7.4%

*Assumed to be the same for Beyond Steak® and beef-based steak tips

4.1.7 Water consumption

The water consumption impact category or consumptive water use is defined as the amount of water used that is not eventually returned to the system (i.e., watershed or terrestrial ecoregion) (Huijbregts et al., 2017). The quantifiable representation of this impact category, or impact category indicator, is cubic meters of water consumed (m^3). "For flows that are already given as consumptive water flows, the midpoint indicator coincides with the inventory [and] for water flows that are reported simply as withdrawal or as extracted water, a factor needs to be applied to account for the water-use efficiency" (Huijbregts et al., 2017). This factor is represented by cubic meters of water consumed per cubic meter of water extracted.

Figure 19 shows the total results (m^3 consumed) per product for the functional unit of 88 grams. The error bars represent uncertainty to the 95% confidence interval resulting from the Monte Carlo simulation (see the *Data Quality Assessment* section for a description of this process). Figure 20 shows these results by product phase.

As mentioned in the *Methods* section, for the impact category of water consumption, a different approach was taken to calculate uncertainty. With the guidance of LCA experts, the uncertainty for this specific impact category was calculated using the pedigree matrix and system-level instead of unit-level datasets to avoid a misrepresentation of uncertainty. Uncertainty values existing in the underlying datasets were not considered in the Monte Carlo simulation. Figures expressing uncertainty for this impact category (Figure 19 and Figure 21) reflect this calculation method adjustment.

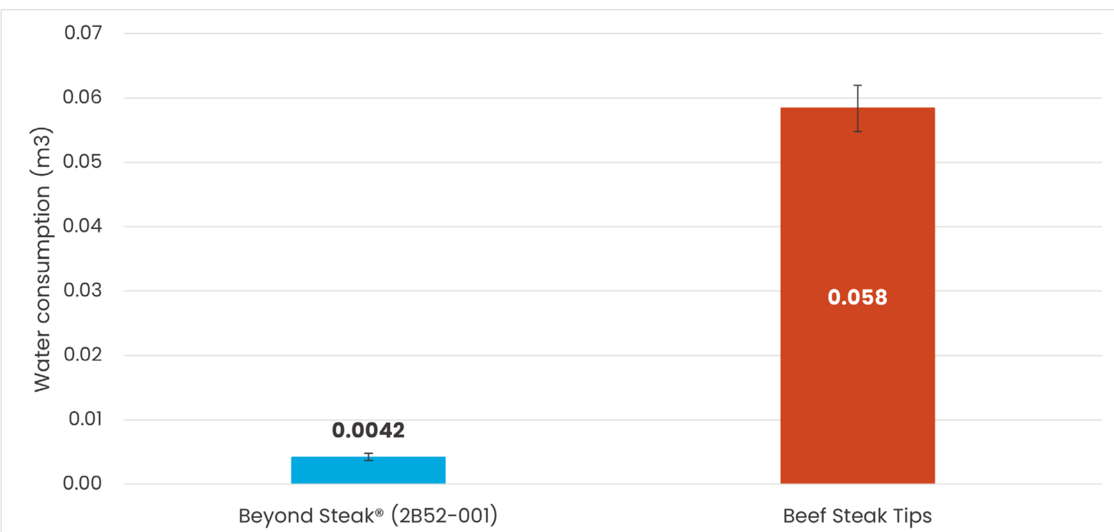

Figure 19: Comparison of water consumption results for Beyond Steak® and beef-based steak tips.

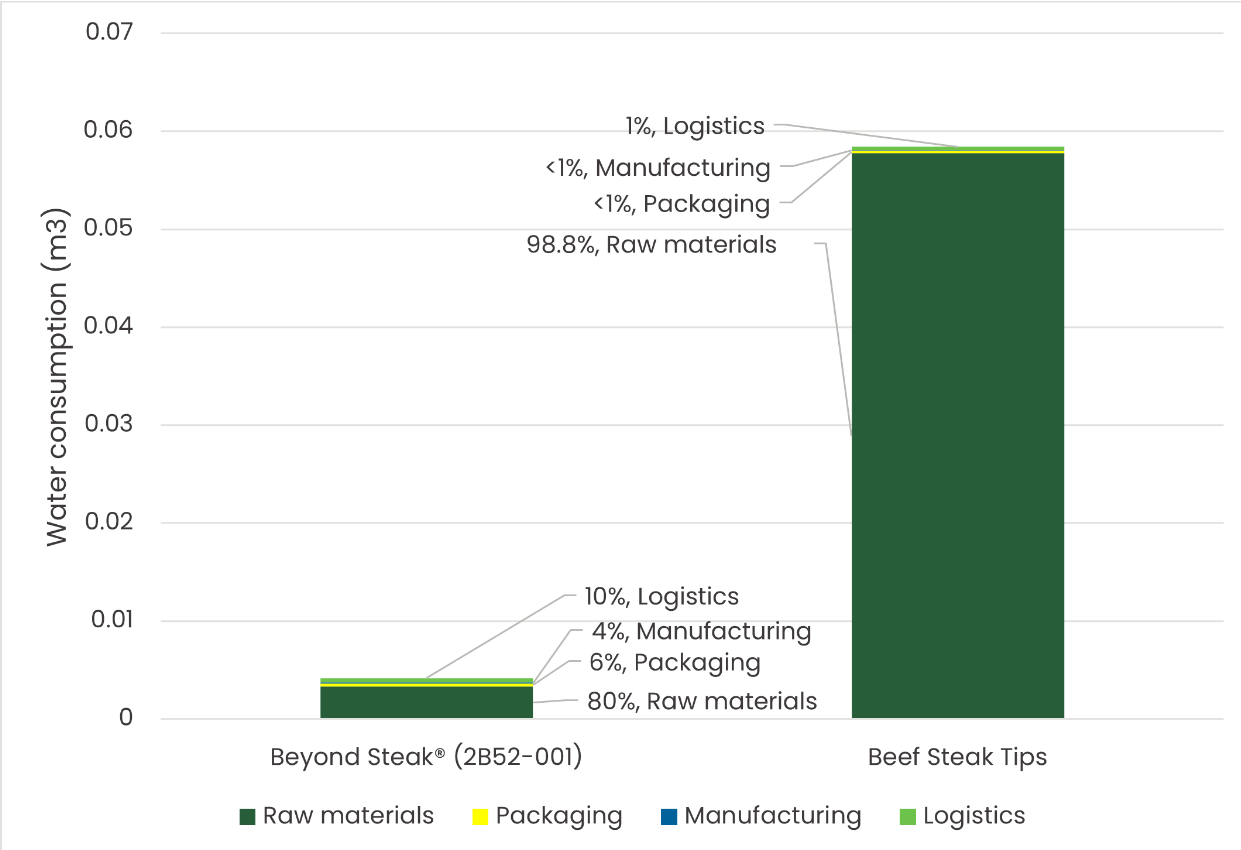

Figure 20: Comparison of water consumption results for Beyond Steak® and beef-based steak tips by life cycle phase.

For both the Beyond Steak® and beef-based steak tips, raw materials were the highest contributor to consumptive water use. Fresh beef contributed over 99% of the total category impact for the beef-based steak tips. For the Beyond Steak®, raw material ingredients of spices, faba bean protein, wheat gluten, and fruit and vegetable juice color contributed approximately 75% of the total category impact. Another major driver for Beyond Steak® is distribution transport (to cold storage), which was responsible for approximately 3.9% of the total category impact. Table 23 shows a breakdown of the top five contributors to the impact category for Beyond Steak®.

Table 23: Top five contributors to water consumption results for Beyond Steak®

Inputs	Percent Contribution
Spices	22.6%
Faba Bean Protein	22.3%
Wheat Gluten	19.8%
Fruit and Vegetable Juice Color	10.7%
Outbound Transport (cold storage to intermediate DC)*	3.9%

*Assumed to be the same for Beyond Steak® and beef-based steak tips

4.2 Comparative Monte Carlo Simulation

As described in the *Data Quality Assessment* section, SimaPro's Monte Carlo simulation was used to estimate uncertainty for this LCA analysis. In addition to product-specific uncertainty assessments to generate the 95% confidence interval shown in the above *Life Cycle Impact Assessment* sections, a comparative uncertainty analysis was also run in SimaPro. "A Monte Carlo analysis can help to determine whether the differences between [two product systems] are significant or not, given the uncertainties in [the data inputs, and] "can be a great aid in interpreting results and the stability of conclusions" (PRé Sustainability, 2023). The results of this comparative analysis, shown in **Figure 21**, provide the percentage of runs for which the impact of the beef-based steak tips is greater than or equal to the Beyond Steak®. For all impact categories, the impact of beef-based steak tips is higher than Beyond Steak® in 100% of the runs.

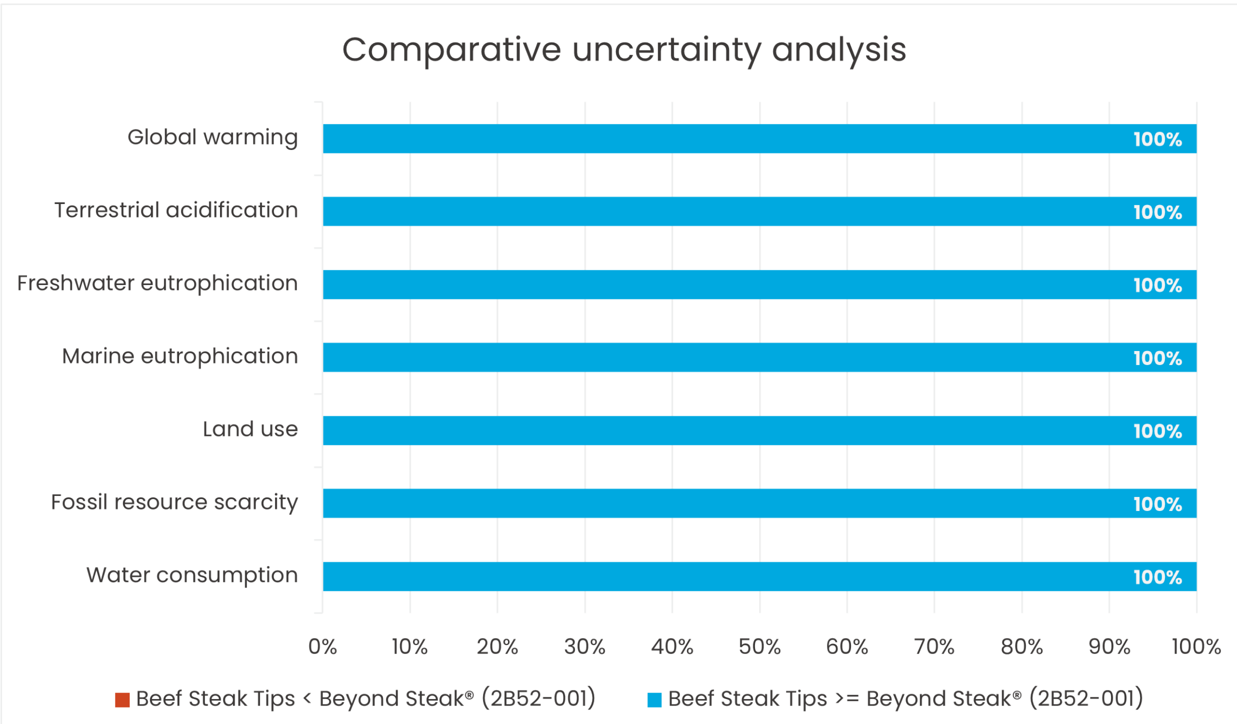

Figure 21: Comparative uncertainty analysis via Monte Carlo simulation.

4.3 Sensitivity Analysis

Sensitivity analysis was used to determine how changes in data and methodological choices affect the results of the LCA. **Table 24** summarizes the core sensitivity and scenario analyses performed and the explanations behind them. Several supplementary sensitivity analyses were also performed; the explanations and findings for which can be found in **Appendix I**.

Table 24: Summary of sensitivity analyses.

Analysis	Explanation
Faba bean protein proxy	To evaluate how changes to the proxy choice for faba bean protein affect comparative results for all impact categories. No faba bean protein dataset was available, therefore other legume-based protein-isolates were considered as potential ingredient proxies.
GWP100 v. GWP20	To evaluate how GWP time horizon affects results for the impact category of global warming. LCIA was performed using IPCC 2021 GWP100 and compared to IPCC 2021 GWP20 for both product systems.
Functional unit (protein- and caloric-content)	To evaluate how alternative functional units affect results for all impact categories. LCIA was performed using functional unit of 10 g of protein and 100 calories.
WFLDB v. Putman et al.	To evaluate how data source selection to model the beef affects results (compared to Beyond Steak®) for impact categories of global warming, land use, fossil resource scarcity, and water consumption.

4.3.1 Faba bean protein proxy

No datasets were available to model the faba bean protein used in the Beyond Steak®, thus a proxy approach was taken. The *Agrifootprint* database includes models for three types of legume-based protein-isolates: pea protein-isolate, soybean protein-isolate, and lupins protein-isolate. While datasets do exist in *ecoinvent* for faba bean production, there is not enough information (whether literature values or primary data) available to determine or justify the parameters that would be needed to take that crop and create a custom faba bean protein-isolate dataset. Thus, this sensitivity analysis was used to (1) select the best available proxy based on information from the ingredient supplier and key known parameters about each crop, and (2) assess the impact of each proxy choice compared to the beef-based steak tips.

The ingredients supplier provided region of origin (i.e., North America) and processing by-products (i.e., hulls and starch) for the faba bean protein. The critical review panel advised on key parameters to consider in proxy selection: growing region, the isolate output from each crop (an indicator of protein-content), crop yield, and application rates of fertilizer and pesticides. Table 25 shows a summary of the protein-isolate datasets available and the initial screening parameters and rank for proxy selection.

Table 25: Protein-isolate proxy choices and initial screening.

Proxy Scenario	Source	Growing regions available	Isolate output from crop	Rank based on initial screening
Pea protein-isolate	Agrifootprint-6	North America & others	25.6%	1
Soybean protein-isolate	Agrifootprint-6	North America & others	37.1%	2
Lupins protein-isolate	Agrifootprint-6	Europe & Australia	25.3%	3

Both the pea protein- and soybean protein-isolates offer crop datasets (*Peas, dry, at farm* and *Soybeans, at farm*, respectively) with the relevant growing region of North America. The lupins protein-isolate, on the other hand, does not offer any crop datasets (*Lupins, at farm*) for growing in North America. As agricultural practices are very regionally dependent, selecting a proxy with a North American-grown crop is important, meaning that the pea and soybean protein datasets are better proxy choices for faba bean protein, over lupins protein.

Regarding processing, each crop can expect to have different by-products (e.g., starch) and subsequent outputs in the creation of the protein isolate. By looking at the required crop input to create the isolate output, we can get an indicator for the protein-content in each crop. Per 1 kg of pea crop input, 256 g of pea protein-isolate can be produced. Per 1 kg of soybean crop input, 371 g of soybean protein-isolate can be produced. This difference in processing output can be partially attributed to the protein-content in each crop. According to a study published in the United States National Library of Medicine, peas have a mean protein-content of 23.4% and soybeans have a mean protein-content of 40.0% (Martineau-Côté et al, 2022). This same study approximates that faba beans have a protein-content of 27.6%, closest to that of peas (see Appendix J for the full table of legume composition comparisons). From a processing perspective, we can expect the manufacturing of faba bean protein to be more like that of pea proteins, given the expected protein-isolate output from the crop.

Based on the initial screening, pea protein is the top ranked proxy for modeling the faba bean protein used in Beyond Steak®. However, it is also worth evaluating the similarities and differences between peas and faba beans as it relates to crop yield and application rates of fertilizer and pesticides in North America. According to grower resources published by the Saskatchewan and Alberta Pulse Growers associations, which represent the two major faba bean growing regions in North America (SPG, 2023a), the crops are similarly considered pulse crops and are nitrogen-fixing, but they have some field operational differences. The resources detail the following:

- For both crops, the majority of nitrogen requirements can come from soil and nitrogen fixation. For faba beans, this rate can be as high as 80% of requirements coming from fixation. Excess nitrogen fertilizer will reduce the amount of nitrogen fixed by the crop, potentially delaying crop maturity, increasing disease levels, and reducing standability (APG, 2024a/b);
- The nitrogen (N) benefit for both crops is similar at 0.5 to 1 pounds of N per bushel of grain removed. Even though faba beans can fix more nitrogen, they also remove more in the grain due to higher yields and slightly higher protein-content (SPG, 2023b);
- Both crops are relatively high users of phosphorus (APG, 2024a/b). Removal rates for phosphorus (P) for faba beans are the same as for peas at 0.7 pounds of P per bushel of grain removed. But higher rates of phosphorus may be used for faba beans given the higher yields (SPG, 2023b);
- Soil potassium levels may be adequate for faba beans and peas (at least 300 pounds per acre) in certain growing regions of North America, such as Alberta (APG, 2024a/b);
- Similarly, sulfur needs for both crops may be contained in topsoil organic matter, or in subsoil (APG, 2024a/b);
- Weed control options and insect susceptibility for faba beans are similar to peas (SPG , 2023b);
- The crops are susceptible to different diseases, but there is limited information on the effect on yield and quality for faba beans, whereas for peas, fungicide application is common practice in the region (SPG, 2023b).

In summary, faba beans are expected to have a higher yield compared to peas, however, their nitrogen fixing capabilities may result in similar fertilizer application per bushel of grain harvested. Information on disease and pest control for faba beans is somewhat limited compared to peas, given that the market for the crop is still under development in the region.

For the baseline model, pea protein-isolate was selected as the proxy for the faba bean protein ingredient. The use of a proxy approach was accounted for in the data quality assessment and subsequent uncertainty analysis. To further understand the significance of proxy selection, additional analysis was performed to assess the impact of each proxy choice compared to the beef-based steak tips. Figure 22 demonstrates that regardless of proxy choice, the Beyond Steak® continues to see a similar reduction in impact across all categories compared to beef-based steak tips.

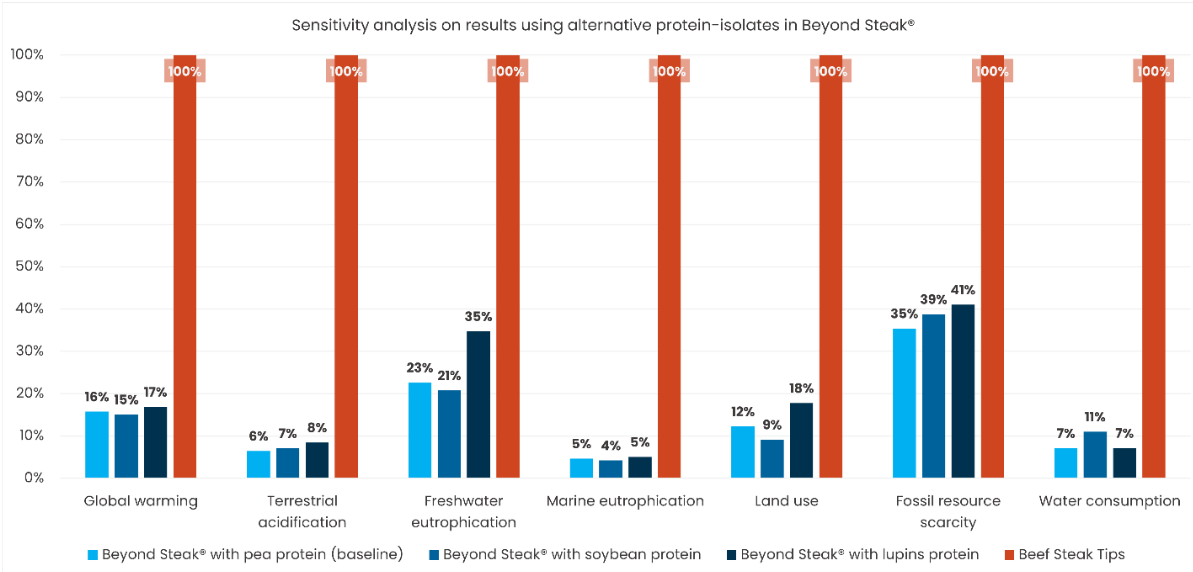

Figure 22: Sensitivity analysis on results using alternative protein-isolates in Beyond Steak®

4.3.2 GWP100 v. GWP20

This sensitivity analysis involves conducting the life cycle impact assessment (LCIA) for global warming using additional characterization models to *ReCiPe 2016 Midpoint (H)*. *ReCiPe 2016 Midpoint (H)* includes the impact category of 100-year time horizon global warming potential (GWP100) with underlying methodology coming from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5). An alternative LCIA was conducted using two other characterization models:

- *IPCC 2021 GWP100*: this method still represents global warming on a 100-year time horizon but relies on the most recent Sixth Assessment Report (AR6) from IPCC;
- *IPCC 2021 GWP20*: this method also uses the most recent AR6 from IPCC but represents global warming on a 20-year time horizon.

Given the difference in potency and lifespan of each GHG, different time horizons for GWP may show different results. For GHGs with a shorter lifespan, GWP20 is typically higher than GWP100. Methane is more potent than carbon dioxide but has a shorter atmospheric lifespan. Consequently, GWP20 results will typically be higher than GWP100 results if the product system produces a meaningful amount of methane. As a result of enteric fermentation happening during a cow's digestive process, cows and the greater beef system are regarded as a large source of methane emissions, relative to other agriculture and livestock products.

For both alternative characterization models, the single-issue models (*GWP100* and *GWP20*) from *IPCC 2021* were used as they represent the most up-to-date publication (AR6) and method from IPCC. The *ReCiPe* characterization model has yet to release a version incorporating the updates from AR6.

Figure 23 shows the results of GWP100 (both AR5 and AR6) v. GWP20 (AR6) for the two product systems. As anticipated, given the known methane emissions associated with beef, Beyond Meat's plant-based product performs even better than the beef-based product using GWP20 than GWP100. Results for both products are slightly decreased when comparing GWP100 from AR5 to AR6, but the conclusions from this study are unchanged. Changes in methodologies or underlying science (such as how potent a gas is or how long it lasts in the atmosphere) likely account for any difference in results between past and present IPCC assessment reports and models.

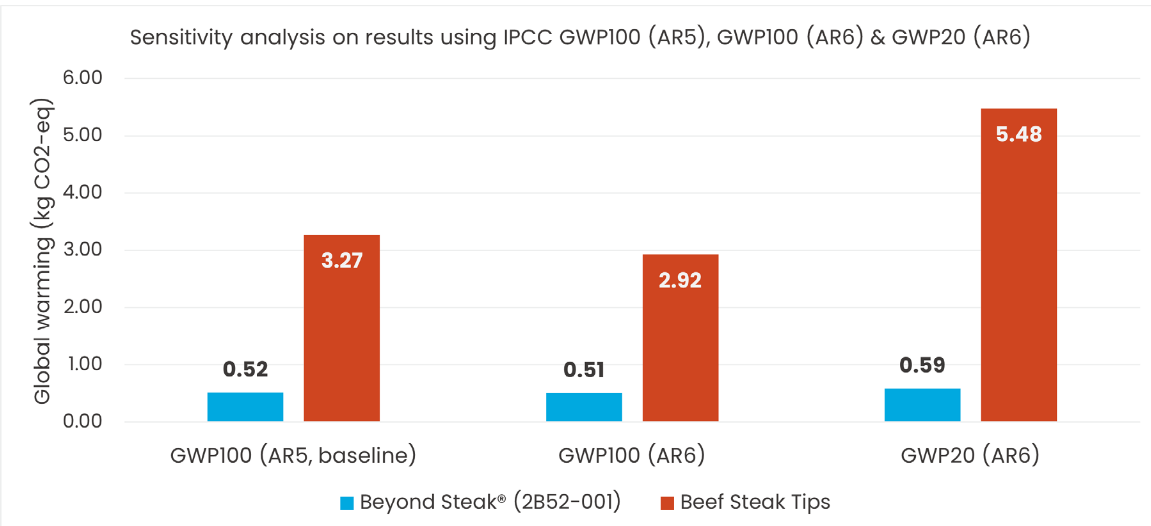

Figure 23: Sensitivity analysis on results using IPCC GWP100 & IPCC GWP20.

4.3.3 Functional unit

As discussed in the *Scope* section, to account for variation in nutritional profile of the two products, this study followed the recommendation of GFI to use multi-issue functional units to evaluate how results are impacted using alternative functional units (Chapman & Murray, 2023).

In the original assessment, 88 grams of each product was compared. However, within these 88 grams there are different associated calories and protein. The Beyond Steak® contains both higher caloric- and protein-content per gram.

Figure 24 shows the results of a protein-content functional unit of 10 grams of protein. **Figure 25** shows the results of a caloric-content functional unit of 100 calories. In both scenarios, the Beyond Steak® impact is even further reduced compared to the beef-based steak tips given the lower mass that needs to be produced and consumed to meet functional units of 10 grams of protein and 100 calories respectively.

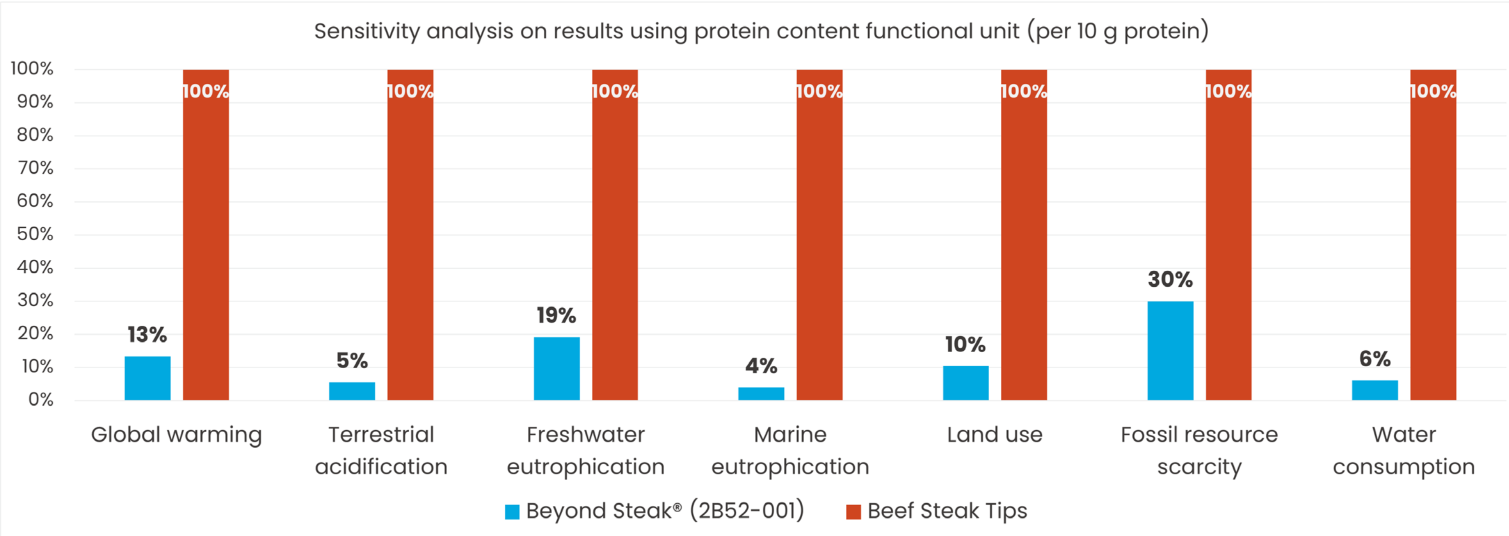

Figure 24: Sensitivity analysis on results using protein content functional unit (per 10 g protein).

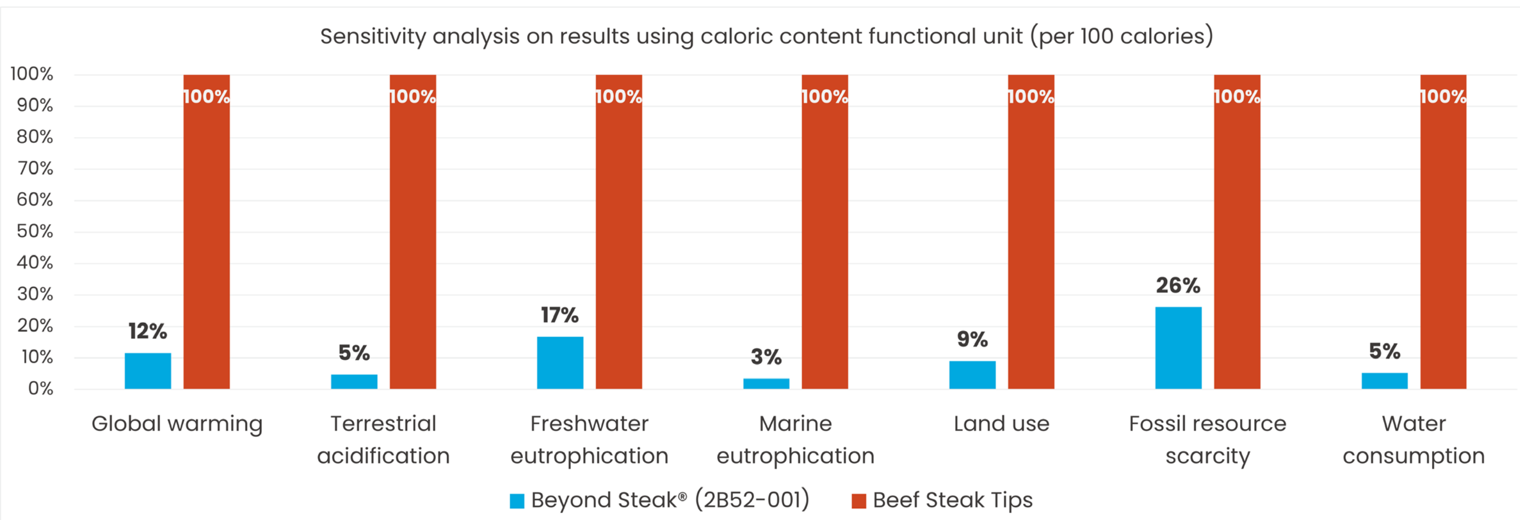

Figure 25: Sensitivity analysis on results using caloric content functional unit (per 100 calories)

4.3.4 WFLDB v. Putman et al.

The *Methods* section of this report details how and why *World Food LCA Database (WFLDB)* was selected as the basis for modelling the beef in the beef-based steak tips. Previous Beyond Meat-commissioned LCAs, however, have relied on data extracted from other published literature sources, such as *A comprehensive environmental assessment of beef production and consumption in the United States* by Putman et al. for the most recent Beyond Burger® 3.0 LCA (Heller et al., 2023; Putman et al., 2023).

To ensure consistency in results compared to the previous Beyond Burger® report, a sensitivity analysis was performed to show how data source selection to model the beef affects results (compared to Beyond Steak®) for impact categories of global warming, land use, fossil resource scarcity, and water consumption. The full range of impact categories in this LCA were not assessed given the difference in scope between this study and the Beyond Burger® 3.0 LCA.

In order to perform the comparison, impact of production, harvesting, and processing per gram of beef was extracted from the Beyond Burger® 3.0 LCA and applied to the weight of beef in our product functional unit. Other inputs in the beef-based steak tips LCI - water, other ingredients, packaging, intermediate transport, manufacturing, cold storage, distribution - were maintained at the same level of impact. Table 26 presents the findings of this sensitivity analysis relative to the *WFLDB* modeled beef-based steak tips.

Table 26: Sensitivity analysis of using Putman et al. study for beef.

Percent change* to total impact by category by extracting beef results from Beyond Burger® 3.0 LCA using Putman et al. study			
Global warming (kg CO2 eq)	Land use (m2a crop eq)	Fossil resource scarcity (kg oil eq)	Water consumption (m3)
4%	294%	-33%	663%

*Positive values highlighted in red mean impacts for beef-based steak tips are larger in the Putman et al. study than in the WFLDB model. Conversely, negative values highlighted in green mean impacts for beef-based steak tips were larger in the WFLDB model than in the Putman et al. study.

Global warming results are the most similar between these two methods. Putman et al. results were characterized using *ReCiPe 2016 Midpoint (H)* which matches the assessment method of this study. However, one known difference in methodology is that climate-carbon feedbacks were removed from the Putman et al. results, but included in this study. The results presented in this study would be slightly lower if climate-carbon feedbacks were not included.

Non-GWP indicators, such as land use and water consumption, are locally relevant and thus may expect to see more variability in results depending on study-specific methodological and data choices. Explicit methodological differences between the studies are uncertain, but are expected to exist given the variety of available data sources in the industry, the possible variation in exact U.S. archetypical simulations of cattle operations considered, allocation methods applied, and so on.

Table 27 shows the percent reduction associated with Beyond Steak® compared to the beef-based steak tips when modeled using the baseline method of *WFLDB* and using the sensitivity analysis method of Putman et al. Figure 26 shows both beef modeling methods side-by-side and compared to the Beyond Steak®.

Table 27: Sensitivity analysis on results of Beyond Steak® compared to WFLDB and Putman et al. study for beef.

Impact category	unit	Percent reduction (Beef-based steak tips using WFLDB → Beyond Steak®)	Percent reduction (Beef-based steak tips using Putman et al. → Beyond Steak®)
Global warming	kg CO_2 equivalent	84%	85%
Land use	m^2a crop equivalent	88%	97%
Fossil resource scarcity	kg oil equivalent	65%	47%
Water consumption	m^3 water consumption	93%	99%

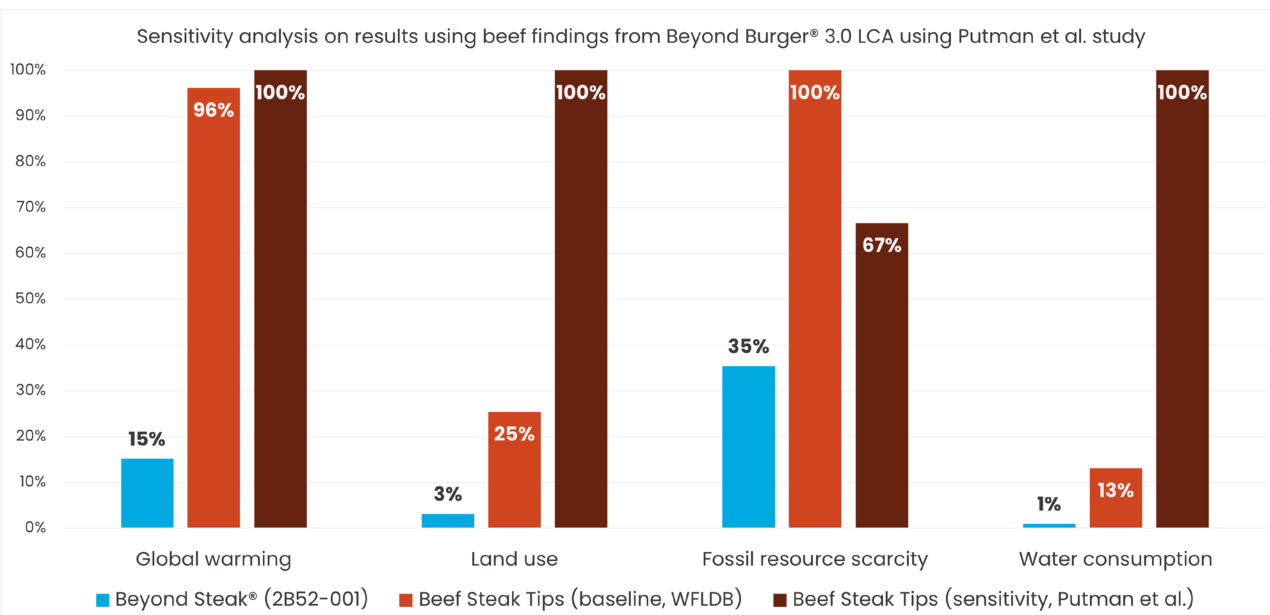

Figure 26: Sensitivity analysis on results compared to Beyond Steak® using Putman et al. study for beef.

There is an inherent challenge in comparing results from studies employing different methods. Therefore, these findings are best used to reaffirm the directional results of this study's use of *WFLDB* to model beef. Relative to Beyond Steak®, both methods result in higher impacts in all four categories. In land use and water consumption, the *WFLDB* method appears to be a relatively conservative approach in that the results for beef are 88-93% higher than Beyond Steak®, compared to 97-99% higher with the Putman et al. results.

4.4 Assessment Limitations and Future Improvements

At the start of this study, several anticipated limitations were identified based on the scope of the study:

- LCAs are inherently limited in their ability to provide an exhaustive assessment of all potential environmental impacts and non-environmental impacts are not considered;
- LCA is just one of several environmental assessment techniques, and comparative LCA should not provide the sole basis of a comparative assertion of overall environmental superiority;
- This LCA study is attributional and thus does not consider potential system-level changes to the market;
- There are limitations associated with modeling local-level impacts, especially for elementary flows where exact locations are unknown or more uncertain;
- There is an absence of primary data for the animal-based meat system given that the product exists outside of the client organization;
- LCAs are not able to capture the multifunctionality of agricultural systems (i.e., ecosystem services, biodiversity, soil health) and are only able to consider one function of an agricultural system, often food, fiber, or energy production (Van der Werf et al., 2020).

Throughout the course of this study, a few additional limitations were identified based on the methods employed:

- Using multiple databases (*WFLDB*, *ecoinvent*, *Agrifootprint*, *AGRIBALSYE*) is critical to identifying the best available LCI data, but inherently means there are different database methodologies being applied;
- The legume-based ingredient in the Beyond Steak®, faba bean protein, is modeled using the best available proxy, a pea-protein isolate from *Agrifootprint*; however, despite the expected similarities between the ingredients, modeled impacts would naturally expect to differ to some degree;
- Remote practitioners – PSC did not physically witness the process, nor was PSC able to verify data on-site.

In the event of future or further assessment, the study could be improved with:

1) Identifying ways to further improve data quality for the animal-based meat system;
2) Integrating more primary data for the faba bean protein, should that become available through a supplier-commissioned LCA, for example;
3) Exploring tools and techniques beyond LCA to categorize the impacts associated with plant-based meat and animal-based meat production; and
4) Conducting a consequential LCA, which would consider how environmental flows may change in response to possible future decisions and would evaluate larger scale system changes.

As part of this evaluation of potential assessment limitations, consistency checks were performed to ensure consistent application of methods and data throughout the study. Table 28 shows the findings of this consistency check.

Table 28: Consistency check.

Criteria	Beyond Steak®	Beef-based steak tips
Functional unit	88 grams of cooked steak	88 grams of cooked steak
Geographical factors	Product SKU (2B52-001) is manufactured for the U.S. market	Comparison product sold in U.S. market and datasets selected reasonably represent average national mix for U.S. beef production
Temporal factors	Calendar year of 2023 is the baseline, minor deviations and extrapolations are discussed	WFLDB dataset has a temporal representativeness of 2005 – 2018; v3.5 represents a 2019 update to the datasets
Allocation rules	Default allocations in LCI datasets used (economic for agriculture products); mass-based allocation used for manufacturing	Default allocations in LCI datasets used (economic for agriculture products); mass-based allocation used for manufacturing
Cut-off criteria	No specific cut-off criteria applied; proxy approach used for some ingredients with low contribution to product mass	No specific cut-off criteria applied; proxy approach used for some ingredients with low contribution to product mass
System boundaries	Cradle-to-distribution: ingredient production, inbound transport of raw materials, preparation of WIP products, WIP transport, intermediate WIP cold storage, finished goods manufacturing and manufacturing, packaging, final product cold storage, final product distribution (transport to cold storage facilities then to customer gates)	Cradle-to-distribution: farm inputs, feed production, animal housing, slaughtering, farm to slaughter transport, slaughter to manufacturer transport, manufacturing and manufacturing, packaging, final product cold storage, final product distribution (transport to cold storage facilities then to customer gates)
Impact assessment methods	ReCiPe 2016 Midpoint (H); IPCC 2021 GWP100 & IPCC 2021 GWP20 in sensitivity	ReCiPe 2016 Midpoint (H); IPCC 2021 GWP100 & IPCC 2021 GWP20 in sensitivity

5.0 Conclusions

This study achieved its goal of communicating the potential environmental impact of Beyond Steak® when compared to animal-based meat, represented with beef-based steak tips. Impacts for Beyond Steak® are 65% to 95% less than those of the beef-based steak tips. Figure 27 from the *Results and Discussion* section summarizes this conclusion by impact category.

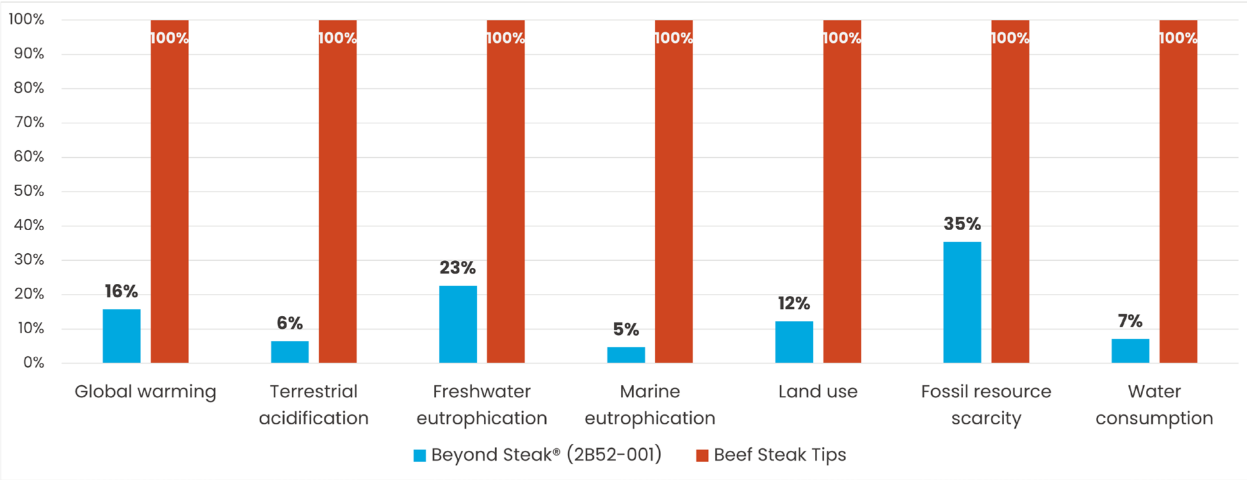

Figure 27: Comparison of results for Beyond Steak® and beef-based steak tips.

In both product systems, across nearly all impact categories considered, ingredient raw material production represents the largest contributor to impact. The phase's highest relative contribution is in marine eutrophication and land use. This is consistent across both product systems.

Table 29 summarizes the percent contribution of the raw material life cycle phase for both product systems by impact category. Only for the Beyond Steak® impact category of fossil resource scarcity is the largest contribution to impact from a different phase, namely logistics. Intra and outbound transport with refrigerated freight trucks is the main driver of impact for the category of fossil resource scarcity.

Table 29: Contribution of the ingredient raw material life cycle phase by impact category.

Impact category	Percent contribution of ingredient raw materials to total impact for:	
	Beyond Steak®	Beef-based steak tips
Global warming	44.8%	92.8%
Terrestrial acidification	52.1%	97.5%
Freshwater eutrophication	66.6%	94.0%
Marine eutrophication	96.1%	99.8%
Land use	96.6%	99.7%
Fossil resource scarcity	31.8%	80.2%
Water consumption	80.3%	98.8%

The uncertainty assessment on these results were conducted to a 95% confidence interval using Monte Carlo simulation with 1,000 runs. In addition to the integration of the data quality assessment into each dataset's pedigree matrix in SimaPro, uncertainty values existing in underlying datasets were also maintained where possible. In reporting results by impact category, uncertainty is represented via error bars generated from this assessment. Additionally, a comparative uncertainty analysis was performed to show the significance of the differences identified between the systems in each impact category. For all impact categories, the impact of beef-based steak tips is higher than Beyond Steak® in 100% of the simulations.

Further analyses were conducted in the *Sensitivity Analysis* section to show how changes in data and methodological choices affected the results of the LCA. Takeaways from these core analyses include:

- Faba bean protein proxy: Based on key parameters, the pea protein-isolate is the best available proxy for the Beyond Steak® faba bean protein; moreover, takeaways on the comparative results between Beyond Steak® and beef-based steak tips are not meaningfully impacted by the proxy selection;
- GWP100 v. GWP20: Using a shorter time horizon for GWP results in a relatively larger increase in the impact category for the beef-based steak tips than Beyond Steak®, likely driven by the methane emissions associated with cattle;
- Functional unit: Beyond Steak® continues to show a benefit in all impact categories over beef-based steak tips when switching to protein- and calorie-based functional units;
- *WFLDB* v. Putman et al.: Both data sources lead to equivalent directional results for beef-based steak tips compared to Beyond Steak®, and further, the *WFLDB* may be relatively conservative in its results for land use and water consumption.

6.0 Critical Review

This study was critically reviewed in accordance with ISO/TS 14071, *Environmental management – Life cycle assessment – Critical review processes and reviewer competencies*. Based on requirements stated in the ISO 14040 and 14044 standards, the critical review for this study is mandatory. Critical review is a mandatory component of this study given its intended use in comparative assertions to be disclosed to the public. For this study, the critical review is performed by a panel of three external and independent reviewers, led by a chair reviewer.

The overarching goal of the critical review is to ensure that:

- the methods used to carry out the study are consistent with ISO 14040 and 14044;
- the methods used to carry out the study are scientifically and technically valid;
- the data used are appropriate and reasonable in relation to the goal of the study;
- the interpretations reflect the limitations identified and the goal of the study;
- the study report is transparent and consistent.

Critical review is not intended to imply that the footprint communication itself is endorsed or verified by an independent third-party.

For this study, the following critical reviewer(s) were assembled by the study commissioner:

- Roland Geyer, Professor at University of California, Santa Barbara (chair)
- Jasmina Burek, Assistant Professor at University of Massachusetts, Lowell
- Alissa Kendall, Professor at University of California, Davis

These reviewer(s) bring experience in LCA, as well as the agriculture industry and specific product systems, to the critical review process.

The critical review performed was at the end of the LCA study, though the goal and scope of the study was reviewed by the chair reviewer prior to analysis. The critical review does not include an assessment of the LCI model and individual datasets. The critical review statement can be found in Appendix A.

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8.0 Appendix

Appendix A: Critical Review Statement

Critical Review of the Study "A Comparative Cradle-to-Distribution Study of Beyond Steak® Plant-Based Seared Tips and Beef-based Steak Tips":

Commissioned by:	Beyond Meat, El Segundo, CA
Performed by:	Brittany Szczepanik, Hannah Fetner, Anna Norman, Positive Scenarios Consulting
Critical Review Panel[1]:	Roland Geyer, Professor, UC Santa Barbara, CA (Chair) Alissa Kendall, Professor, UC Davis, CA Jasmina Burek, Assistant Professor, University of Massachusetts, Lowell, MA
Draft Date:	25 July 2024
Reference	ISO 14044: 2006. Environmental Management - Life Cycle Assessment – Requirements and Guidelines ISO/TS 14071: 2014. Environmental management — Life cycle assessment — Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006

The Scope of the Critical Review

The review panel had the task to assess whether

- the methods used to carry out the LCA are consistent with ISO 14044:2006 and ISO/TS 14071: 2014
- the methods used to carry out the LCA are scientifically and technically valid,
- the data used are appropriate and reasonable in relation to the goal of the study,
- the interpretations reflect the limitations identified and the goal of the study, and
- the study report is transparent and consistent.

The review was performed according to ISO 14044 and ISO/TS 14071 in their strictest sense as the results of the study are intended to be used for comparative assertions to be disclosed to the public.

The extent to which the unit process data are appropriate and representative, given the goal and scope of the study, was determined by a critical review of the available metadata, i.e. process descriptions, etc. Analysis and validation of the process inputs and outputs themselves was outside the scope of this review.

General evaluation

The defined scope for this LCA study was found to be appropriate to achieve the defined goals. The Life Cycle Inventory models are suitable for the purpose of the study and are

[1] While the professional affiliations of the peer reviewers have been provided, their effort was personally compensated. Thus, their reviews do not represent any endorsements by their Universities.

thus capable to support the goal of the study. All primary and secondary data are adequate in terms of quality, and technological, geographical and temporal coverage. The data quality is found to be mostly high for the most important processes and at least adequate for all others. Study results are reported using seven impact categories from ReCiPe 2016. This selection was found to be appropriate and reasonable in relation to the goal of the study. As a result, the report is deemed to be representative and complete. The study is reported in a transparent manner. Various assumptions were addressed by uncertainty and sensitivity analyses of critical data and methodological choices. The interpretations of the results reflect the identified limitations of the study and are considered to be conservative.

The critical review process was open and constructive. The LCA commissioner and practitioner were cooperative and forthcoming and addressed all questions, comments, and requests of the review panel to its full satisfaction.

This Review Statement summarizes the review process and its outcome. The review process is documented in the Review Report, which is available as a separate document and contains all reviewer comments and practitioner responses.

Conclusion

The study has been carried out in compliance with ISO 14044 and ISO/TS 14071. The critical review panel found the overall quality of the report high, its methods scientifically and technically valid, and the used data appropriate and reasonable. The study report is transparent and consistent, and the interpretation of the results reflects the goal and the identified limitations of the study.

Roland Geyer | Alissa Kendall | Jasmina Burek

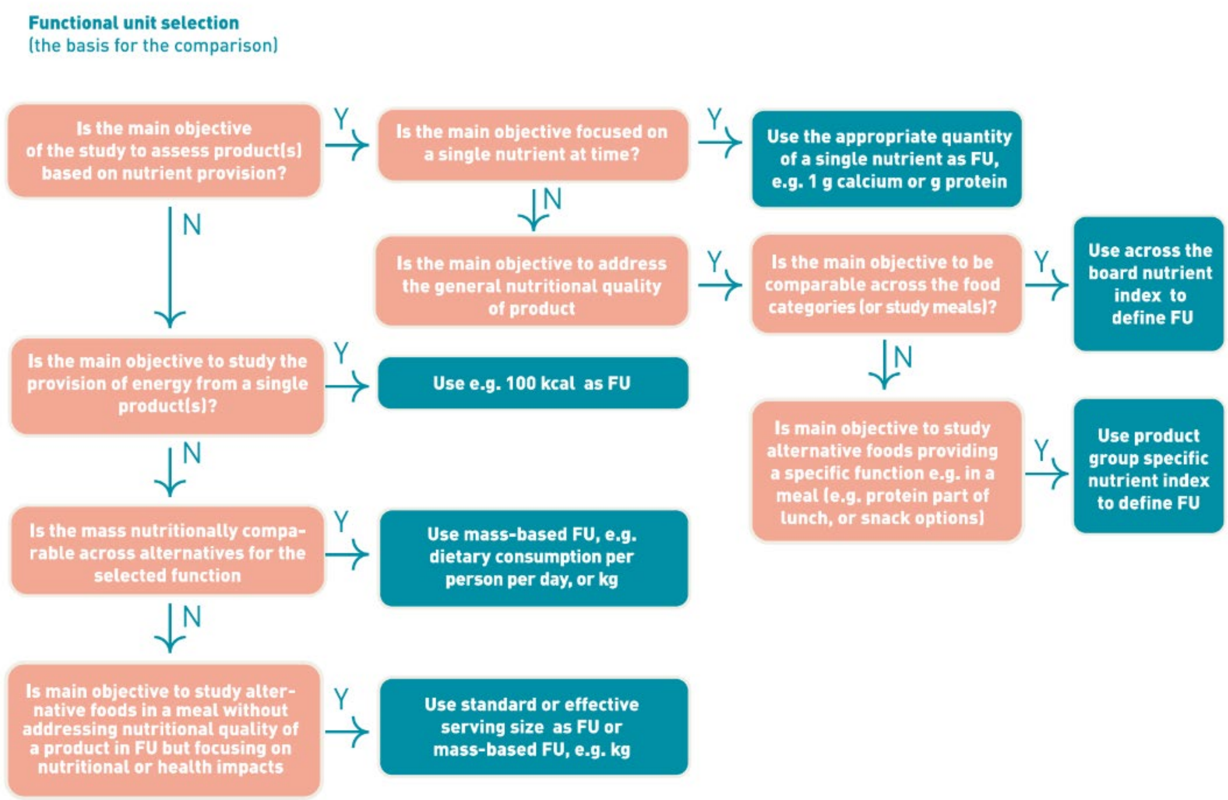
Appendix B: List of Acronyms

3PL - Third-party logistics
AP – Acidification potential
AR5 – Fifth Assessment Report
AR6 – Sixth Assessment Report
B2B – Business-to-business
CF – Characterization factor
COMO – Columbia, Missouri
COO – Country of origin
CY – Calendar year
EP – Eutrophication potential
ESG – Environmental, social and governance
FAO - United Nations Food and Agriculture Organization
FFP – Fossil fuel potential
FTC – Federal Trade Commission
GFI – Good Food Institute
GHG – Greenhouse gas
GMO – Genetically modified organism
GWP – Global warming potential
IPCC - Intergovernmental Panel on Climate Change
ISO - International Standard Organization
LCA – Life Cycle Assessment
LCI – Life Cycle Inventory
LCIA – Life Cycle Impact Assessment
NGO – Non-governmental organization
PSC – Positive Scenarios Consulting, Inc.
SKU – Stock keeping unit
USDA – United States Department of Agriculture
WFLDB – World Food LCA Database
WIP – Work in progress

Appendix C: FAO functional unit decision tree

Source: McLaren et al., 2021

Figure 5: A decision tree for selecting the functional unit



Appendix D: ReCiPe 2016 indicators

Midpoint impact categories, related indicators, and key references

Source: Huijbregts et al., 2017

Midpoint impact category	Indicator	CF_m	Unit	Key references
Climate change	Infrared radiative forcing increase	Global warming potential (GWP)	kg CO_2-eq to air	IPCC 2013; Joos et al. 2013
Ozone depletion	Stratospheric ozone decrease	Ozone depletion potential (ODP)	kg CFC-11-eq to air	WMO 2011
Ionising radiation	Absorbed dose increase	Ionising radiation potential (IRP)	kBq Co-60-eq to air	Frischknecht et al. 2000
Fine particulate matter formation	PM2.5 population intake increase	Particulate matter formation potential (PMFP)	kg PM2.5-eq to air	Van Zelm et al. 2016
Photochemical oxidant formation: terrestrial ecosystems	Tropospheric ozone increase	Photochemical oxidant formation potential: ecosystems (EOFP)	kg NOx-eq to air	Van Zelm et al. 2016
Photochemical oxidant formation: human health	Tropospheric ozone population intake increase	Photochemical oxidant formation potential: humans (HOFP)	kg NOx-eq to air	Van Zelm et al. 2016
Terrestrial acidification	Proton increase in natural soils	Terrestrial acidification potential (TAP)	kg SO_2-eq to air	Roy et al. 2014
Freshwater eutrophication	Phosphorus increase in freshwater	Freshwater eutrophication potential (FEP)	kg P-eq to freshwater	Helmes et al. 2012
Human toxicity: cancer	Risk increase of cancer disease incidence	Human toxicity potential (HTPc)	kg 1,4-DCB-eq to urban air	Van Zelm et al. 2009
Human toxicity: non-cancer	Risk increase of non-cancer disease incidence	Human toxicity potential (HTPnc)	kg 1,4-DCB-eq to urban air	Van Zelm et al. 2009
Terrestrial ecotoxicity	Hazard-weighted increase in natural soils	Terrestrial ecotoxicity potential (TETP)	kg 1,4-DCB-eq to industrial soil	Van Zelm et al. 2009
Freshwater ecotoxicity	Hazard-weighted increase in freshwaters	Freshwater ecotoxicity potential (FETP)	kg 1,4-DCB-eq to freshwater	Van Zelm et al. 2009
Marine ecotoxicity	Hazard-weighted increase in marine water	Marine ecotoxicity potential (METP)	kg 1,4-DCB-eq to marine water	Van Zelm et al. 2009
Land use	Occupation and time-integrated land transformation	Agricultural land occupation potential (LOP)	m^2 × yr annual cropland-eq	De Baan et al. 2013; Curran et al. 2014
Water use	Increase of water consumed	Water consumption potential (WCP)	m^3 water-eq consumed	Döll and Siebert 2002; Hoekstra and Mekonnen 2012
Mineral resource scarcity	Increase of ore extracted	Surplus ore potential (SOP)	kg Cu-eq	Vieira et al. 2016a
Fossil resource scarcity	Upper heating value	Fossil fuel potential (FFP)	kg oil-eq	Jungbluth and Frischknecht 2010

Appendix E: WFLDB Beef Dataset Description

	WFLDB dataset: *Beef, fresh meat at slaughterhouse*
Descriptions of the data:	▫ "The dataset represents the average national mix for beef cattle live weight production in the United States" including "12% cattle from mixed production systems, 77% cattle from feedlot production systems, and 11% cattle from grassland-based systems". ▫ "dataset is built according to GLEAM 2.0 methodology (FAO 2018)" ▫ "System boundaries: Cradle-to-gate: The process includes all inputs such as infrastructure, energy, water and feed for the calf for growing as well as the fattening of cattle. Transport of feed from regional warehouse to animal farm is included. Direct (enteric) emissions from animals to air and manure management emissions for the overall system are also accounted for. " ▫ Feed archetypes are based on FAO GLEAM 2.0 regionalized feed baskets. ▫ Direct emissions are based on IPCC 2006 tier 2. ▫ Temporal data representation: 2005-2018 ▫ Data quality rating (DQR) = 2.2 (i.e. good quality) (For dataset: Beef cattle, live weight at farm, US)

Appendix F: Data Quality Assessment Results & Rationale

Beyond Steak® Plant-Based Seared Tips

Data Type	Pedigree Matrix for Data Quality of Beyond Steak® Plant-Based Seared Tips									
	Reliability		Completeness		Temporal Representativeness		Geographic Representativeness		Technological Representativeness	
	Score	Comment	Score	Comment	Score	Comment	Score	Comment	Score	Comment
Product ingredient components and mass	1	Formulation followed for production	1	BOM is per SKU, which is market and channel specific	1	BOM represents current version sold	1	BOM represents version sold in U.S. market	1	BOM represents same technology/product
Product ingredient component yields	4	Yields are documented estimates from BYND engineers/R&D	1	BOM is per SKU, which is market and channel specific	1	BOM represents current version sold	1	BOM represents version sold in U.S. market	1	BOM represents same technology/product
Water weights per product	2	Calculated by PSC based on dry mass in BOM and finished product weight. Verified by BYND.	1	BOM is per SKU, which is market and channel specific	1	BOM represents current version sold	1	BOM represents version sold in U.S. market	1	BOM represents same technology/product
Packaging mass	1	Weights are measured	2	Packaging mass not broken down to sub-component level. Gaps were filled in with physical measurement by PSC.	1	Database represents current version sold	1	Database represents version sold in U.S. market	1	Database represents same technology/product
Packaging materials	1	From verified product BOM	1	BOM is per SKU, which is market and channel specific	1	BOM represents current version sold	1	BOM represents version sold in U.S. market	1	BOM represents same technology/product
Ingredient country of origin	1	Tracked by Beyond Meat procurement & suppliers	2	Ingredient modeled to COO for >50% of total dry mass	1	Country of origin represents current supply	1	Data collected to the country-level and ingredients	1	Country of origin represents supply of exact product to BYND as in BOM

						of product to BYND		modeled using databases to the country-level		
Inbound Transport - raw material ingredients	4	Distance estimated based on country of origin, nearest port to manufacturing facility, & ports.com	1	Included transport for main ingredients only, achieving >80% coverage of dry ingredient weight	1	Country of origin represents current supply of product to BYND	1	Data collected to the country-level and ingredients modeled using databases to the country-level	2	Exact type of transport truck & ship unknown
Intra Transport - WIP ingredients	2	Calculated distances based on addresses and fastest route on Google Maps	1	Calculated for all WIP ingredients & all known movement	1	Flow / facility locations represents current movement of WIP product	1	Flow / facility locations represents exact geography of current movement of WIP products	2	Exact type of transport truck unknown
Electricity usage at BYND facilities	2	Based on measurement of consumption tied to invoices	2	At least 6 months worth of usage available, missing months extrapolated where needed	1	Data represents production in CY 2023	1	Data represents actual physical location of production	1	Data represents actual facility of production
Natural gas consumption at BYND facilities	2	Based on measurement of consumption tied to invoices	2	At least 6 months worth of usage available, missing months extrapolated where needed	1	Data represents production in CY 2023	1	Data represents actual physical location of production	1	Data represents actual facility of production
Electricity usage at co-manufacturing facility	3	Based on calculation of consumption allocated to BYND production days	1	Average based on full year of production of BYND products	1	Data represents production in CY 2023	1	Data represents actual physical location of production	1	Data represents actual facility of production

Natural gas consumption at co-manufacturing facility	3	Based on calculation of consumption allocated to BYND production days	1	Average based on full year of production of BYND products	1	Data represents production in CY 2023	1	Data represents actual physical location of production	1	Data represents actual facility of production
Throughput at COMO (WIP facilities)	2	Data based on actual production calculations	1	Full year worth of production provided	1	Data represents production in CY 2023	1	Data represents actual physical location of production	1	Data represents actual facility of production
Throughput at finished goods manufacturing facility	2	Data based on actual production calculations	1	Full year worth of production provided	1	Data represents production in CY 2023	1	Data represents actual physical location of production	1	Data represents actual facility of production
Electricity usage at cold storage facilities	4	Estimated value used from other critically reviewed BYND study	2	6 months worth of usage evaluated, missing months extrapolated where needed	1	Data represents cold storage in CY 2022	4	Value represents cold storage at facility in PA, USA. Actual cold storage in MO, GA, TX, PA, IN, and CA USA.	2	Value represents electricity used in cold storage. Does not include other potential inputs (e.g., refrigerants)
Volume occupation at cold storage facilities	3	Calculated based on pallet configuration data and mass of material (for WIP)	1	Calculate for all WIP ingredients and final product	1	Data represents current WIP ingredient weights and final product pallet configurations	1	Data represents current WIP ingredient weights and final product pallet configurations	1	Data represents current WIP ingredient weights and final product pallet configurations
Days on hand at cold storage facilities	4	Estimate by BYND logistics for all WIP materials and final product	1	Estimated based on SKUs and locations of focus	1	Data represents current inventory	1	Data represents location where inventory is held	1	Data represents same warehousing activity
Outbound transport from finished goods manufacturing facility to cold storage facilities	2	Calculated distances based on addresses and fastest route on Google Maps	1	Calculated for all known final product movement in CY 2023	1	Flow / facility locations represents average CY 2023 known movement	1	Flow / facility locations represents exact geography of movement of final products	2	Exact type of transport truck unknown

Outbound transport (delivery) from fulfillment centers to customers	1	Distances measured through transportation management system	1	Includes all known final product movement in CY 2023	1	Flow / facility & customer locations represents average CY 2023 known movement	1	Flow / facility & customer locations represents exact geography of movement of final products	2	Exact type of transport truck unknown
Outbound transport (will call) from fulfillment centers to customers	4	Distances estimated based on coordinates of origin and destination cities and great circle distance formula in Microsoft Excel (not exact routes)	1	Includes all known final product movement in CY 2023	1	Flow / facility & customer locations represents average CY 2023 known movement	2	Exact customer locations and routes unknown, distances estimated to the city-level	2	Exact type of transport truck unknown

Pre-cooked beef-based steak tips

Data Type	Pedigree Matrix for Data Quality of pre-cooked beef-based steak tips									
	Reliability		Completeness		Temporal Representativeness		Geographic Representativeness		Technological Representativeness	
	Score	Comment	Score	Comment	Score	Comment	Score	Comment	Score	Comment
Product ingredient components and mass	2	Data represents sample, representative product	2	Data represents sample, representative product	1	Data represents current representative products sold	1	Data represents version sold in U.S. Market	1	Data represents sample, representative product
Water, protein, and fat percentages per product	1	Data measurement represents sample, representative product	2	Data represents sample, representative product	1	Data represents current representative products sold	1	Data represents version sold in U.S. Market	1	Data represents sample, representative product
Ingredient Transport	4	Exact shipping route and truck type is unknown, estimate	5	Exact shipping route and truck type is unknown	2	Exact shipping route is unknown	2	Exact shipping route is unknown	2	Exact type of transport truck unknown

Packaging mass	2	Weights are measured, proxy from BYND	3	Packaging mass not broken down to sub-component level. Gaps were filled in with physical measurement by PSC. Proxy from BYND.	1	Data represents current representative products sold	2	Database represents version sold in U.S. market	3	Data represents actual packaging for a similar production. Proxy from BYND.
Packaging materials	2	From verified product BOM, proxy from BYND	2	BOM is per SKU, which is market and channel specific. Proxy from BYND	1	Data represents current representative products sold	2	Data represents version sold in U.S. Market	3	Data represents actual packaging for a similar production. Proxy from BYND.
Electricity usage for manufacturing	3	Based on measurement of consumption tied to invoices. Proxy from BYND.	3	At least 6 months worth of usage available, missing months extrapolated where needed. Proxy from BYND.	1	Data represents production in CY 2023	2	Data represents location of production for U.S. Market	3	Data represents actual facility production for a similar production process. Proxy from BYND.
Natural gas consumption for manufacturing	3	Based on measurement of consumption tied to invoices. Proxy from BYND.	3	At least 6 months worth of usage available, missing months extrapolated where needed. Proxy from BYND.	1	Data represents production in CY 2023	2	Data represents location of production for U.S. Market	3	Data represents actual facility production for a similar production process. Proxy from BYND.
Electricity usage at cold storage facilities	4	Proxy from BYND, based on estimate.	3	6 months worth of usage evaluated, missing months extrapolated where needed. Proxy from BYND.	1	Data represents cold storage in CY 2022 from proxy.	4	Value represents cold storage at facility in PA, USA. Actual cold storage unknown.	2	Value represents electricity used in cold storage. Does not include other potential inputs (e.g., refrigerants). Proxy from BYND.
Volume occupation at cold storage facilities	3	Proxy from BYND, based on calculation.	4	Proxy from BYND sites.	2	Data represents current final product pallet configurations from proxy.	3	Proxy data from area with likely similar conditions for	2	Proxy data from facility with likely similar technology for pallet configuration

								pallet configuration		
Days on hand at cold storage facilities	4	Proxy from BYND, based on estimate.	4	Proxy from BYND sites.	1	Data represents current inventory practices from proxy.	3	Proxy data from area with likely similar conditions for inventory practices	2	Proxy data from facility with likely similar technology for inventory practices
Outbound transport from manufacturing facility to cold storage facilities	4	Exact shipping route and truck type is unknown. Proxy from BYND.	5	Exact shipping route and truck type is unknown	1	Data represents distribution in CY 2023 from proxy	2	Exact shipping route is unknown, but likely occurs in same larger area of study as proxy	2	Exact type of transport truck unknown
Outbound transport (delivery) from fulfillment centers to customers	4	Exact shipping route and truck type is unknown. Proxy from BYND.	5	Exact shipping route and truck type is unknown	1	Data represents distribution in CY 2023 from proxy	2	Exact shipping route is unknown, but likely occurs in same larger area of study as proxy	2	Exact type of transport truck unknown
Outbound transport (will call) from fulfillment centers to customers	4	Exact shipping route and truck type is unknown. Proxy from BYND.	5	Exact shipping route and truck type is unknown	1	Data represents distribution in CY 2023 from proxy	2	Exact shipping route is unknown, but likely occurs in same larger area of study as proxy	2	Exact type of transport truck unknown

Appendix G: Data Quality Assessment Pedigree Matrix

Data Quality Indicator	Description	Score criteria				
		Very good	Good	Fair	Poor	Very poor (default)
		1	2	3	4	5
Reliability	The degree to which the sources, data collection methods and verification procedures used to obtain the data are dependable	Verified data based on measurements	Verified data based on a calculation or non-verified data based on measurements	Non-verified data based on a calculation	Documented estimate	Undocumented estimate
Completeness	The degree to which the data are statistically representative of the relevant activity. Completeness depends on many factors including the percentage of sites for which data are used out of the total number of relevant sites, coverage of seasonal and other fluctuations in data, etc.	Data from >80% of relevant sites/market over an adequate time period	Data from >50% of sites/relevant market over an adequate time period	Data from <50% of sites/ relevant market over an adequate time period or from >50% of sites/market for a short time period	Data from only one site relevant for the market or some sites but from shorter periods	Unknown or Data from a small number of sites and from shorter periods
Temporal representativeness	The degree to which the data reflects the actual time (e.g., year) or age of the activity.	Data with less than 3 years of difference	Data with less than 6 years of difference	Data with less than 10 years of difference	Data with less than 15 years of difference	Age of data unknown or more than 15 years of difference
Geographical representativeness	The degree to which the data reflects the actual geographic location of the activity (e.g., country or site).	Data from the same area of study	Average data from larger area in which area under study is included	Data from an area with similar production conditions	Data from area with slightly similar production conditions	From a distinctly different or unknown area of study
Technological representativeness	The degree to which the data reflects the actual technologies used.	Data from the same / equivalent technology	Data from a similar but different technology	Data from a different technology	Data from processes and materials under study but from different industries/ enterprises	Data from an unknown technology

Appendix H: Pea protein-isolate, at processing {modified to CA} Economic, U

Available dataset: Pea protein-isolate, at processing {NL} Economic, U			
Dataset component	Dataset used	Amt	Modification made
Outputs to technosphere: products and co-products	Pea protein-isolate, at processing {modified to CA} Economic, U	256 kg	renamed
Inputs from technosphere: materials/fuels	Pea slurry, at processing {modified to CA} Economic, U	698 kg	Y, see below
Inputs from technosphere: electricity/heat	Heat, district or industrial, natural gas {RoW}| heat production, natural gas, at industrial furnace >100kW | Cut-off, U	2223 MJ	N

Modified dataset: Pea slurry, at processing {modified to CA} Economic, U			
Dataset component	Dataset used	Amt	Modification made
Outputs to technosphere: products and co-products	Pea slurry, at processing {modified to CA} Economic, U	698 kg	renamed
	Pea starch slurry, at processing {modified to CA} Economic, U	990 kg	renamed
	Pea wet animal feed, at processing {modified to CA} Economic, U	1267 kg	renamed
Inputs from nature	Water, unspecified natural origin, CA	4000 dm^3	CA dataset selected
Inputs from technosphere: materials/fuels	Hydrochloric acid, without water, in 30% solution state {RoW}| market for | Cut-off, S - Copied from ecoinvent U	5.001 kg	N
	Pea meal, at processing {modified to CA} Economic, U	1000 kg	Y, see below
	Sodium hydroxide, without water, in 50% solution state {GLO}| market for | Cut-off, S - Copied from ecoinvent U	1 kg	N
Inputs from technosphere: electricity/heat	Electricity, low voltage {CA}| market group for | Cut-off, S - Copied from ecoinvent	312.48 MJ	CA dataset selected

Modified dataset: Pea meal, at processing {modified to CA} Economic, U			
Dataset component	Dataset used	Amt	Modification made
Outputs to technosphere: products and co-products	Pea meal, at processing {modified to CA} Economic, U	709.08 kg	renamed
	Pea hull, at processing {modified to CA} Economic, U	186.6 kg	renamed
Inputs from technosphere: materials/fuels	Peas, dry, dried, market mix, at regional storage {RNA} Economic, U	1000 kg	RNA dataset selected
	Heat, district or industrial, other than natural gas {RoW}| heat production, heavy fuel oil, at industrial furnace 1MW | Cut-off, S - Copied from ecoinvent U	460 MJ	N
Inputs from technosphere: electricity/heat	Electricity, low voltage {CA}| market group for | Cut-off, S - Copied from ecoinvent	209 kWh	CA dataset selected

Appendix I: Supplementary sensitivity analyses

Analysis	Explanation
Ingredient yields	To evaluate how changes to ingredient yields (an estimated value) affect results for all impact categories.
Country of origin	To evaluate how ingredient country of origin in LCI datasets may affect results for all impact categories. LCIA was performed on wheat gluten.
Distribution distance	To evaluate how changes to final product distribution distance (to cold storage facilities and to customers) may affect results for all impact categories.
Packaging inputs	To evaluate how changes to packaging mass (primary and secondary) may affect results for all impact categories.
Manufacturing inputs	To evaluate how changes to manufacturing inputs (WIP preparation and manufacturing) may affect results for all impact categories.

Ingredient yields

Product losses can be expected at various stages throughout production at the raw material level, WIP assembly level, or finished goods manufacturing level. Specifically in the cooking process, we can expect to see shrinkage in the mass of the product. As a result, more than 88 g of input ingredients are needed to produce 88 g of a cooked product. As mentioned in the data quality assessment, ingredient yields are estimated by Beyond Meat based on the product, ingredient level in the BOM, and other relevant findings. To determine the significance of this specific source of uncertainty, an analysis was conducted wherein the percent change to total impact by category was calculated for every 1% improvement to average ingredient yield. The findings of that analysis can be found in the below table.

Sensitivity analysis on ingredient yields.

Percent change to total impact by category for every 1% improvement to average ingredient yield						
Global warming (kg CO_2 eq)	Terrestrial acidification (kg SO2 eq)	Freshwater eutrophication (kg P eq)	Marine eutrophication (kg N eq)	Land use (m2a crop eq)	Fossil resource scarcity (kg oil eq)	Water consumption (m3)
-0.4%	-0.5%	-0.6%	-1.0%	-1.0%	-0.3%	-0.8%

This table demonstrates that improving ingredient yield, through better data collection or management, is a very efficient method of seeing improvements to the result total. The biggest proportional benefits (at least 0.8% per 1% improved) are possible in the impact categories of marine eutrophication, land use, and water consumption. Efficient use of ingredients means less input material needed and greatest benefit for the impact categories with the most impact coming from the raw material phase.

Country of origin

Given the variation in agricultural and production processes in different parts of the world, region and country of origin can have a significant bearing on the impact associated with raw materials. LCI datasets are often created with specific countries and regions in mind to account for this variation. This study sought to model ingredients as closely as possible to the actual country of origin of the Beyond Meat supply. This sensitivity analysis evaluates how ingredient country of origin in LCI datasets may affect results for all impact categories. Wheat gluten is currently sourced from Europe, but *Agrifootprint* also has datasets representing wheat gluten in North America and China. Expeller-pressed canola oil is currently sourced from two countries: Canada (80% of supply) and Australia (20% of supply). The below table shows the results of these sensitivity analyses.

Sensitivity analysis on dataset country of origin of wheat gluten.

	Percent change to total impact by category by changing country of origin of wheat gluten						
Country of Origin Scenario	Global warming (kg CO2 eq)	Terrestrial acidification (kg SO2 eq)	Freshwater eutrophication (kg P eq)	Marine eutrophication (kg N eq)	Land use (m2a crop eq)	Fossil resource scarcity (kg oil eq)	Water consumption (m3)
100% from North America (RNA)	3%	32%	14%	4%	22%	2%	65%
100% from China (CN)	7%	42%	19%	-17%	-10%	6%	329%

Sensitivity analysis on dataset country of origin of canola oil.

	Percent change to total impact by category by changing country of origin of canola oil						
Country of Origin Scenario	Global warming (kg CO2 eq)	Terrestrial acidification (kg SO2 eq)	Freshwater eutrophication (kg P eq)	Marine eutrophication (kg N eq)	Land use (m2a crop eq)	Fossil resource scarcity (kg oil eq)	Water consumption (m3)
100% from Australia (AU)	-1.6%	3.1%	0.0%	0.0%	0.0%	0.0%	0.0%
100% from Canada (CA)	0.4%	10.1%	0.0%	0.0%	0.0%	0.0%	0.0%

Caution should be used when interpreting these results as they are based on models or estimations, not on real impacts associated from sourcing ingredients from one country over another. Even within countries and regions, there is still high variation in agricultural and production processes that impact the categories of study. Further, an analysis like this one demonstrates the complexities and trade-offs inherent in the study.

Distribution distance

Logistics overall, and notably the refrigerated distribution of final product, is a top driver of impact in several categories, including fossil resource scarcity and global warming. This sensitivity analysis evaluates how changes to the total distance of two legs of distribution via refrigerated truck (from finished goods manufacturing to cold storage and from cold storage to customers) affect results for all impact categories. The below table shows how a 10% reduction in distribution distance impacts total results in each category. Changes to total impact are most significant for fossil resource scarcity, global warming, and terrestrial acidification.

Sensitivity analysis on distance of refrigerated distribution.

	Percent change to total impact by category for every 10% reduction in distribution distance						
Distribution leg	Global warming (kg CO2 eq)	Terrestrial acidification (kg SO2 eq)	Freshwater eutrophication (kg P eq)	Marine eutrophication (kg N eq)	Land use (m2a crop eq)	Fossil resource scarcity (kg oil eq)	Water consumption (m3)
To cold storage facilities	-1.8%	-1.5%	-0.6%	-0.1%	0.0%	-2.1%	-0.4%
To customers	-1.7%	-1.4%	-0.5%	-0.1%	0.0%	-2.0%	-0.4%

Packaging inputs

Though packaging is not the top driver of impact in any category, primary and secondary packaging combined is still a material source of impact (greater than 1% in all categories), with up to nearly 10% of total impact for fossil resource scarcity. This sensitivity analysis evaluates how changes to packaging mass (primary and secondary) affect results for all impact categories. The below table shows how a 10% reduction in packaging mass impacts total results in each category. Changes to total impact are most significant for fossil resource scarcity, but otherwise inconsequential.

Sensitivity analysis on mass of packaging inputs.

	Percent change to total impact by category for every 10% improvement to packaging mass						
Packaging type	Global warming (kg CO2 eq)	Terrestrial acidification (kg SO2 eq)	Freshwater eutrophication (kg P eq)	Marine eutrophication (kg N eq)	Land use (m2a crop eq)	Fossil resource scarcity (kg oil eq)	Water consumption (m3)
Primary (retail)	-0.3%	-0.3%	-0.3%	0.0%	0.0%	-0.6%	-0.3%
Secondary (case)	-0.3%	-0.4%	-0.5%	-0.1%	-0.2%	-0.4%	-0.3%

Manufacturing Inputs

Similar to packaging, manufacturing is not the top driver of impact in any category. However, it is still a material category, especially for fossil resource scarcity. This sensitivity analysis evaluates how changes to manufacturing inputs (electricity and natural gas in preparation and finished goods manufacturing) affect results for all impact categories. The below table shows how a 10% reduction in total manufacturing energy use impacts total results in each category. Changes to total impact are most significant for fossil resource scarcity, freshwater eutrophication, and global warming.

Sensitivity analysis on manufacturing energy use.

	Percent change to total impact by category for every 10% improvement to manufacturing energy use						
Manufacturing phase	Global warming (kg CO2 eq)	Terrestrial acidification (kg SO2 eq)	Freshwater eutrophication (kg P eq)	Marine eutrophication (kg N eq)	Land use (m2a crop eq)	Fossil resource scarcity (kg oil eq)	Water consumption (m3)
Preparation (WIP)	-0.6%	-0.3%	-0.8%	0.0%	0.0%	-0.7%	-0.3%
Finished goods manufacturing	-0.1%	0.0%	0.0%	0.0%	0.0%	-0.2%	0.0%

Appendix J: Composition comparison of legumes

Source: Martineau-Côté et al., 2022

Table 1

Proximate compositions of the faba bean compared to pea and soy (g/100 g dry base) compiled from various studies [25,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67].

Legume		Proteins	Carbohydrates						Ash	Fat
			TCH [1]	Starch	Amylose [2]	TDF [3]	IDF [4]	SDF [5]		
Faba bean	Mean	27.6	66.0	40.0	34.0	12.9	15.1	1.4	3.4	1.4
	SD	3.0	5.1	3.4	6.4	9.0	4.6	1.8	0.4	0.4
	Min	22.7	55.2	28.1	18.6	6.4	10.7	0.6	2.6	0.7
	Max	34.7	71.4	47.5	44.4	34.9	30.3	7.6	4.4	3.2
	n1 [6]	106	57	46	24	17	18	18	94	80
	n2 [7]	13	6	7	3	6	4	4	11	11
Pea	Mean	23.4	63.5	44.9	29.6	14.7	11.0	2.5	3.0	1.6
	SD	2.4	7.1	1.2	3.5	2.6	0.9	1.4	0.3	0.5
	Min	18.1	52.8	42.2	19.1	12.2	9.7	1.7	2.4	1.0
	Max	27.5	70.0	46.6	31.6	19.4	12.9	5.6	3.7	2.9
	n1	34	5	18	12	11	8	8	23	23
	n2	12	4	6	3	6	3	3	10	10
Soy	Mean	40.0	28.6	2.7	-	21.9	24.8	2.6	5.2	19.7
	SD	3.0	3.0	2.7	-	8.3	8.6	2.3	0.6	2.2
	Min	31.5	19.7	0.2	-	13.7	15.4	0.6	3.0	14.0
	Max	46.8	33.2	6.7	-	35.5	32.6	6.1	6.3	23.6
	n1	48	31	19	-	9	5	5	40	60
	n2	12	5	2	-	5	4	4	8	12

Open in a separate window

[1] TCH: total carbohydrate; [2] percentage of total starch; [3] TDF: total dietary fibres; [4] IDF: insoluble dietary fibres; [5] SDF: soluble dietary fibres; [6] n1: number of cultivars; [7] n2: number of references.

Critical Review of the Study "A Comparative Cradle-to-Distribution Study of Beyond Steak® Plant-Based Seared Tips and Beef-based Steak Tips":

Commissioned by:	Beyond Meat, El Segundo, CA
Performed by:	Brittany Szczepanik, Hannah Fetner, Anna Norman, Positive Scenarios Consulting
Critical Review Panel[1]:	Roland Geyer, Professor, UC Santa Barbara, CA (Chair) Alissa Kendall, Professor, UC Davis, CA Jasmina Burek, Assistant Professor, University of Massachusetts, Lowell, MA
Draft Date:	25 July 2024
Reference	ISO 14044: 2006. Environmental Management - Life Cycle Assessment – Requirements and Guidelines ISO/TS 14071: 2014. Environmental management — Life cycle assessment — Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006

The Scope of the Critical Review

The review panel had the task to assess whether

- the methods used to carry out the LCA are consistent with ISO 14044:2006 and ISO/TS 14071: 2014
- the methods used to carry out the LCA are scientifically and technically valid,
- the data used are appropriate and reasonable in relation to the goal of the study,
- the interpretations reflect the limitations identified and the goal of the study, and
- the study report is transparent and consistent.

The review was performed according to ISO 14044 and ISO/TS 14071 in their strictest sense as the results of the study are intended to be used for comparative assertions to be disclosed to the public.

The extent to which the unit process data are appropriate and representative, given the goal and scope of the study, was determined by a critical review of the available metadata, i.e. process descriptions, etc. Analysis and validation of the process inputs and outputs themselves was outside the scope of this review.

General evaluation

The defined scope for this LCA study was found to be appropriate to achieve the defined goals. The Life Cycle Inventory models are suitable for the purpose of the study and are

[1] While the professional affiliations of the peer reviewers have been provided, their effort was personally compensated. Thus, their reviews do not represent any endorsements by their Universities.

thus capable to support the goal of the study. All primary and secondary data are adequate in terms of quality, and technological, geographical and temporal coverage. The data quality is found to be mostly high for the most important processes and at least adequate for all others. Study results are reported using seven impact categories from ReCiPe 2016. This selection was found to be appropriate and reasonable in relation to the goal of the study. As a result, the report is deemed to be representative and complete. The study is reported in a transparent manner. Various assumptions were addressed by uncertainty and sensitivity analyses of critical data and methodological choices. The interpretations of the results reflect the identified limitations of the study and are considered to be conservative.

The critical review process was open and constructive. The LCA commissioner and practitioner were cooperative and forthcoming and addressed all questions, comments, and requests of the review panel to its full satisfaction.

This Review Statement summarizes the review process and its outcome. The review process is documented in the Review Report, which is available as a separate document and contains all reviewer comments and practitioner responses.

Conclusion

The study has been carried out in compliance with ISO 14044 and ISO/TS 14071. The critical review panel found the overall quality of the report high, its methods scientifically and technically valid, and the used data appropriate and reasonable. The study report is transparent and consistent, and the interpretation of the results reflects the goal and the identified limitations of the study.

Roland Geyer   Alissa Kendall   Jasmina Burek