Report 2025

Beyond Burger® 4.0 Life Cycle Assessment

Commissioned by Beyond Meat®

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Mérieux NutriSciences | Blonk

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About us

Mérieux NutriSciences | Blonk is a leading international expert in food system sustainability, inspiring and enabling the agri-food sector to give shape to sustainability. Our purpose is to create a sustainable and healthy planet for current and future generations. We support organizations in understanding their environmental impact in the agri-food value chain by offering advice and developing tailored software tools based on the latest scientific developments and data.

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Summary

This cradle-to-distribution life cycle assessment (LCA) study of the latest Beyond Burger® (version 4.0) from Beyond Meat® utilizes U.S. production data from 2024 to estimate the environmental impact of a ¼ lb. Beyond Burger in the retail format packaging of two patties in a sealed PET tray. Primary data were provided by Beyond Meat on product formulation, packaging materials and weights, processing utility demands, processing locations, intermediary transport distances and cold storage, and final product cold storage and distribution distances. Secondary (background) data were used for ingredient and packaging material production, electricity generation, municipal water supply, and transportation impacts. LCA modeling follows ISO 14040 / 14044 recommendations, and the study has been critically reviewed by a panel of three independent, external reviewers, as recommended for comparative LCA studies that are to be externally communicated business to business or business to consumer.

Table S1 provides the environmental impact results for one ¼ lb. patty of Beyond Burger, alongside the impacts of a ¼ lb. patty of US-produced beef, based on the industry benchmarking LCA on U.S. beef production (Putman, Rotz and Thoma, 2023). In both cases, the ReCiPe 2016 hierarchist impact assessment method was used. The four indicators presented were chosen as the most relevant (based on previous experience) in comparisons between plant- and animal-based protein sources.

Table S1. Summary of environmental impact intensities per ¼ lb. Beyond Burger patty relative to a 80/20 ¼ lb. beef patty.

indicator	Unit (per ¼ lb)	Beyond Burger 4.0	Beef Patty	% reduction (Beef Patty →Beyond Burger 4.0)
global warming	kg CO_2 eq	0.51	4.22	88%
fossil resource scarcity	kg oil eq	0.13	0.18	28%
land use	m^2a crop eq	0.54	17.52	97%
water consumption	liters	16.9	219.19	92%

Based on a comparative assessment of the Beyond Burger 4.0 production system in 2024 with the 2023 beef LCA by Putman et al, the Beyond Burger 4.0 generates 88% less global warming impact (aka, greenhouse gas (GHG) emissions), and requires 28% less fossil resources (aka, non-renewable energy use), 97% less land use, and 92% less water consumption, as shown in Table S1.

Production of ingredients for the Beyond Burger 4.0 represents 35% of global warming (greenhouse gas emission) impacts, 25% of non-renewable energy use, 90% of land use, and 75% of water consumption. Contributions from production are also notable at, at 23% and 24% to global warming and non-renewable energy use, respectively.

A limited uncertainty assessment shows coefficient of variation of around 3.5% for global warming and non-renewable energy, 14% for land use and 10% for water consumption. Sensitivity assessment around key parameters that were either based on limited data or could be expected to change through fairly routine business operation adjustments, such as the energy used in cold storage warehousing, time in storage, and distance to storage, demonstrated minimal influence on the final results. These uncertainties do not affect the conclusion that the Beyond Burger 4.0 has significantly better environmental performance than a U.S. industry-average produced beef patty.

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List of acronyms & abbreviations

AFP – Agri-footprint (LCI database)

Original Beyond Burger 1.0 = first generation Beyond Burger

Beyond Burger 3.0 = third generation Beyond Burger

Beyond Burger 4.0 = fourth generation Beyond Burger

COMO – Beyond Meat facilities in Columbia, Missouri, used for production of woven protein and dry blend flavor systems, warehousing and dry blending.

DEPA – Beyond Meat facility in Devault, Pennsylvania used for production of finished goods.

EC – European Commission

FAO – Food & Agriculture Organization of the United Nations

ISO – International Organization for Standardization

LCA – Life Cycle Assessment

LCI – Life Cycle Inventory

LEAP – Livestock Environmental Assessment and Performance Partnership

LUC – land use change

PE – polyethylene. LDPE = low density polyethylene; LLDPE = linear low-density polyethylene

PEF – Product Environmental Footprint

PET – polyethylene terephthalate

PPI – yellow pea protein isolate

USDA – United States Department of Agriculture

WIP – work in progress

1. Introduction

Beyond Meat® is a US-based company producing plant-based meat substitutes. The Original Beyond Burger® 1.0, initially released in 2015, is a yellow pea protein-based patty designed to look, cook and taste like fresh ground beef. On September 14, 2018, the Center for Sustainable Systems at the University of Michigan (Marty Heller, principal researcher) published a report commissioned by Beyond Meat documenting a life cycle assessment (LCA) of the original Beyond Burger (version 1.0) and comparisons against a typical American ground beef patty (Heller and Keoleian, 2018). Blonk Consultants performed an update to the LCA, reflecting Beyond Burger 3.0 production in North American in 2022. The current study, conducted by Blonk Consultants and commissioned by Beyond Meat, uses the LCA methodology outlined below to calculate the environmental impact of Beyond Burger (version 4.0) produced in the U.S. in 2024, and compares it with a ground beef patty, based on U.S. industry-average production. The study serves as an update to the Beyond Burger 3.0 LCA from 2023, addressing product reformulation as well as changes in business and manufacturing practices. No further changes have been made to the LCA of U.S. beef patty production used for the 2023 comparison, except for an update to the distribution contributions to align with those of Beyond Burger 4.0.

LCA is a framework that allows the quantitative analysis of the environmental burdens of a product or system throughout all the stages of its life cycle. LCAs take a holistic approach, revealing how individual life cycle stages contribute to a product's overall environmental impact. This insight helps identify opportunities for direct and indirect environmental management actions that may lead to a reduction of emissions throughout the life cycle.

This LCA is conducted according to the iterative, multi-step methodology proposed in ISO 14040 and 14044 LCA methodological standards (ISO, 2006a, 2006b), including an external review.

The LCA is conducted according to the following steps, as defined by the abovementioned ISO standards and illustrated in Figure 1.

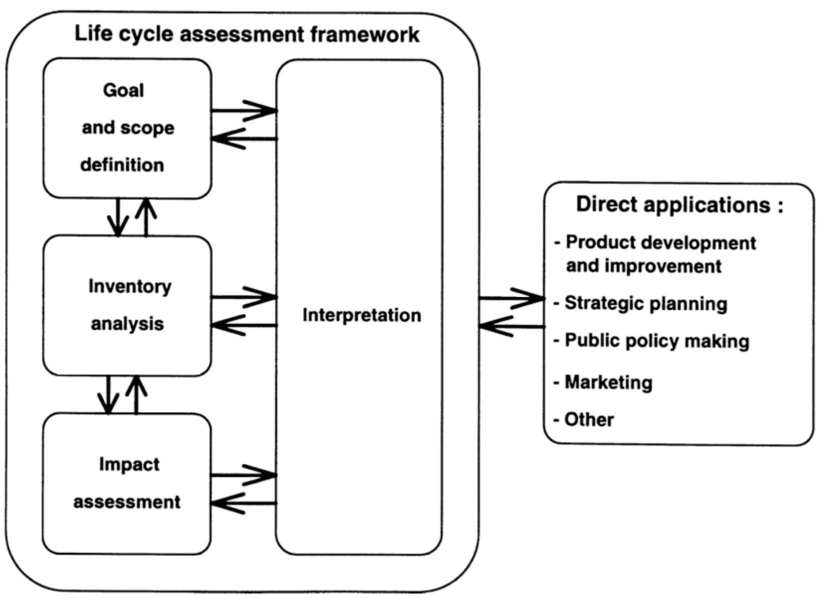

Figure 1: Methodological phases in LCA based on ISO 14040

- **Goal & scope definition**: This phase provides a description of the product system in terms of the system boundary and functional unit.
- **Life cycle inventory analysis**: (LCI) is a methodology for estimating the consumption of resources and the quantities of waste flows and emissions caused by or otherwise attributable to a product's life cycle.
- **Life cycle impact assessment:** (LCIA) provides indicators and the basis for analyzing the potential contributions of the resource extractions and emissions in an inventory to a number of potential impacts.
- **Interpretation**: In this phase, the results of the analysis and all choices and assumptions made during the analysis are evaluated in terms of soundness and robustness. After this, overall conclusions are drawn.

This report follows the steps as defined above: it describes the study's goal and scope, the data and methodology used to model the products, and presents the results along with interpretations for the main analyses and a number of sensitivity analyses.

2. LCA Methodology

2.1 Goal

The goals of this study are i) to evaluate the environmental impact of producing and distributing the Beyond Burger 4.0 product for purposes of identifying hotspots (inputs or activities driving environmental impact) and directing continued improvement in environmental performance, and ii) to compare the environmental performance of the Beyond Burger 4.0 against a beef patty represented by U.S. national-average beef production, for purposes of making comparative claims. This evaluation is limited to a subset of environmental impact categories – global warming, fossil resource scarcity, land use, and water consumption – which were selected based on their relevance to food product comparisons and consistency with previous Beyond Burger LCAs. As such, all findings and comparative assertions are constrained to these indicators.

While references to the previous Beyond Burger 3.0 LCA are made, the goal of this study is not to track progress in environmental performance between Beyond Burger versions 3.0 and 4.0. Instead, this study is intended to update environmental performance data to reflect Beyond Burger's re-formulation and its evolved supply chain practices.

The intended audiences for this report are internal stakeholders at Beyond Meat and external customers and consumers. Results from this study are intended to be used in comparative assertions to be disclosed to the public.

2.2 Scope of study

The scope of the study generally follows that of the 2023 Beyond Burger 3.0 LCA (Heller and Salim, 2023)[1]. This section outlines the assessed product systems, the product function(s), functional unit, system boundary, and representative coverage.

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[1] The 2018 Original Beyond Burger 1.0 report is publicly available at: https://css.umich.edu/sites/default/files/publication/CSS18-10.pdf
The 2023 Beyond Burger 3.0 LCA report is available at: https://investors.beyondmeat.com/static-files/758cf494-d46d-441c-8e96-86ddb57fbed4

2.2.1 Product System

This is a cradle-to-distribution attributional LCA study of a plant-based protein burger with production located in North America. Comparisons are made with a beef patty produced in the U.S.

- The Beyond Burger is a plant-based patty with a protein blend that comes from yellow peas, red lentils, faba beans and brown rice, and is designed to look, cook and taste like fresh ground beef. While Beyond Meat markets beef analogue products in different formats, this LCA focuses on the Beyond Burger 4.0 offered through retail sales as two quarter pound (4 oz.) patties packaged in a sealed tray. The product system is defined and informed through direct communications with the product developer and manufacturer, Beyond Meat.
- The U.S. beef industry is complex and multi-faceted. Here, we rely on a recently published LCA study of industry-average beef production in the U.S. (Putman, Rotz and Thoma, 2023) in order to quantify impacts of a beef burger patty. One of the study's authors provided additional data through direct communication with Blonk, which was not included in the published journal article. See Section 3.3 for details on the study used to assess the environmental impact of beef production and the adjustments necessary to align it with this study's boundary conditions.

2.2.2 Product Functions and Functional Unit

Establishing the function of food products, and in turn, the functional unit, is difficult as food products supply a variety of functions (Schau and Fet, 2008). Supplying human nutrition can be considered the primary function of food, but nutrition is multi-dimensional and quite complex, and not easily reduced to a straightforward quantifiable parameter. Foods also provide additional non-nutritional functions including pleasure, emotional and psychological value, and cultural identity. While important, these additional functions are equally challenging to quantify. In the case of the Beyond Burger 4.0, as its flavor and texture profiles are designed to mimic beef, it is reasonable to assume qualitatively that the two products provide similar non-nutritional functions.

One serving size of Beyond Burger 4.0 – a quarter pound (¼ lb.) plant-based patty – delivers an equivalent amount of protein as a ¼ lb. 80/20 beef patty (80% lean meat, 20% fat)[2], the most commonly sold animal-based beef patty found in retail[3] (Table 1). Note that while 80/20 ground beef is assumed in the nutritional comparison in Table 1, the ratio of lean meat to fat does not influence the LCA results, as all edible beef, regardless of cut/quality, has the same footprint (as recommended by international guidelines (FAO LEAP, 2016)). As in the previous Beyond Burger LCAs (Heller and Keoleian, 2018; Heller and Salim, 2023), the functional unit for this study is defined as **one 4 oz. (¼ lb., 0.113 kg) uncooked patty delivered to retail distribution outlets**.

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[2] Beef nutritional data from USDA FoodData Central (https://fdc.nal.usda.gov/) "Beef, ground, 80% lean meat / 20% fat, raw", Foundational Foods database; except saturated fat which is from the SR Legacy Foods database.

[3] https://www.beefitswhatsfordinner.com/retail/sales-data-shopper-insights/ground-beef-at-retail-and-foodservice

Table 1. Nutritional comparison of Beyond Burger 4.0 and 80/20 beef patty[2]

	4 oz. Beyond Burger 4.0 patty[4]	4 oz. 80/20 beef patty[2]
Protein (g)	21	20
Iron (mg)	4	2.2
Saturated fat (g)	2	9
Cholesterol (mg)	0	77
Total fat (g)	14	22
Calories	230	280

2.2.3 System Boundaries

Figure 2 provides a graphical representation of the system boundaries considered in this study. The study represents a cradle-to-distribution assessment of the Beyond Burger 4.0 product chain. As such, the study will exclude activities at the retail and consumer level. This cradle-to-distribution boundary scope was chosen primarily because, especially given the uncertainties present in generic modeling of these downstream stages, retail and consumer activities are considered to be equivalent between the Beyond Burger 4.0 and beef product systems. Further, the "cradle-to-distribution" boundary also corresponds with the supply chain controlled by Beyond Meat. Table 2 describes the items included and excluded from system boundaries. The system boundary for the beef patty comparison (Putman, Rotz and Thoma, 2023) is provided in Section 3.3.

Note that packaging end-of-life disposal, as implemented in the initial LCA, made negligible contributions across all impact categories. Informing decisions about packaging options is *not* a goal of the current study, and it is expected that there will be little to no difference in packaging end-of-life impacts between Beyond Burger 4.0 and the beef comparison. Packaging end-of-life has therefore been excluded from the scope in this update. Capital goods and infrastructure are excluded in accordance with EC Product Environmental Footprint guidelines (Zampori and Pant, 2019), as previous LCAs have consistently shown their impact to be negligible when amortized over their expected lifetimes.

[4] https://www.beyondmeat.com/en-US/products/the-beyond-burger

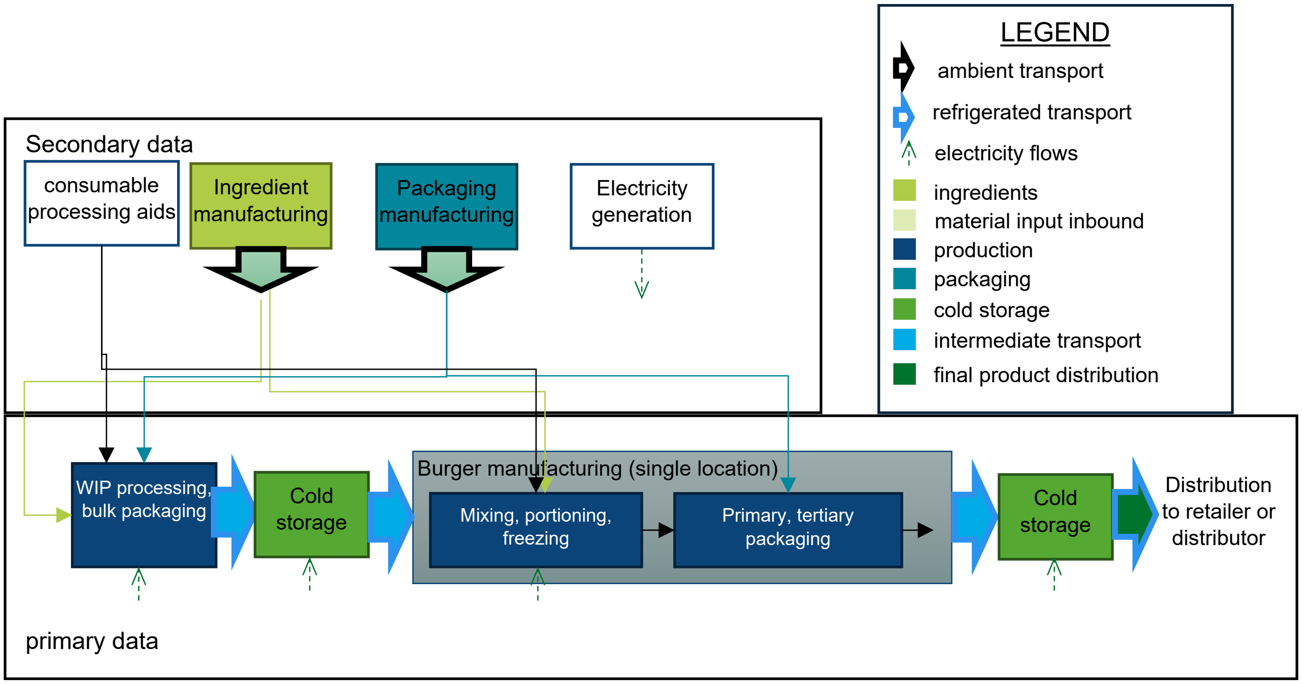

Figure 2. Life cycle stages included in the cradle-to-distribution system boundary of the Beyond Burger 4.0 product. WIP (work in progress) represents intermediary product components. Note that color designations correspond with contribution groupings used in results presentation.

For the production time window reflected in this study, all WIP processing occurs in Columbia, MO (COMO) whereas burger manufacturing occurs in Devault, PA (DEPA). WIP cold storage is in Carthage, MO and Leesport, PA, whereas final product cold storage occurs at Leesport, PA, Vernon, CA and Dallas, TX.

Table 2. Description of items included and excluded from system boundary of the Beyond Burger 4.0 product.

included	***excluded***
• Raw material supply, including ingredients, primary and tertiary packaging	• Retail and consumer stages
• Production and packaging operations	• Packaging disposal
• Facility-level energy use (including lighting and other overhead uses)	• Capital goods and infrastructure
• Facility-level water use	• Employee travel
• Inbound transport of ingredients and packaging	• Additional production facility overhead such as forklift operation
• Cold storage of intermediaries and final product	• Food waste disposal
• Refrigerated transport of intermediaries and final product	
• Losses of product and packaging at manufacturing level	• Losses of final packaged product (inventory shrink)

2.2.4 Time coverage

Data collection targeted the production window of January 1 through December 31, 2024. Ingredients, suppliers, facility energy demands, and intermediary and final product distribution transport are representative of this timeframe.

The beef patty comparison is based on a comprehensive industry study (Putman, Rotz and Thoma, 2023) that is representative of beef produced and consumed in the U.S. circa 2017. As beef production is a very mature industry in the U.S., there is no reason to expect notable changes in environmental impact over the seven-year difference in time coverage between the Beyond Burger 4.0 data collection period and the beef production data underlying the comparative study.

2.2.5 Technology coverage

The study represents Beyond Meat's U.S. production of the Beyond Burger 4.0, specifically the retail-packaged version in 2-patty trays (SKU 1B01-004).

The beef comparison represents industry-average beef production in U.S., based on 160 archetypical cattle production systems across all 50 states, and includes contributions to beef supply from dairy operations (both culled animals and excess calves fed to market weight) reflective of market practices in the U.S. See Section 3.3 and the original published study (Putman, Rotz and Thoma, 2023) for further detail.

2.2.6 Geographical coverage

The study represents Beyond Burger 4.0 production in the U.S., using electricity grid data specific to the production location. Where available, ingredient production reflects its place of origin, with transportation included to Beyond Meat production facilities.

The beef comparison is representative of industry-average beef production in the U.S.

2.3 Allocation principles

Facility-level utility demands at the Columbia, MO (COMO) facility, where pea protein extrusion and dry blend manufacturing takes place, were allocated to specific SKUs based on production rates. Thus, this is in essence a mass allocation.

Energy required for cold storage was approximated by distributing annual electricity demand in 2024 at each of four cold storage facilities across maximum pallet capacity (see Section 3.1.5 for details). When choosing secondary data, economic allocation was consistently selected for Agri-footprint 6.3 processes. This means environmental impacts are distributed among co-products in agricultural cultivation and ingredient processing based on their revenue ratio (price times yield). This is aligned with the recommendations from the European Commission's Product Environmental Footprint (PEF) guidelines (Zampori and Pant, 2019). For processes from ecoinvent v3.6, the 'Cut-off Allocation' dataset was used. Since ecoinvent applies economic allocation across all dataset options, this choice primarily impacts end-of-life and recycling allocation –relevant to this study as recycled materials are used in packaging.

In the beef comparison study (Putman, Rotz and Thoma, 2023), modified ecoinvent processes were used for co-product feeds such as distiller's grains, maize gluten meal, soybean oil and soybean meal, and therefore also were based on economic allocation. Biophysical allocation was applied between milk and meat from dairy operations included in the beef study, which is in accordance with International Dairy Federation recommendations (IDF, 2022). This method is based on the known relationships between net energy for lactation and net energy for growth, with net energy for lactation (in MJ/kg) being multiplied by the mass of milk produced, and net energy for growth multiplied by the live weight of animals sold. Allocation between edible meat, hides and beef byproducts at the slaughterhouse was made on a generated-revenue (i.e., economic allocation) basis.

2.4 Cut-off criteria

All efforts have been made to be as inclusive as possible, and no cut-off criteria*, per se*, are defined for this study. Instead, we follow the EC PEF guidelines (Zampori and Pant, 2019) by using a proxy approach. For the processes within the system boundary, all available energy and material flow data have been included in the model. In cases where no matching life cycle inventories are available to represent a flow, proxy data have been applied based on conservative assumptions regarding environmental impacts. The choice of proxy data is documented in Section 3.2.3. The exception to this is the exclusion of capital goods in both the Beyond Burger 4.0 and beef production systems, which, as described in Section 2.2.3, have been excluded as they are known to be negligible in agriculture/food production systems.

2.5 Life Cycle Impact Assessment Methodology and Impact Categories

The impact categories chosen for this study follow those in the previous LCA and include: greenhouse gas emissions (carbon footprint), non-renewable energy use (fossil resource scarcity), water consumption and land use. The ReCiPe 2016 hierarchist midpoint impact assessment was chosen based on its common contemporary usage. The comparison beef LCA (Putman, Rotz, and Thoma 2023) also uses ReCiPe 2016, however, for carbon footprint, they chose to implement global warming potential characterization factors *without* climate-carbon feedback (IPCC 2013 100a). In the Beyond Burger 3.0 LCA, we demonstrated that excluding climate-carbon feedback made only a small change to the Beyond Burger footprint (0.6% reduction), which we consider negligible within the broader context of LCA estimates. Therefore, here we compare the ReCiPe indicator including climate-carbon feedback directly with the results from the beef LCA (Putman, Rotz, and Thoma 2023).

Note that the land use indicator in ReCiPe includes characterization factors for different land use types (e.g., differentiation between annual croplands and perennial grasslands). This is relevant in the current comparison because impacts from beef production (which utilizes extensive grass and rangelands in the US) would likely be higher if an unweighted assessment were used. In addition, while the ReCiPe method uses the terminology 'fossil resource scarcity', this is in essence an indicator of fossil energy use; the only characterization applied 'normalizes' fossil resources by the ratio between the energy content of the fossil resource and the energy content of crude oil, such that the unit for the indicator is kg oil equivalents (kg oil eq). The water consumption indicator in ReCiPe (as implemented in SimaPro) is essentially a life cycle inventory, tabulating the balance of water withdrawals (characterization of +1) and water emissions or returns (characterization of -1).

Life cycle impact assessment results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.

2.6 Data quality rating

Defining statistical uncertainty for individual input and output data points requires a level of information that simply was not available in this study. Instead, SimaPro's pedigree uncertainty calculator was used to qualitatively evaluate the data quality of primary data. This calculator computes a combined uncertainty value based on the rating for each of the four data quality criteria (see Table 3 below). The pedigree uncertainty calculator in SimaPro is used to calculate the SD^2 (square of the geometric standard deviation, assuming lognormal distribution) for each data point, which is used for the uncertainty analysis. Qualitative evaluation of data quality is a largely subjective process based on expert judgment of the study practitioner.

Table 3 detailed data quality ranking, based on SimaPro's Pedigree uncertainty calculator

	1 (Excellent)	2 (Very good)	3 (Good)	4 (Fair)	5 (Poor)
Precision	Verified based on measurements	Non-verified measurements/ verified assumptions	Non-verified data based on qualified estimate	Qualified estimate	Non-qualified estimate
Temporal	<3 years	<6 years	<10 years	<15 years	>15 years
Geographical	From area under study	Larger area in which area under study is included	Area with similar production conditions	Area with slightly similar production conditions	Unknown/distinctly different area
Technological	Data from processes under study	Data from processes under study, but different enterprise	Data from processes under study, but different technology	Data on related processes	Data on related processes from different technology

2.7 Type and format of the report

In accordance with the ISO requirements (ISO, 2006), the results, data, methods, assumptions and limitations from this study are presented in a transparent manner and in sufficient detail to convey the complexities, limitations, and trade-offs inherent in the LCA to the reader. This allows the results to be interpreted and used in a manner consistent with the goals of the study.

2.8 Software and databases

The LCA model was created using the SimaPro 9.6.0.1 software system, developed by PRé Sustainability. LCI databases accompanying SimaPro, including ecoinvent 3.10 (Ecoinvent, 2024) and Agri-footprint 6.3, were utilized for background materials and processes in the model. When not available in these databases, some data on production of lesser ingredients were taken from an expanded beta version of Agri-footprint 6.3, which contains additional datasets modelled in a consistent way but have not been intensively reviewed as in the official database, as well as the Blonk Food Database (Blonk Sustainability Tools, 2023), which provides cradle-to-processing-gate models for various food items.

2.9 Critical review

The ISO 14040/14044 standards require a critical review by a panel of at least three independent experts when the study results are intended to support comparative assertions that will be disclosed to the public. The primary goals of a critical review are to provide an independent evaluation of the LCA study and to provide input on how to improve the quality and transparency of the study. The benefits of employing a critical review are to ensure that:

- 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.

If applicable, the critical review panel can comment on suggested priorities for potential improvements.

For this study, the critical review panel consisted of

- Prof. Roland Geyer, University of California, Santa Barbara (chair)
- Prof. Jasmina Burek, University of Massachusetts, Lowell

- Prof. Alissa Kendall, University of California, Davis

The review was performed according to section 6.3 of ISO 14044 on comparative assertions to be disclosed to the public. A draft copy of this report was made available to the panel. Note that the same reviewers were involved in reviewing the Beyond Burger 3.0 LCA. The panel provided feedback on the methodology, assumptions, and interpretation. The draft report was subsequently revised, and a final copy submitted to the review panel along with responses to comments.

The Critical Review Statement can be found in Appendix II. The Critical Review Report containing the comments and recommendations of the independent experts as well as the practitioner's responses is also available in the Appendix.

3. Life Cycle Inventory Analysis

3.1 Beyond Burger 4.0 production system

Key foreground data were provided by Beyond Meat, including information on product formulation, manufacturing, process energy use, packaging, storage and distribution. The following sections describe both the bases for foreground (primary) data, as well as the interconnected background (secondary) data within the LCA model. As electricity and transport processes are relevant across all stages, these are presented first. Descriptions then follow the Beyond Burger 4.0 life cycle stages: ingredient production (Section 3.1.3), manufacturing and packaging (3.1.4), cold storage (3.1.5), and distribution (3.1.6). Note that specifics of life cycle inventories have been withheld from this public-facing document in order to protect proprietary information; however, these specifics were provided to the review panel (under non-disclosure agreements) as a supplemental Appendix.

3.1.1 Electricity grids

For electricity consumption by facilities in the Beyond Burger 4.0 production chain, electricity grid mixes at the North American Electric Reliability Corporation (NERC) region-level available in ecoinevent 3.10 were used. The shares of generating technologies/fuels within these datasets are based on 2021 statistics from U.S. EPA eGRID[5] and grid losses are based on 2020 data from the International Energy Agency[6].

The following datasets were used for the different locations within the Beyond Burger 4.0 production chain:

- Columbia & Carthage, MO: Electricity, low voltage {US-SERC}| market for electricity, low voltage | Cut-off
- Devault & Malvern, PA: Electricity, low voltage {US-RFC}| market for electricity, low voltage | Cut-off
- Vernon, CA: Electricity, low voltage {US-WECC}| market for electricity, low voltage | Cut-off
- Dallas, TX: Electricity, low voltage {US-TRE}| market for electricity, low voltage | Cut-off

3.1.2 Transport

Inbound transport was included for the 10 ingredients with the largest mass contribution, representing 94% of ingredients in total (excluding water). Transport distance was estimated as best as possible based on sourcing information provided by Beyond Meat: sea transport distances were determined using

[5] https://www.epa.gov/egrid
[6] https://www.iea.org/data-and-statistics/data-product/world-energy-statistics-and-balances

www.ecotransit.org, whereas land-based distances were from Google Maps. Inbound transport was modeled with the following processes:

- [ecoinvent 3.10] Transport, freight, lorry 16-32 metric ton, euro5 {RoW}| market for transport, freight, lorry 16-32 metric ton, EURO5 | Cut-off
- [Agri-footprint 6.3] Transport, sea ship, 80000 DWT, 80%LF, middle, default/GLO Economic

The transport of 'work in progress' (WIP) components to cold storage and then to other manufacturing facilities, as well as the transport of finished product to cold storage and final distribution, is carried out using freight trucks with refrigeration units operating at frozen temperatures. These transport legs were modeled using the ecoinvent process as above, with modifications to account for 20% additional energy consumption and emissions, as well as refrigerant inputs (17.125 mg R134a per tkm) and associated refrigerant emissions. This approach mimics ecoinvent's methodology for refrigerated freight, though refrigerated freight processes in ecoinvent are only available for smaller truck sizes.

3.1.3 Ingredients

Beyond Burger 4.0 ingredient quantities were based on information supplied by Beyond Meat. Modeling approaches for each ingredient are provided in Table 5, where ingredients are named as on the product label. Formulation composition was provided but redacted here for proprietary reasons. Additional details for prominent ingredients follow.

Table 4. Beyond Burger 4.0 ingredients and LCA modeling approach (database key below table).

ingredient	Data approach ([xxx] = source database)	Production region based on primary data (✓) or proxy(X)
Water	[ecoinvent] Tap water {GLO}| market group for | Cut-off	✓
Yellow Pea Protein	[AFP6] pea protein isolate process from AFP (economic allocation), modified so that dry pea sourcing is from Canada (see Section 3.1.3.1)	✓
Red lentil protein	[AFP6 expanded beta] Lentils, dried, market mix at regional storage/Canada economic, modified so that market mix is 50% Canada and 50% US. [AFP6] Pea concentrate used as a proxy for processing	✓
Avocado oil	[AFP6 expanded beta] Avocados, at orchard, using country-specific data where possible; processing proxies: [AFP6] Crude palm kernel oil, at processing and [AFP6] Refined palm kernel oil, at processing (see Section 3.1.3.2)	✓
Natural flavors[7]		
#1	Facility-level average impact data from manufacturer, as described in (Heller and Keoleian, 2018)	X
#2	LCA data from manufacturer (see Section 3.1.3.3)	X
#3	PROXY: average of 5 amino acids available in [AFP6]: L-lysine, DL-methionine, L-threonine, L-tryptophan, L-valine	X
#4	PROXY: [AFP6] MetAMINO®, 99% DL-Methionine, at Evonik plant {BE} Economic	X
#5, 6	LCA data from manufacturer (only climate change impact useable, see Section 3.1.3.3). Water use estimated through PROXY with natural flavor #1	X
#7, 8	PROXY: average of 5 amino acids available in [AFP6]: L-lysine, DL-methionine, L-threonine, L-tryptophan, L-valine	X

[7] Note that while the number of natural flavors included in the formulation has increased in Beyond Burger 4.0, the total quantity of natural flavors has decreased relative to the Beyond Burger 3.0 formulation.

Brown Rice Protein	LCA data from manufacturer (see Section 3.1.3.4)	✓
Methylcellulose	PROXY: [ecoinvent] Carboxymethyl cellulose, powder {GLO}| market for | Cut-off, S	X
Potato starch	[AFP6] Potato starch dried, at processing/DE Economic	✓
Pea starch	[AFP6 expanded beta] Pea starch-concentrate, at processing/DE Economic & [AFP expanded beta] Pea starch-concentrate, at processing/FR Economic	✓
Faba bean protein	[ecoinvent] Fava bean {CA-MB} | fava bean production | Cut-off, S , Uses pea concentrate for processing proxy	✓
Salt (calcium chloride)	[ecoinvent] Calcium chloride {RER}| market for calcium chloride | Cut-off, S	X
Potassium chloride	[AFP6] Potassium chloride (NPK 0-0-60), at plant/RER Economic	X
Apple extract	[Blonk Food DB] Apple concentrate, at processing/NL Economic	X
Vinegar	[Blonk Food DB] Vinegar (wine), at processing/NL Economic	X
Beet juice color	Modeled as described in (Heller and Keoleian, 2018) [AFP5] carrots and turnips, at farm/NL Economic used as proxy for red beet, [ecoinvent] Evaporation of milk {CA-QC}|milk evaporation | Cut-off, S used to represent water removal to make concentrated juice. 10kg beets required for 1 kg juice extract; concentration requires removal of 7.8 kg water.	X
Pomegranate concentrate	Supplier indicates that this product is extracted from pomegranate pulp after juicing; the juice is allocated all of the impacts of pomegranate cultivation; this is therefore considered an 'upcycled' waste product and allocated no impact. Further energy consumed in processing is considered negligible. Thus, this product (<1% of dry ingredient weight) is modeled as zero impact.	
Maltodextrin	[Blonk Food DB] Maltodextrin, at processing/NL, adapted maize sourcing and background data to make U.S. specific	✓
White pepper	PROXY [Blonk Food DB] Pepper (fresh), at processing/NL Economic	X
Potassium lactate	[ecoinvent] Lactic acid {GLO}| market for lactic acid | Cut-off, S and [ecoinvent] Potassium hydroxide {GLO}| market for potassium hydroxide | Cut-off, S	X
Pure Red Carrot	Same PROXY as beet juice color	X

Database key: [AFP6.3] = AgriFootprint 6.3 (Blonk Sustainability Tools, 2022)
[Blonk Food DB] = LCI database of food products consumed in the Netherlands (Blonk Sustainability Tools, 2023)
[ecoinvent] = ecoinvent 3.10 (Ecoinvent, 2024)

3.1.3.1 Yellow Pea protein

The primary ingredient and main protein source for the Beyond Burger 4.0 is a yellow pea protein isolate (PPI) which (along with other proteins) undergoes an extrusion process prior to mixing with other ingredients. One supplier of PPI provided (under confidentiality) an LCA of regional industry-average production during the Beyond Burger 3.0 LCA. Review of this study identified incompatibility in allocation methods to the internationally recognized approach taken in this study. In addition, the LCA was based on impact assessment methods found to be incompatible with methods used here. Instead, we use the indicative data for PPI production available in Agri-footprint.

Country-level datasets used for yellow pea cultivation were based on sourcing information provided by Beyond Meat. In Beyond Burger 3.0, a portion of the PPI was sourced from France and China. However, in Beyond Burger 4.0, all PPI is sourced from Canada. Pea cultivation processes and electricity grid are adjusted to reflect the country of origin, while the PPI manufacturing processes remain the same (Agri-footprint dataset) for both PPI sources.

Electricity, natural gas and consumable inputs used in the extrusion process at COMO were calculated by compiling facility-level utility invoices and allocating between the extrusion process and (other SKU) finished goods production occurring in the same facility. An estimated fixed monthly freezer electricity usage was isolated and distributed to all facility outputs based on production rates (mass allocation). Electricity intensity (kWh per pound) for the finished goods lines were estimated from months when these finished goods were the dominant outputs (with no extrusion occurring). These intensities were adjusted to reflect demonstrated efficiency gains, multiplied by finished goods monthly production, and subtracted from the monthly facility-level electricity consumption. The remaining monthly electricity use was divided by woven protein (extrusion) production and averaged across 10 months of production to result in an electricity intensity per pound of woven protein slightly higher than what would result from a straight mass-based allocation. Utility-level natural gas and water use were distributed on a mass basis to all facility production, as was liquid nitrogen, but with adjustments based on engineering estimates of use intensity. Specific bill of material data was used to reflect actual yield of woven protein (i.e., to estimate losses), which was then packaged (intermediate packaging included in LCA) and shipped to one of two cold storage facilities in Leesport, PA (69% of volume) and Carthage, MO (31%). Units of pre-treated protein were in cold storage for an average of 37.8 and 53.9 days for Leesport and Carthage, respectively, before being shipped to DEPA for burger manufacturing (cold storage energy use estimates were as described in Section 3.2.5).

3.1.3.2 Avocado oil

The primary reformulation between Beyond Burger 3.0 and Beyond Burger 4.0 is a change in the fat source, replacing a blend of canola, sunflower, and coconut oil with cold-pressed, refined avocado oil. Beyond Meat received from their supplier an estimate of the mix of countries where the ripe fruit is harvested and pressed, as well as where the crude oil is refined. Primary data were unavailable; avocado production processes were therefore sourced from the expanded beta version Agri-footprint 6.3. As modeled, crude avocado oil (as well as avocado cultivation) sourcing was as follows: 87.4% Spain, 10.6% Kenya, 2.0% Chile (as a proxy for Peru). A palm oil fruit crushing process from AFP6 was used as the starting point for a crude oil pressing process; oil yields were set at 14.1% (i.e., 14.1 kg oil per 100 kg whole avocado) based on the average of reported yields from literature (Costagli and Betti, 2015). As usage of co-product pulp is uncertain, impacts were allocated 100% to oil. Energy and water demands remained as in the AFP palm oil crushing process. Oil refining, which takes place in Spain, was modeled using the palm oil refining process from AFP6 as proxy (with no modifications to flow quantities). Transportation was included for all legs of the avocado supply chain: crude oil from country of origin to Spain, refined oil from Spain to manufacturing facilities in U.S.

3.1.3.3 Primary data for natural flavors

Impact results from an LCA study on the production of natural flavor #2 from Beyond Meat's supplier was provided under confidentiality. Their LCA study was conducted in accordance with ISO 14040 and 14044 and spanned the year prior to this study, i.e. January to December 2023. Impact assessment results based on the ReCiPe midpoint method were provided for four impact categories, namely global warming (kg CO_2 eq), fossil resource scarcity (kg oil eq), land use (m^2a crop eq), and water consumption (m^3).

Environmental impact summary information was also provided by the supplier for natural flavors #5 and #6. In this case, the impact assessment method utilized was not compatible with the current study; however, the carbon footprint method was consistent and this information could be utilized. Water use for manufacture of these natural flavors was proxied based on data as received and used for natural flavor #1 as part of the Beyond Burger LCA conducted in 2018.

3.1.3.4 Brown rice protein

An LCA study on the production of rice protein from Beyond Meat's supplier was provided under confidentiality for the Beyond Burger 3.0 LCA. The study was reviewed and determined to be of sufficient quality. This study used an Agri-footprint 2.0 process for "broken rice" (a by-product of milling) produced in

China to represent upstream cultivation. Impact assessment results based on the ReCiPe midpoint method and a mass allocation approach were used as reported to represent production of rice protein. Although mass allocation is inconsistent with the allocation methods used in this study, the rice protein report included a sensitivity assessment using economic allocation, which showed lower global warming impacts compared to mass allocation. However, results from this economic allocation sensitivity did not cover all environmental indicators assessed in this study. Thus, mass allocation results were used as a conservative estimate of the brown rice protein final product's impact.

3.1.4 Burger manufacturing and packaging

Two additional WIP mixtures were also assembled at the COMO facilities, and followed the same cold storage and intermediate shipping as described above for yellow pea protein, but with different cold storage durations. WF87 was stored for an average of 18.2 and 30.8 days at Leesport and Carthage, respectively, whereas WF84 spent 21.7 and 35 days at Leesport and Carthage, respectively. Beyond Meat provided electricity and water demand data per pound processed for WIP assembly/mixing . The remaining burger ingredients and packaging materials were assumed to be delivered directly to the DEPA facility.

For the DEPA facility, facility-level electricity use from January 1 through December 31, 2024 was summed and divided by total facility production, then allocated to Beyond Burger 4.0 production based on the portion of total facility production, with adjustments made based on engineering estimates of power demand per processing line (estimates provided by Beyond Meat). This average electricity use per pound of Beyond Burger 4.0 produced was assumed to cover all burger manufacturing energy demands including: on-site cold storage, ingredient mixing/blending, burger manufacturing lines including portioning, patty forming and packaging, and overhead usage for lighting, air handling and climate control. Similarly, liquid nitrogen and liquid carbon dioxide consumed during burger manufacturing was also derived from annual facility-level use, distributed across active production lines that utilized these inputs. Bill of Material records were used to account for losses of ingredients and packaging materials.

Primary packaging trays, each containing two ¼ pound patties, were assembled into tertiary packaging cases at a rate of 8 trays per case. These cases were then stacked 96 per pallet. Details on packaging materials are provided in Section 3.1.4.1).

Finished product was then shipped frozen to cold storage warehouses in multiple locations, with a weighted (by number of cases shipped) average shipping distance from transfer order data over the study time period. An average cold storage inventory holding period of 42 days was used. Final product was then distributed frozen to distributors or retailers, with distances averaged as described in Section 3.1.6.

3.1.4.1 Packaging materials

Information on packaging weights per unit and material composition was provided by Beyond Meat. Table 6 summarizes the packaging material weights and background data used to represent each component.

Table 5. Packaging materials and modeling approaches

Packaging component	Weight	Data approach (all from ecoinvent database)
50% post-consumer recycled PET tray	24.6g/tray	Polyethylene terephthalate, granulate, amorphous, recycled {US}| market for polyethylene terephthalate, granulate, amorphous, recycled | Cut-off (remainder modeled as virgin) Polyethylene terephthalate, granulate, amorphous {GLO}| market for | Cut-off Thermoforming of plastic sheets {GLO}| market for | Cut-off
PE lid film (assumed 50% LDPE, 50% LLDPE)	0.86g/tray	Polyethylene, low density, granulate {GLO}| market for | Cut-off Polyethylene, linear low density, granulate {GLO}| market for | Cut-off Extrusion, plastic film {GLO}| market for | Cut-off
Patty paper	2 sheets per tray at 0.5g ea.	90% paper: Tissue paper {GLO}| market for | Cut-off 10% wax Paraffin {GLO}| market for | Cut-off
Cardboard sleeve	18.1g / tray; 0.33g printing ink	Folding boxboard/chipboard {RoW}| chipboard production, white lined | Cut-off Printing ink, offset, without solvent, in 47.5% solution state {RoW}| market for printing ink, offset, without solvent, in 47.5% solution state | Cut-off
Corrugated case	213.2g/case (8 trays)	Corrugated board box {RoW}| market for corrugated board box | Cut-off
Wood pallet	1 per 96 cases	EUR-flat pallet {GLO}| market for | Cut-off
Pallet pad	1.2 lb.(0.54kg) per pallet	Corrugated board box {RoW}| market for corrugated board box | Cut-off
Pallet wrap	1 lb.(0.45kg) per pallet	Polyethylene, linear low density, granulate {GLO}| market for | Cut-off Extrusion, plastic film {GLO}| market for | Cut-off

3.1.5 Cold storage energy demand

Annual (2024) electricity consumption and maximum pallet capacity was provided by the cold storage operators for the four locations utilized in the Beyond Burger 4.0 supply chain. These data were used to provide an energy intensity per pallet per day for each location, as shown in Table 7.

Table 6. Cold storage energy intensity for each cold storage warehousing location utilized in the Beyond Burger 4.0 supply chain.

location	Energy intensity (kWh/pallet/day)
Carthage, MO	0.95
Leesport, PA	0.50
Vernon, CA	0.46
Dallas, TX	1.30

3.1.6 Distribution

Sales order data for the January 1 through December 31, 2024 time period were used to calculate a weighted average (weighted by number of cases shipped) distribution distance from cold storage to final Beyond Meat customer (typically a distributor or retailer). Shipping quantities and distances were provided by Beyond Meat. The weighted average distance was 654 miles.

3.1.7 Comparison with previous LCA modeling

While changes have been made to ingredient formulation and sourcing from Beyond Burger 3.0 to Beyond Burger 4.0, a similar approach was taken for data collection, primary data availability, background databases and modeling approaches. Another key difference from Beyond Burger 3.0 is that Beyond Burger 4.0 is produced in Beyond Meat's own manufacturing facility, rather than using co-manufacturers. This transition allows for the collection of higher-quality data. Differences in data quality mean that caution should be exercised in making comparisons between Beyond Burger 3.0 and Beyond Burger 4.0 LCAs. The most relevant differences are summarized in Table 8.

Table 7. Comparisons between the Beyond Burger 3.0 and the Beyond Burger 4.0 LCA modeling approaches

Data	Beyond Burger 3.0 LCA approach	Beyond Burger 4.0 LCA approach
Manufacturing energy demand	Facility-level energy use over 6 months, divided by product output or allocated based on product flow rates (mass allocation). Assume energy estimates apply to other facilities	Facility-level energy use over 12 months, divided by product output or allocated based on product flow rates (mass allocation), with adjustments based on production line power demand.
Product losses	Based on Bill of Material calculations: 4.2%	Based on Bill of Material calculations: 7.5%
Cold storage energy demand	Estimated using total energy use from one warehouse, divided over pallet positions (40 kWh m^{-3} yr^{-1}, assuming pallet volume of 5.95m^3)	Based on energy intensity estimates at each cold storage warehousing location utilized (see Section 3.1.5)

3.2 U.S. beef production: baseline for comparison

U.S. beef production has been examined extensively in (primarily) cradle-to-gate LCAs (for example, Capper 2011; Lupo et al. 2013; Pelletier, Pirog, and Rasmussen 2010; Rotz et al. 2013; Stackhouse-Lawson et al. 2012; Webb et al. 2020; Asem-Hiablie et al. 2019). A recent study expands on these efforts to extend the LCA to the full life cycle and include a more comprehensive set of environmental impact categories (Putman, Rotz and Thoma, 2023). Sponsored by The Beef Checkoff Program (a U.S. national marketing and research program overseen by the Cattlemen's Beef Board (CBB), with oversight by the U.S. Department of Agriculture (USDA)), this recent assessment also serves as a current benchmark for the environmental sustainability profile of the production and consumption of beef in the U.S.

The benchmark U.S. beef LCA uses a series of regionalized archetypical simulations of cattle operations along with primary data for post-farm gate activities including processing, packaging, distribution (as well as retail, consumption and disposal). This effort is intended to capture the variation in production practices across supply chain stages throughout the U.S. such that in aggregate, the assessment provides a robust, nationally representative benchmark for the U.S. beef industry. Figure 3 shows a system boundary diagram from the Putman *et al.* study. Included in the assessment are the roughly 24% of beef supply that are culled from dairy operations, with biophysical allocation applied between milk and culled animals.

Impact assessment results published in Putman *et al.* were characterized using ReCiPe 2016 Midpoint (H), and therefore directly compatible with this study (with the exception that carbon climate feedback contributions were removed from global warming characterization factors). Note that land use change contributions to global warming were not accounted for in the Putman *et al.* study; as agricultural land use has been reasonably stable in the U.S. over the past 20 years (the time window for land use change assessments) and it is assumed that all feed is produced within the US, this is not anticipated to be a significant omission. The full life cycle results are summarized per kg of beef consumed in Table 9, including contributions from the different life cycle stages. However, adaptations were required in order to match system boundaries in the current study, as described in the following section.

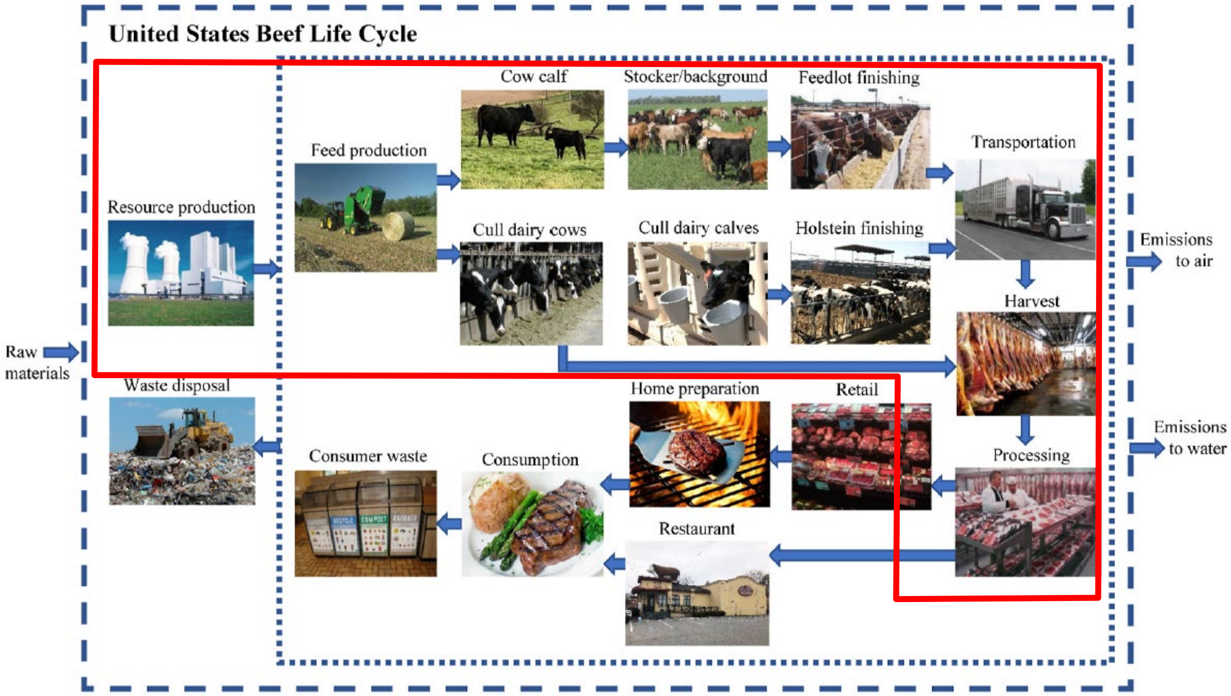

Figure 3. U.S. beef life cycle system boundary diagram (Putman, Rotz and Thoma, 2023). The red line indicates the portion of the life cycle (cradle to distribution) utilized in the comparisons with Beyond Burger 3.0 and Beyond Burger 4.0.

Table 8. Life cycle impact assessment results for one kg beef produced, cooked, and consumed in the U.S. (Putman, Rotz and Thoma, 2023).

indicator	Unit	TOTAL	production	harvesting	processing	retail	home	Full service restaurant	Limited-service restaurant
per kg beef produced, cooked and consumed in the U.S.									
global warming	kg CO_2 eq	42.7	33.5	0.95	0.50	1.34	1.38	3.24	1.79
fossil resource scarcity	kg oil eq	3.89	1.4	0.27	0.15	0.33	0.34	0.91	0.48
land use	m^2a crop eq	196	195	0.06	0.01	0.02	0.58	0.04	0.02
water consumption	liters	2479	2422	15.9	2.09	5.75	5.77	19.86	7.82

3.2.1 Adaptations to match system boundaries

The Putman *et al.* reporting includes the life cycle stages of retailing as well as storage and preparation at home and in restaurants. Notable shrinkage at retail and food waste at consumption were included in these assessments, which have a multiplicative effect on upstream production and processing. For the Beyond Burger 3.0 LCA, we received through personal communication with Greg Thoma the life cycle impact assessment results for *1 kg ground beef at processing, including packaging,* which excludes contributions from downstream stages as well as the production impacts of retail- and consumer-level losses. Note that the Putman *et al.* study distinguishes between beef cuts and ground beef through the stages of processing, packaging, and preparation/consumption; however, beef production and harvest are identical for beef cuts and ground beef. Therefore, the data received from Thoma includes national average beef production (including contributions from dairy operations), transportation and harvest, as well as processing and packaging for ground beef.

Since distribution impacts specific to the ground beef supply chain were not available, we assumed the same distribution impacts as with the Beyond Burger 4.0 life cycle. These results are summarized in Table 10.

Table 9. Impact assessment results for ground beef (Greg Thoma, personal communication). Note that distribution contributions are assumed to be the same as for Beyond Burger 4.0.

		per kg	per 1/4 lb. patty	distribution	total
global warming	kg CO_2 eq	36.8	4.18	0.04	4.22
fossil resource scarcity	kg oil eq	1.5	0.17	0.01	0.18
land use	m^2a crop eq	154.3	17.51	0.00	17.51
water consumption	liters	1930.7	219.14	0.05	219.19

4. Life Cycle Impact Assessment Results

4.1 Beyond Burger 4.0

4.1.1 ReCiPe impact assessment results

The environmental impact of the Beyond Burger 4.0 life cycle, based on the ReCiPe 2016 impact assessment method, are summarized in Table 11. Note that global warming impacts associated with land use change are presented separately here, in line with reporting guidelines. Figure 4 offers a visual representation of the distribution of impacts across life cycle stages.

Table 10. Cradle-to-distribution LCA results for ¼ lb. **Beyond Burger 4.0**, based on the ReCiPe 2016 impact assessment method.

indicator	Unit (per ¼ lb. patty)	TOTAL	ingredients	ingredient inbound transport	production	packaging	cold storage	intermediate transport	final product distribution
global warming	kg CO_2 eq	0.51	0.18	0.01	0.12	0.09	0.01	0.07	0.04
global warming (land use change)	kg CO_2 eq	0.08	0.08	0.00	0.00	0.00	0.00	0.00	0.00
fossil resource scarcity	kg oil eq	0.13	0.03	0.00	0.03	0.03	0.003	0.02	0.01
land use	m^2a crop eq	0.54	0.49	0.00	0.00	0.04	0.00	0.01	0.004
water consumption	liters	16.88	12.72	0.02	3.22	0.71	0.06	0.09	0.05

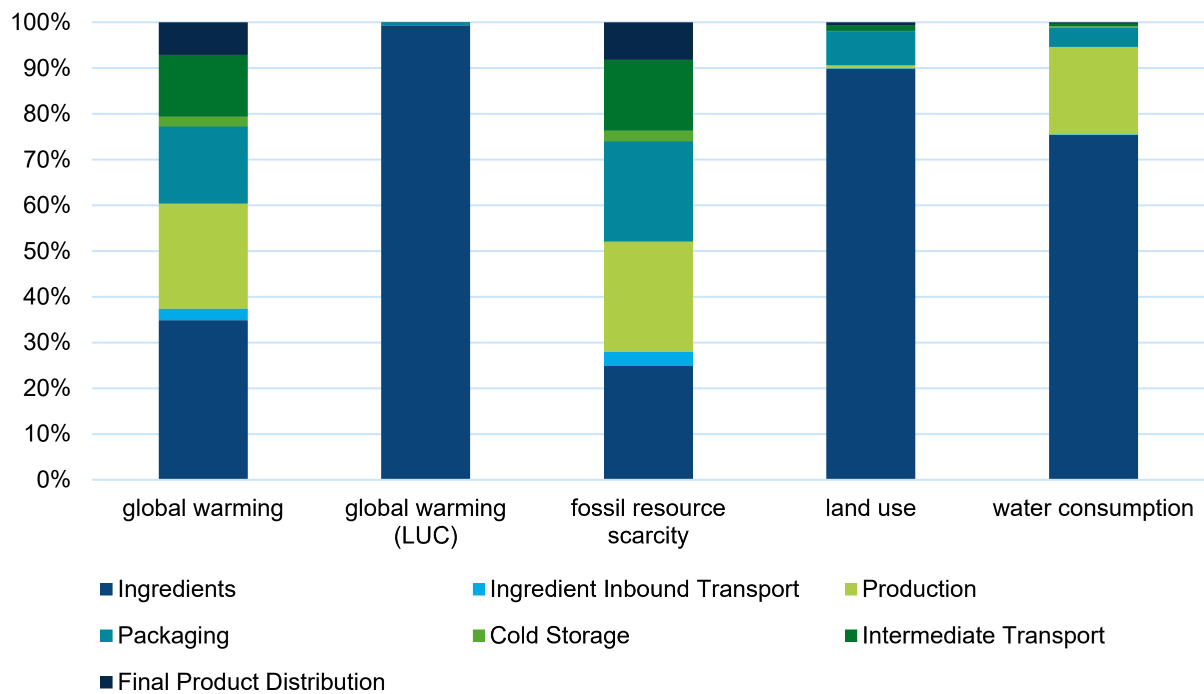

Figure 4. Distribution of impacts across life cycle stages for the Beyond Burger 4.0, using the ReCiPe LCIA method. LUC = land use change.

4.1.1.1 Global warming

The global warming (greenhouse gas emissions) associated with producing and delivering a ¼ pound Beyond Burger 4.0 are 0.51 kgCO_2eq/quarter lb. Beyond Burger 4.0, plus 0.08 kgCO_2eq/quarter lb. from land use change. This equates to 4.48 kg CO_2 eq per kg Beyond Burger 4.0 (+0.68 kg CO_2 eq per kg from land use change). Table 12 offers additional insight into the important contributors to global warming impact. Global warming due to land use change is attributable primarily to cultivation of peas and lentils in Canada.

Table 11. Percent contributions to Global Warming (excluding land use change) from stages and processes in the Beyond Burger 4.0 life cycle.

contributor		% contribution
ingredients	**34.9%**	
yellow pea protein		8.3%
avocado oil		7.7%
natural flavor #6		4.8%
rice protein		4.0%
natural flavor #2		3.6%
methylcellulose		1.7%
red lentil protein		1.6%
other		3.3%
ingredient inbound transport	**2.5%**	
production	**23.0%**	
pea protein extrusion		3.5%
burger manufacturing		18.6%
packaging	**16.9%**	
tray and lid film		8.2%
cardboard sleeve		3.0%
case		3.5%
other		2.2%
cold storage	**2.1%**	
intermediate cold storage		0.6%
final product cold storage		1.6%
refrigerated transport	**20.6%**	
intermediate transport		13.5%
final distribution		7.1%

4.1.1.2 Fossil resource scarcity (non-renewable energy use)

Fossil resource scarcity is an indicator of fossil energy use. As can be seen in Figure 4, the contributions of the different life cycle stages to fossil resource scarcity are very similar to that of global warming. Notable contributions to fossil resource use include ingredients (25%), production (24%), packaging (22%), intermediate transport (15%) and final distribution (8%). Among ingredients, pea protein is the highest contributor (8% of total), followed by avocado oil (3.9%), natural flavor #2 (3.3%), and rice protein (3.2%). Manufacture of the plastic tray and lid represents 12% of fossil energy use.

4.1.1.3 Land use

The land use indicator within ReCiPe primarily reflects cropping acreage, with characterizations for other land usages including urban, industrial, grasslands, etc. Within the Beyond Burger 4.0 life cycle, land use is dominated by ingredient production (90%) and packaging material production (7%). The top contributors to land use are shown in Table 13.

Table 12. Top contributors to Land use in the Beyond Burger 4.0 life cycle.

contributor	%
pea protein	55%
avocado oil	12%
faba bean concentrate	7%
red lentil protein	6%
pallet	4%
tertiary case	2%
cardboard sleeve	1%

4.1.1.4 Water consumption

The water consumption metric in ReCiPe reflects absolute water consumption (without characterization applied). For Beyond Burger 4.0, it is dominated by ingredient production (75%) with avocado oil contributing 53%, rice protein 8%, pea protein 4%, and apple extract 5%. About 4% of water consumption is used directly in the Beyond Burger 4.0 production process, either incorporated into the product or direct use in manufacturing facilities. The remainder of the water consumption associated with production is connected to electricity generation processes or production of liquified gases. Manufacture of packaging components represents 4% of water consumption, with the thermoformed tray being the largest contributor to this.

4.2 Comparisons with beef

Table 14 provides a direct comparison of the impacts attributable to a ¼ lb. Beyond Burger 4.0 with a ¼ lb. beef patty. Based on the results of this study, ingredient provision, production, packaging and distribution of the Beyond Burger 4.0 generates 88% less greenhouse gas emissions (86% if land use change emissions in the Beyond Burger 4.0 supply chain is included), and requires 28% less non-renewable energy use, 97% less land use, and 92% less water consumption.

Table 13. Comparison of cradle-to-distribution impacts of ¼ lb. Beyond Burger 4.0 and ¼ lb. average U.S. beef patty.

indicator	Unit (per ¼ lb. patty)	Beyond Burger 4.0	Beef patty	% reduction (beef→Beyond Burger 4.0)
global warming	kg CO_2 eq	0.51	4.22	88%
global warming (including land use change)	kg CO_2 eq	0.59		86%
fossil resource scarcity	kg oil eq	0.13	0.18	28%
land use	m^2a crop eq	0.54	17.52	97%
water consumption	liters	16.88	219.19	92%

5. Interpretation

5.1 Identification of relevant findings

The Beyond Burger 4.0 LCA demonstrates many relevant findings. Ingredient provision is an important contributor across all impact categories assessed, and ingredients are the dominant contributor to land use and water consumption. Yellow pea protein isolate is the most significant ingredient contributor, except for water consumption. Refrigerated transport – both of intermediate components and final distribution – contributes 13% of the Beyond Burger 4.0 global warming impact and 7% of non-renewable energy use.

When compared with a typical U.S. beef patty, the Beyond Burger 4.0 generates 88% less greenhouse gas emissions (86% if land use change emissions in the Beyond Burger 4.0 supply chain are included), and requires 28% less non-renewable energy use, 97% less land use, and 92% less water consumption. While greenhouse gas emissions and fossil resource use are often closely correlated in product life cycles when greenhouse gas emissions are dominated by CO_2 from the combustion of fossil fuels, the beef life cycle has notable contributions from biogenic methane and nitrous oxide. Non-fossil methane from enteric fermentation as well as manure management contributes more than 40% to the beef global warming impact, and nitrous oxide, primarily from field-level emissions during cultivation of feed crops, contributes more than 30% (Putman, Rotz and Thoma, 2023). These factors are the primary reasons why there is less difference in fossil resource scarcity than global warming between Beyond Burger 4.0 and the beef patty. In addition, the Beyond Burger 4.0 plastic packaging is derived from fossil resources, but this fossil carbon is embodied in the plastic (i.e., not released to the atmosphere as with combusted fossil fuels) so contributes less to global warming (note that while packaging end-of-life has not been included in this study, plastics are primarily landfilled or recycled in the US, again avoiding the carbon emissions associated with incineration.)

This study serves as an update to the previous Beyond Burger (v. 3.0) LCA findings, but improvements in data quality, in particular regarding energy and other 'consumed' inputs for burger manufacturing and supplier-provided data for natural flavors, introduce variation between the two LCAs. Therefore, comparisons with the previous LCA may offer valuable insights, but require careful interpretation and should not be construed simply as 'better' or 'worse' environmental performance.

5.2 Assumptions and limitations

The choice to compare the Beyond Burger 4.0 with beef patties on a weight-based functional unit assumes that the two products provide equivalent functions. As mentioned in Section 2.2.2, since the Beyond Burger 4.0 is designed to mimic the flavor and texture profiles of beef patties, it is reasonable to assume qualitatively that the two products provide similar non-nutritional functions. Meat and meat analogues are commonly considered as dietary protein sources, and this key nutritional component is identical in the two products (see Table 1). The Beyond Burger 4.0 supplies about 18% fewer calories per serving than the 80/20 U.S. beef patty, largely due to a lower fat content (36% less fat than 80/20 beef patty), which would be considered a nutritional benefit to many Americans. In addition, saturated fat and cholesterol, which are linked to heart disease, are notably lower in the Beyond Burger 4.0 compared to the beef patty. While numerous nutrient profiling schemes exist that attempt to aggregate nutritional criteria into a composite index, there is little consensus as to the preferred approach or their accuracy (Cooper, Pelly and Lowe, 2016; Santos *et al.*, 2021), and certainly no widely accepted method exists for incorporating such nutrient profiling into LCA (McAuliffe, Takahashi and Lee, 2020). Given the uncertainty introduced by such schemes, therefore, we consider comparison on a weight basis to be a conservative assumption with respect to the comparative assertions in environmental performance made here. In other words, incorporating a more complex nutrient profiling functional unit would most likely further favor the Beyond Burger 4.0 over the beef patty.

The boundary conditions employed in this study follow the products up to the point of delivery to retail distribution centers (or wholesale distributors), and therefore do not include retail and at-home use stages. In addition, the contribution from food waste at the retail and consumer level, as well as potential waste through distribution, are not included. Note, however, that product and packaging losses at the manufacturing stage were included in the Beyond Burger 4.0 life cycle. Excluding the retail and consumer stages is appropriate as there are unlikely to be major absolute differences between Beyond Burger 4.0 and beef patties through these stages. Beyond Burger 4.0 is distributed frozen but is sometimes displayed in a retail refrigerated counter. Cooking is similar to that of a beef patty. Waste rates are extremely difficult to estimate, but there is no indication that significant differences would exist between the two products. If anything, because the Beyond Burger 4.0 is distributed and stored frozen, there may be reduced retail-level waste compared to beef patties. Excluding the retail and consumption stages, however, can affect the relative differences between the products, as these stages would represent a larger percentage of the Beyond Burger 4.0 life cycle than the beef patty life cycle.

The study used to represent U.S. beef production in this comparison relies on archetype modelling to represent different stages and production methods contributing to beef supply in the U.S., with this modelling informed by statistical information from USDA and other sources. While primary data gathered from beef production operations may be considered of higher quality, given the complexity of beef production in the U.S., including different operations in differing locations involved in each stage (cow-calf, stocker/backgrounder, finishing), such primary data collection is extremely challenging. The beef study did account for regional differences in production, but authors acknowledged the limitation of not being able to account for animal movements between regions. Despite these limitations, the study is widely regarded as the most representative and complete assessment of the environmental footprint associated with U.S. beef production.

In the absence of specific data for U.S. beef patty distribution, we have assumed the same distribution impacts as for Beyond Burger 4.0. This may be an overestimation, as beef processing is likely more geographically distributed, reducing average transportation distances to retail. However, since the contribution from distribution is minor relative to overall life cycle impacts, this assumption does not affect the study's overall conclusions.

In alignment with the FAO Livestock Environmental Assessment and Performance Partnership (LEAP) guidelines (FAO LEAP, 2016), the beef LCA considered all products edible by humans to receive equivalent environmental footprints. In other words, while the data used to represent the beef patty in this comparison does include some contribution from processing and packaging that is specific to ground beef, there is no differentiation between 'cuts' or quality grades of the harvested, human-edible beef; ground beef receives the same share of the impacts associated with raising and producing beef as does a high-end steak. While this is common practice in LCA, it is nonetheless an important assumption to appreciate when interpreting results.

The beef LCA excludes emissions associated with land use change. In addition, climate carbon feedback is excluded from the global warming potentials used to characterize the beef carbon footprint. While exclusion of climate carbon feedback has a small influence on the Beyond Burger 4.0 results, it will likely have a larger impact on beef results due to the large contribution from methane emissions within the beef production system. These limitations suggest that the beef environmental impacts may be an underestimate (i.e., a conservative comparison).

As with any LCA, the life cycle impact assessment results presented here are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks. Further, this study focuses on four impact categories deemed most relevant for comparing plant and animal based proteins, but omits other environmental impact categories. Thus, conclusions cannot be drawn regarding other environmental impact categories.

Additional limitations of Beyond Burger 4.0 LCA include the following:

- Life cycle assessment data provided by a pea protein isolate supplier were deemed incompatible with this study and generic pea protein isolate data from the Agri-footprint database, adapted for pea country of origin, were used instead.
- Primary data on avocado and avocado oil production was not available from suppliers; thus, secondary data were used to model avocado production and processing. Avocado production remains poorly represented in LCA databases and published research. While the avocado production datasets from the Agri-footprint 6.3 expanded beta version that were used here are based on country-specific yields and input data, a limitation is that the avocado orchard is modelled as an annual rather than a perennial system. As a result, the impacts of avocado production may be slightly underestimated. A published LCA study from a single country showed that accounting for the entire orchard lifespan increased the carbon footprint of avocado by 15% (and resulted in a 13-24% increase in other impact categories) (Majumdar and McLaren, 2024). As avocado oil represents 7% of the Beyond Burger global warming impact, such an increase would result in approximately a 1% change in the Burger's footprint. Still, additional information from suppliers, including better representation of country-of-origin supply mix, characteristics of avocado cultivation in the supply chain, and primary data on oil pressing (including potential usage of byproducts) and refining would improve data quality and reduce uncertainty.
- Minimal information was available on the composition and production methods for some minor ingredients, and these ingredients were represented in the LCA model by fairly coarse proxies. Based on these estimates, most contributions to system impacts of these minor ingredients are negligible. The two minor ingredients that demonstrate notable contributions, natural flavor #2 and #6, were represented with improved secondary data provided by suppliers.
- Ingredient inbound transport was via sea freight and truck. However, occasional "urgent need" air freight is possible. One such instance was identified in 2024 for a small quantity (~7% of annual usage) of one ingredient. A test inclusion of this instance within the LCA demonstrated that it did not influence the Beyond Burger footprint results as presented, and was therefore omitted from the inventory.
- Storage of raw ingredients coming into the DEPA facility occurs off-site at nearby warehousing facilities. While this involves an additional transport leg, it does not notably influence the net transport distance (at the level of accuracy acceptable for LCA). Thus, this transport leg was disregarded.

5.3 Sensitivity analyses

Sensitivity analyses can aid in resolving concerns regarding (for example) data quality, estimation or modeling approaches and modeling or methodological assumptions, by demonstrating the influence on environmental performance of perturbations in parameter values or model choices/assumptions.

5.3.1 Parameter sensitivity

This section considers a number of foreground parameters that are either based on limited data or could be expected to change through fairly routine business operations changes. Table 15 summarizes the effect on the Beyond Burger 4.0 environmental performance due to a *20% increase* in a number of parameters. Note that these effects are linear (tested by considering greater increases and decreases), meaning that a 60% increase in the noted parameter will result in three times the reported change in impact indicator, and a 20% decrease would result in the reported decrease. For reference, Table 15 also includes the baseline value for each parameter.

This analysis demonstrates that, for most parameters considered, a 20% increase would have less than a 1% effect on the final environmental performance results. For instance, large deviations in energy demand to process Beyond Burger 4.0 would have a minor influence on the environmental footprints. The time that both WIP and the finished product spend in cold storage is likely to vary as inventory fluctuates; however, this analysis suggests that a 20% change from storage time estimated in the baseline will have less than 0.35% influence across all four indicators. In addition, this update includes cold storage energy intensity utilizing primary data from each individual facility utilized in the Beyond Burger supply chain. A 20% increase in all of these values results in only a 0.4% increase in the final product carbon footprint.

Footprints are also only mildly sensitive to transport distances of the finished product, with 20% increases in distance to cold storage increasing global warming by 2%, and distance from cold storage to final customer (distribution) increasing global warming by 1.4%. These distances are weighted averages and represent full national logistics. Changes in supply chain logistics since the Beyond Burger 3.0 LCA have resulted in notable decreases in the contributions from these transport legs, and therefore decreases in the sensitivity of the overall footprint to transport distance.

Table 14. Sensitivity analysis considering a 20% increase in various model parameters.

Influence of 20% increase in…	Global warming	Fossil resource scarcity	Land use	Water consumption	(Baseline value)
Beyond Burger 4.0 manufacturing energy use	0.54%	0.56%	0.01%	0.09%	0.10 kWh/lb. patty
Burger manufacturing liquid nitrogen use	2.02%	2.30%	0.05%	2.32%	1.64 lb./lb.
Burger manufacturing liquid CO_2 use	1.14%	0.84%	0.02%	0.26%	0.33 lb./lb.
Finished product distance to cold storage	2.01%	2.31%	0.18%	0.08%	920 miles
Finished product cold storage time	0.32%	0.35%	0.00%	0.05%	42 days
finished product distribution distance	1.43%	1.64%	0.13%	0.06%	654 miles
Woven protein storage time	0.06%	0.07%	0.00%	0.01%	35 days
Cold storage energy	0.43%	0.47%	0.01%	0.07%	See Table 7

5.3.2 Pea country of origin

Yellow pea protein is the largest single contributor to the Beyond Burger 4.0 carbon footprint, fossil energy use, and land use. In the baseline model, all of the yellow pea protein isolate comes from Canada, but France is also an important global supplier.

Here, we consider extremes in these PPI sourcing percentages in order to demonstrate the influence of pea cultivation country of origin on Beyond Burger 4.0 environmental performance. Note that in these scenarios, the PPI processing remains the same (aside from electricity grid used); only the pea cultivation processes (based on Agri-Footprint datasets) and transport distances change.

Table 15. Influence of yellow pea protein isolate (PPI) sourcing on the Beyond Burger 4.0 environmental performance

scenario	percent change from baseline values					
	Global warming	Global warming (LUC)	Global warming (total)	Fossil resource scarcity	Land use	Water consumption
50/50 Canada / France	0.01%	-42.1%	-5.1%	0.17%	-10.3%	2.1%
All PPI from France	0.03%	-84.2%	-10.2%	0.35%	-20.7%	4.13%

Table 16 demonstrates that extreme changes in PPI sourcing can influence the overall environmental performance of the Beyond Burger 4.0. These are most prominent in land use change (LUC) emissions, direct land use (occupation), and water consumption. According to the LUC model implemented in Agri-footprint, Canadian grown peas have an emission contribution from LUC; therefore, shifts away from Canada grown peas reduce these emissions. However, since LUC is only 12% of the total global warming impact in the baseline, the effects are tempered somewhat when considering total global warming impact. Canada grown peas require no irrigation (according to the Agri-footprint dataset) whereas France require some irrigation; therefore shifts away from Canada grown peas increase water consumption. In addition, French peas show somewhat higher yield; thus land use decreases in scenarios including French peas.

5.3.3 PET tray post-consumer recycled content

The baseline PET tray is modeled with 50% of the required resin weight recycled post-consumer. The remaining is virgin PET. Here, we consider the influence on Beyond Burger 4.0 environmental performance of varying these ratios at the extreme.

Table 17 demonstrates that the recycled content in the PET tray has a small but still noticeable effect on the Beyond Burger 4.0 environmental performance. Because virgin PET is derived from fossil resources, this indicator is most strongly influenced. These results also demonstrate the benefits of the current post-consumer content of the PET tray: without this recycled content, the carbon footprint (global warming impact) of Beyond Burger 4.0 would increase 3%, and fossil resource scarcity would increase 7%.

Table 16. Sensitivity analysis demonstrating the effect on Beyond Burger 4.0 impact assessment results due to changes in the post-consumer recycled content of the PET tray.

	Percent change from baseline	
	100% post-consumer	100% virgin
Global warming	-3.11%	3.11%
Fossil resource scarcity	-6.81%	6.81%
Land use	-0.05%	-0.05%
Water consumption	-0.62%	0.62%

5.4 Data quality assessment

As described in Section 2.6, data quality of primary data was qualitatively assessed using SimaPro's pedigree uncertainty calculator. These data quality ratings are reported in Appendix II. Overall, the foreground data quality for the Beyond Burger 4.0 LCA was very good as most primary data were based on measurements or records from Beyond Meat, and were temporally and geographically relevant. As described in limitations, proxy assignments were required for some minor ingredients, and these data are considered of lower quality.

No formal data quality evaluation was provided in the study used for the beef comparison. The authors acknowledge some limitations on data availability and a lack of detailed knowledge on the movement of beef animals during the life cycle (Putman, Rotz and Thoma, 2023). These were primarily considered as limitations in establishing representative supply chains at the *regional level*, and the aggregated national data were believed to provide a full accounting of the U.S. beef industry.

5.5 Uncertainty analyses

A Monte Carlo uncertainty analysis was performed in SimaPro utilizing 500 iterations. Uncertainty distributions in background datasets were not modified and therefore rely on distributions reported by database developers. Foreground (primary inventory) data were assigned uncertainty distributions using the SimaPro pedigree uncertainty calculator tool, as described in Section 2.6 and reported in Appendix I.

Table 18 provides the outcome of the Monte Carlo analysis, and suggests relatively small uncertainty within the Beyond Burger 4.0 life cycle model. The 95% confidence interval indicates that 95% of the results of the Monte Carlo iterations were within this range. It is important to note that this uncertainty estimate is dependent on the uncertainty distributions within the database and those estimated using the Pedigree approach (which is a fairly subjective and imprecise method). Still, this analysis suggests minimal uncertainty in the reported environmental performance values.

Uncertainty was not reported in the study used for the beef comparison, and because we do not possess that life cycle model, a paired Monte Carlo analysis was not possible.

Table 17. Summary of the Beyond Burger 4.0 LCA uncertainty analysis

Indicator	Unit (per ¼ lb. patty)	Baseline	Coefficient of variation	95% confidence interval	
Global warming	kg CO_2 eq	0.509	3.68%	0.476	0.549
Global warming (LUC)	kg CO_2 eq	0.077	20.33%	0.054	0.114
Fossil resource scarcity	kg oil eq	0.133	3.43%	0.124	0.143
Land use	m^2a crop eq	0.546	13.59%	0.425	0.714
Water consumption	liters	16.97	9.86%	13.75	20.76

5.6 Completeness and consistency check

The tables below provide a check on data completeness (Table 19) and consistency of the study (Table 20). The objective of the completeness check is to demonstrate that all relevant information and data needed for the interpretation are available and complete.

Table 18. Completeness check

	Complete?	Included	Excluded
Beyond Burger 4.0			
Ingredient agricultural cultivation	Yes	• Upstream extraction and production of cultivation inputs • Direct emissions (e.g., N2O) • LUC emissions	n/a
Ingredient processing	Yes	• All material, water and energy inputs • Co-products and waste streams are considered	• Capital goods
Transport	Yes	• Mode of transport, transport distances	• Capital goods
Production step 1:extrusion of yellow pea protein; WIP assembly	Yes	• All material and energy inputs • All water consumption (in recipe and for cleaning)	• Capital goods
WIP transport and storage	Yes	• Mode of transport, transport distance, cold chain • Energy consumption in cold storage	• Capital goods • Refrigerant emissions
Production step 2: patty manufacture	Yes	• All material and energy inputs • All water consumption (in recipe and for cleaning) • Manufacturing losses	• Capital goods
Packaging	Yes	• Packaging raw materials type and mass • Energy for forming packaging materials • Transport of packaging material • Recycled content of packaging material	• Capital goods
Finished product transport and storage		• Mode of transport, transport distance, cold chain • Energy consumption in cold storage	• Capital goods • Refrigerant emissions
Distribution	Yes	• Mode of transport, transport distance, cold chain	• Capital goods
Beef patty			
Feed cultivation	Yes	• Cultivation data for U.S. feeds generated using IFSM • Upstream extraction and production of cultivation inputs • Direct emissions (e.g., N2O)	• Capital goods • Land use change
Feed processing	Yes	• All material (feed crops and other ingredients) and energy inputs for compound feed processing	• Capital goods
Transport	Yes	• Mode and load of transport, transport distances	• Capital goods • Movement of animals within production stage
beef and dairy farms	Yes	• Feed ration per animal type • Vitamins, minerals, feed additives • Housing system (energy, material and water inputs) • Manure management emissions • Emissions from enteric fermentation	• Capital goods
Harvest and processing	Yes	• Energy and material inputs for slaughter and meat processing • revenue for economic allocation at slaughter	• Capital goods
Packaging	Yes	• Packaging raw materials type and mass	• Capital goods
Distribution	Yes	• Assumed same as Beyond Burger 3.0	• Capital goods

The objective of the consistency check is to demonstrate whether the assumptions, methods and data are consistent with the goal and scope and between product systems.

Table 19. Consistency check

Criteria	Beyond Burger 4.0	Beef patty
Data quality:	Very good	Good (sufficient for benchmarking national average production)
Geographical representativeness:	US manufacturing and distribution	Benchmark for U.S. beef industry
Temporal representativeness:	2023 calendar year	circa 2017 (most recent and representative data available)
Allocation rules:	Economic allocation in background data; mass allocation at facility level	Economic allocation at harvest/slaughter; biophysical (metabolizable energy) allocation applied at dairy farms (per international guidelines)
System boundaries:	Cradle to distribution, including ingredient cultivation and processing, inbound transport, pre-processing, WIP transport and storage, manufacturing, packaging, final product transport and storage, distribution	Original study cradle to grave; adapted to cradle to distribution boundary with data from study author. Includes feed production, various beef operation stages, dairy operations (cull animals), transport, harvest, processing, packaging, distribution
Impact assessment methodology:	ReCiPe 2016 midpoint hierarchist	ReCiPe 2016 midpoint hierarchist (adapted to use GWP100 characterization factors without climate-carbon feedback)

6. Conclusions and recommendations

Beyond Meat's Beyond Burger 4.0 has evolved both in formulation and in its supply and production chain since the Beyond Burger 3.0 LCA. The main formulation difference between Beyond Burger 3.0 and Beyond Burger 4.0 is the replacement of canola oil with avocado oil, while simplification of the supply chain to a single burger manufacturing location reduced intermediate and final distribution transport.

The Beyond Burger 4.0 LCA reported here focuses on four impact indicators: global warming (Greenhouse gas emissions), fossil resource (non-renewable energy) use, land use, and water consumption. Ingredient provision is an important contributor across all impact categories assessed, and ingredients are the dominant contributor to land use and water consumption. Yellow pea protein isolate is the most contributing ingredient, except in water consumption where avocado oil is most contributing. Contributions from refrigerated transport – both of intermediate components and final distribution – have decreased since the v3.0 LCA, whereas impacts attributable to production (specifically, burger manufacturing) have increased.

The Beyond Burger 4.0 LCA was compared with impacts associated with an average U.S. beef patty, based on a 2023 published study that serves as a current benchmark for the U.S. beef industry. The relative impacts (normalized such that Beyond Burger 4.0 = 1 for each impact category) between a Beyond Burger 4.0 and beef patty are shown in Figure 5. The resulting comparative statement from this study is as follows:

Based on a comparative assessment of the Beyond Burger 4.0 production system with a beef patty based on the 2023 beef LCA by Putman et al, the Beyond Burger 4.0 generates 88% less greenhouse gas emissions, and requires 28% less non-renewable energy, 97% less land use, and 92% less water consumption.

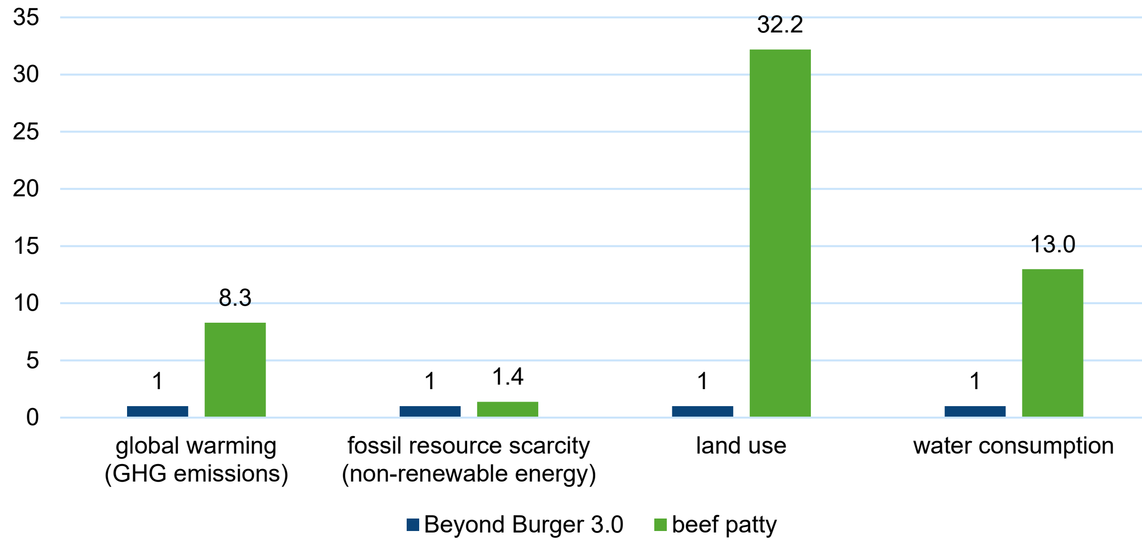

Figure 5. Relative comparison between Beyond Burger 4.0 and beef patty across four impact categories. Values normalized so that Beyond Burger 4.0 = 1 for each category.

While uncertainty and sensitivity analysis suggest that the absolute values of these comparative numbers may vary somewhat, there is no indication that a situation or condition may arise in which the environmental performance, as indicated by the categories considered here, of the Beyond Burger 4.0 would be worse than that of a beef patty. Note, however, that as other environmental impact categories have not been evaluated, conclusions regarding other categories cannot be made.

It is recommended that communication of the relative environmental benefits of Beyond Burger 4.0 over beef shall occur with acknowledgement of the specific environmental metrics used and the limitations and uncertainties present in this study. Additional recommendations that will support future LCA work include integrating LCA-relevant data collection (material and energy inputs relative to product outputs) into routine business accounting and further engaging suppliers to provide LCA-based environmental impact data on the manufacture of their products.

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Appendix I Data quality and uncertainty (pedigree matrix evaluation)

The following table summarizes the data quality values used within SimaPro's pedigree uncertainty calculator in order to establish uncertainty distributions for primary data. See Section 2.6 and Table 2 for data quality matrix and definitions of pedigree values. Note that in some instances, such as the quantities in recipe, while the actual quantity used is known with high certainty, the data quality rating applied to this parameter is being used to represent uncertainty in the underlying process (e.g., production of ingredient).

Ingredient/process	Modeled as	Data Quality (pedigree values)	SD^2	Uncertainty Applied to:
Apple Extract	apple concentrate (AFP)	1,1,1,3,4	1.51	quantity in recipe
Avocado Oil	avocado oil	2,2,1,4,4	1.51	quantity in recipe
Brown Rice Protein	from supplier	1,1,1,1,1	1.05	quantity in recipe
burger manuf. Electricity use		1,1,1,2,2	1.07	
burger manuf. liq CO2 use		1,1,1,3,2	1.07	
burger manuf. liq N2 use		1,1,1,3,2	1.07	
burger manuf. losses		1,1,1,1,1	1.05	
burger manuf. Water use		1,1,1,3,2	1.07	
Calcium Chloride	calcium chloride	1,1,1,5,2	1.12	quantity in recipe
cardboard sleeve	folding boxboard, printing ink	1,1,1,1,1	1.05	quantity used
cartons per pallet		1,1,1,1,1	1.05	
cold storage energy demand	(separate value for each facility)	1,1,1,1,1	1.05	
dry blend days in storage		1,1,1,2,2	1.07	
dry blend electricity use		1,1,2,2,2	1.08	
dry blend losses		1,1,1,1,1	1.05	
dry blend natural gas use		1,1,1,4,2	1.09	
dry blend water use		1,1,1,3,2	1.07	
Empure Potato Starch	dried potato starch (AFP)	1,1,1,3,2	1.07	quantity in recipe
fat blend losses		1,1,1,1,1	1.05	
Fava Bean Concentrate	fava bean starch-concentrate (AFP)	1,1,1,3,2	1.07	quantity in recipe
FlavorNrich Master	average of amino acids	1,1,1,3,4	1.51	quantity in recipe
fraction of peas from CA		1,1,1,1,1	1.05	
hydration blend losses		1,1,1,1,1	1.05	
hydration blend water in recipe		1,1,1,3,2	1.07	
Methylcellulose	carboxymethyl cellulose powder	1,1,1,3,2	1.07	quantity in recipe
Natural Flavor #1	from supplier (modeled as in Heller & Keoleian 2018)	1,1,1,1,1	1.05	quantity in recipe
Natural Flavor #2	from supplier	1,1,1,1,1	1.05	quantity in recipe
Natural Flavor #3	average of amino acids	1,1,1,3,4	1.51	quantity in recipe
Natural Flavor #4	DL-Methionine (AFP)	1,1,1,3,4	1.51	quantity in recipe
Natural Flavor #5	from supplier	1,1,1,1,1	1.05	quantity in recipe

Natural Flavor #6	from supplier	1,1,1,3,4	1.51	quantity in recipe
Natural Flavor #7	average of amino acids	1,1,1,4,4	1.51	quantity in recipe
Natural Flavor #8	average of amino acids	1,1,1,3,4	1.51	quantity in recipe
NF Masking	maltodextrin	1,1,1,3,4	1.51	quantity in recipe
Octobin, liner, cover	materials required	1,1,1,3,2	1.07	each Component
pallet wrap film	extruded LLDPE	1,1,1,1,1	1.05	quantity used
Patty paper	tissue paper, paraffin	1,1,1,1,4	1.5	each Component
patty tray and lid	PET	1,1,1,1,1	1.05	quantity used
protein extrusion liq N2 use	liquid nitrogen	1,1,1,3,2	1.07	quantity used
woven protein days in storage		1,1,1,2,2	1.07	
protein extrusion electricity use		1,1,2,2,2	1.08	
protein extrusion losses		1,1,1,1,1	1.05	
protein extrusion natural gas use		1,1,1,4,2	1.09	
woven protein water in recipe		1,1,1,3,2	1.07	
Protein extrusion water use		1,1,1,3,2	1.07	
Yellow Pea Protein Isolate	Yellow pea protein isolate	1,1,1,3,4	1.5	quantity in recipe
Pea Starch	pea starch-concentrate (AFP)	1,1,1,3,4	1.51	quantity in recipe
Pepper WHT GRD	fresh pepper	1,1,1,4,4	1.51	quantity in recipe
Pom x-pomegranate extract	pomegranate fruit extract	1,1,1,3,2	1.07	quantity in recipe
Potassium Chloride	potassium chloride	1,1,1,3,2	1.07	quantity in recipe
Potassium Hydrogen Carbonate	potassium carbonate	1,1,1,3,2	1.07	quantity in recipe
Purasal HiPure Plus	potassium lactate	1,1,1,3,1	1.05	quantity in recipe
Pure Red Carrot	beet juice extract	1,1,1,3,2	1.07	quantity in recipe
Red Beet Powder	modeled as in Heller & Keoleian 2018	1,1,1,3,4	1.51	quantity in recipe
Red Lentil Protein	red lentil protein isolate	1,1,1,3,2	1.07	quantity in recipe
Vinegar	vinegar (AFP)	1,1,1,3,2	1.07	quantity in recipe
WIP packaging	extruded LLDPE	1,1,1,1,1	1.05	quantity used

Appendix II Review Statement

Review Statement follows. The Review Report is available upon request to:

BYND-ESG@BeyondMeat.com

Critical Review of the Study "Beyond Burger® 4.0 Life Cycle Assessment"

Commissioned by: Beyond Meat, El Segundo, CA

Performed by: Martin C. Heller, Blonk Consultants
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Brandon Taylor, Blonk Consultants

Critical Review Panel[1]: Roland Geyer, Professor, (Chair)
University of California, Santa Barbara, CA
Alissa Kendall, Professor,
University of California, Davis, CA
Jasmina Burek, Professor,
University of Massachusetts, Lowell, MA

Date: 10 June, 2025

Reference ISO 14044: 2006. Environmental Management - Life Cycle Assessment – Requirements and Guidelines
ISO/TS 14071: 2024. 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: 2024
- 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 four impact categories: Climate change, non-renewable energy use, water consumption, and land use. This selection was found to be appropriate and reasonable in relation to the goal of the study, which includes comparative assessment relative to previous studies with limited use of impact categories. As a result, the report is deemed to be representative and complete relative to its goal and scope. 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 past literature) 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 conformance 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.

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