Report No. CSS21-21
October 6, 2021

CHEF WOO HIGH-PROTEIN RAMEN NOODLE LIFE CYCLE ASSESSMENT:

A detailed comparison with animal-based protein sources

Martin Heller and Gregory Keoleian

CENTER FOR
SUSTAINABLE SYSTEMS
UNIVERSITY OF MICHIGAN

Client: Borealis Foods

Title: **Chef Woo high-protein ramen noodle Life Cycle Assessment: A detailed comparison with animal-based protein sources**

Report version: v.1.0

Report date: October 6, 2021

On behalf of the Regents of the University of Michigan

Document prepared by

Martin C. Heller
Senior Research Specialist
Center for Sustainable Systems
University of Michigan

Under the supervision of

Gregory A. Keoleian gregak@umich.edu (please address questions here)
Peter M. Wege Endowed Professor of Sustainable Systems
Director, Center for Sustainable Systems
University of Michigan

This study has been conducted according to the requirements of ISO 14040-2006, ISO 14044-2006, and reviewed according to ISO 14071-2014.

Table of Contents

List of Figures

List of Tables

List of Acronyms

AFP = AgriFootprint (food LCA database developed by Blonk Consultants)

CO_2eq. = carbon dioxide equivalents, a mid-point climate change indicator in which the radiative forcing of various greenhouse gases are expressed relative to carbon dioxide.

CW = Chef Woo

eGRID = Emissions & Generation Resource Integrated Database, source of data from US EPA on electric power generated in the US.

GHGE = greenhouse gas emissions

IPCC = International Panel on Climate Change

LCA = Life Cycle Assessment

LCI = life cycle inventory

USDA = United States Department of Agriculture

USLCI = United States Life Cycle Inventory Database (https://www.nrel.gov/lci/)

WFLDB = World Food LCA DataBase (food databased developed by Quantis)

Executive Summary

The Center for Sustainable Systems at University of Michigan conducted for Borealis Foods a "cradle to grave" life cycle assessment of Chef Woo (CW) instant ramen noodle, a unique product that supplies 20g of plant-based complete protein per serving. The purpose of this study is to compare environmental impacts – chosen here as greenhouse gas emissions, fossil energy use, land use and water use – with those from supplying an equivalent amount of protein from meat, including beef, pork and chicken. In addition, we compare the high-protein ramen with a meal of regular ramen supplemented with pork or chicken to provide 20g protein total as well as a Beyond Burger patty (plant-based beef analog). A secondary purpose of the study is to highlight opportunities for improvement in the environmental performance of the Chef Woo product chain and provide Borealis Foods with a benchmark against which improvement efforts can be measured. The primary audiences are both internal stakeholders at Borealis Foods as well as external customers, consumers and interested stakeholders.

The chosen functional unit is "provision of 20g of protein to end consumer," which is supplied in one ready-to-rehydrate cup of Chef Woo and 116g, 111g, and 89g of beef, pork, or chicken, respectively. System boundaries included upstream ingredient and raw material supply (including farm production of agricultural crops), processing and packaging operations, distribution to point of sale, storage and preparation for consumption, and disposal of packaging materials. Impacts at retail were excluded, as were contributions due to retail- or consumer-level food losses. Borealis Foods provided detailed information on ingredient quantities and sources, packaging materials, and processing facility energy demands. This was complemented with primary data from the pea protein isolate supplier (primary protein source in Chef Woo) and additional information from other ingredient suppliers. The environmental impact of meat production came from three studies designed to be representative of U.S. production methods (Putman et al. 2017; Putman et al. 2018; Rotz et al. 2019). These farm-gate studies were used as inputs into a cradle-to-grave life cycle model that also included representative harvesting/processing, packaging, distribution (equivalent distance to Chef Woo), at-home storage and cooking for consumption. Production and packaging of Beyond Burger came from (Heller and Keoleian 2018), with other downstream stages modeled the same as meats. Ramen Express, a regular (wheat-based) ramen noodle manufactured in the same facility as Chef Woo, was modeled similarly to Chef Woo, with necessary changes to ingredients.

Table ES1 provides a comparison of the total life cycle impacts for Chef Woo high-protein ramen noodle and beef, pork, chicken, Beyond Burger, and Ramen Express plus beef, pork or chicken.

Table ES1. Total life cycle impacts of providing 20g protein from various sources.

	GHGE	fossil energy	land use	water use
	kg CO_2eq	MJ	m^2a	liter
Chef Woo	0.4	5.1	0.9	8.2
beef	3.3	10.3	3.1	289.0
pork	0.9	7.6	0.7	35.7
chicken	0.4	4.2	0.4	15.2
Beyond Burger	0.6	8.4	0.5	4.3
Ramen Express + beef	2.8	10.8	2.7	220.5
Ramen Express + pork	1.0	8.7	0.9	30.1
Ramen Express + chicken	0.6	6.2	0.6	14.8

Table ES2 offers a simplified summary of the differences in environmental performance between meats, noodles plus meat, and plant-based burger and Chef Woo.

Table ES2. Relative change in environmental impact resulting from substituting one serving (20g of protein) of each with Chef Woo.

	GHGE	fossil energy	land use	water use
beef	>50% reduction	>50% reduction	>50% reduction	>50% reduction
pork	>50% reduction	between 25% and 50% reduction	between 25% and 50% greater	>50% reduction
chicken	unable to determine difference	unable to determine difference	>50% greater impact	between 25% and 50% reduction
Beyond Burger	between 25% and 50% reduction	between 25% and 50% reduction	>50% greater impact	>50% greater impact
Ramen Express + beef	>50% reduction	>50% reduction	>50% reduction	>50% reduction
Ramen Express + pork	>50% reduction	between 25% and 50% reduction	unable to determine difference	>50% reduction
Ramen Express + chicken	between 25% and 50% reduction	unable to determine difference	between 25% and 50% greater	between 25% and 50% reduction

KEY

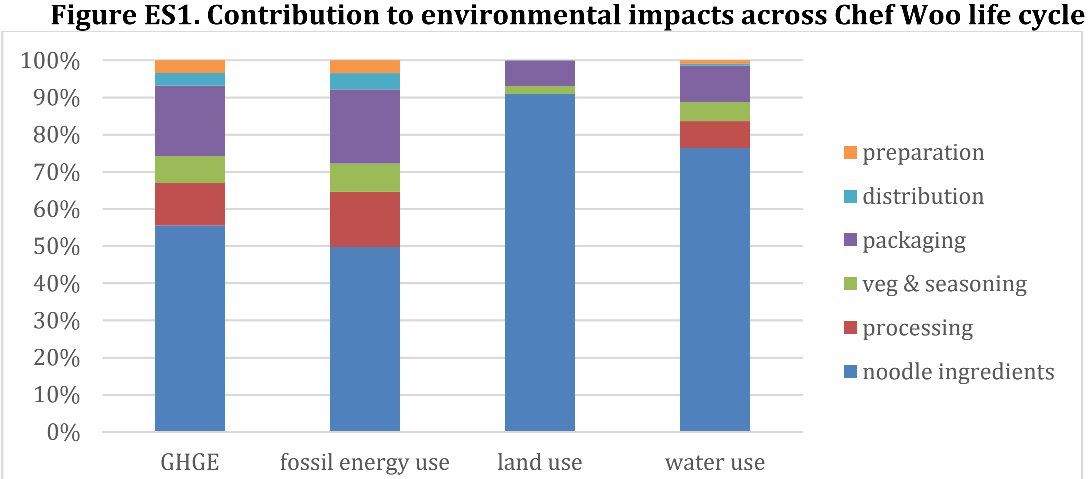
green	>50% reduction
blue	between 25% and 50% reduction
grey	unable to determine difference
yellow	between 25% and 50% greater
orange	>50% greater impact

When comparing an equivalent provision of protein, Chef Woo greenhouse gas emissions are significantly less than beef or pork, and somewhat less than Beyond Burger. Chef Woo fossil energy use is significantly less than beef, and somewhat less than pork and Beyond Burger. Chef Woo land use is significantly less than beef, somewhat more than pork and significantly more than chicken or Beyond Burger. Chef Woo water use is significantly less than beef and pork, somewhat less than chicken, and significantly more than Beyond Burger. Differences in greenhouse gas emissions and fossil energy use between Chef Woo and chicken cannot be determined by this study, due to underlying uncertainties.

Supplying 20 g of protein through CW rather than a traditional noodle meal (regular ramen supplemented with meat) leads to significantly less impacts across all categories when using beef, significantly less greenhouse gas emissions and water use when using pork, and somewhat less greenhouse gas emissions and water use when using chicken.

Figure ES1 summarizes the contribution analysis for the Chef Woo life cycle, demonstrating the relative contributions of key inputs and life cycle stages. In general, producing noodle ingredients, including frying oil, is the largest contributor across all impact categories.

Figure ES1. Contribution to environmental impacts across Chef Woo life cycle stages



Higher land use impacts for Chef Woo appear to be driven, in part, by the use of sunflower oil for frying. The meat production studies used for comparison here report lower values than similar studies found elsewhere, reflecting the high production efficiencies of US agriculture, and suggesting that the conclusions for Chef Woo performance drawn here will likely be conservative in other contexts.

1. Introduction and Goal of the study

The Center for Sustainable Systems, at the request of Borealis Foods, conducted a life cycle assessment (LCA) of Chef Woo (CW) high-protein instant ramen noodle to compare it against animal-based protein sources (beef, pork, chicken) and traditional ramen plus meat (for an equivalent serving of protein). The primary reason for the study is to advance knowledge on the environmental impact of plant-based protein alternatives. In addition, Borealis is interested in sharing results on the potential environmental benefits of CW publicly to consumers and provide scientifically based evidence to support claims of the environmental impacts of consuming CW versus meat. A secondary goal is to provide Borealis with a benchmark against which to measure future improvements in the environmental performance of the CW product chain as well as to highlight hotspots within the product chain. The impact categories of interest include greenhouse gas emissions, non-renewable energy demand, water use, and land use.

The intended audience is both internal stakeholders at Borealis, as well as external customers, consumers, and interested stakeholders.

A goal of the study is to conduct a comparative assessment of CW and meat and support comparative assertions intended for public communication. Accordingly, Critical Review was conducted per Section 6.3 of the ISO 14044-2006 Standard. The ISO standard requires LCA studies to undergo a Critical Review by a panel of no less than three (3) reviewers when the results are intended to support comparative assertions that are intended to be disclosed to the public.

2. LCA Methodology

2.1. Scope of the Study

The following sections describe the general scope of the project to achieve the stated goals. This includes the identification of specific product systems to be assessed, the product function(s), functional unit and reference flows, the system boundary, allocation procedures, and cut-off criteria of the study.

2.1.1. Product Systems

This cradle-to-grave LCA study compares an instant ramen noodle with 20g of plant-based protein with 20g of protein supplied by beef, pork, chicken, and regular (wheat flour) ramen noodle plus meat.

- Chef Woo is an instant ramen noodle product utilizing (primarily) pea protein to supply 20g of protein per serving. It is sold dehydrated (shelf-stable) in sealed cups, to be rehydrated for consumption by the addition of hot water. The product system is defined and informed through direct communications with the product developer and manufacturer, Borealis Foods. Note that while CW is currently available in four different flavors, this only influences the composition of the “seasoning”, and within the confines of this LCA, all four flavors are considered identical.
- Production of beef, pork and chicken for the US market are considered. An appropriate quantity to provide 20g protein is analyzed.
- Wheat based instant ramen is produced in the same facility as CW, marketed under the brand, Ramen Express; life cycle inventory data were adjusted to represent this wheat based ramen (with 5g protein per cup). An equivalent of 15g of protein from meat was then added to supply the equivalent 20g protein serving (noodle + meat).

2.1.2. Product Functions and Functional Unit

Establishing the function of foods, and in turn, the functional unit, is difficult (Schau and Fet 2008) as foods supply a variety of functions. 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.

Table 1 provides a comparison of the relevant nutritional profiles of CW and the meats used for comparison. Note that while the nutritional data provided in Table 1 are for raw meat, the LCA compares fully prepared (cooked) meat.

Table 1. Nutritional comparison of Chef Woo noodle and beef, pork and chicken

% daily value (DV) shown in italicized parentheses	Chef Woo noodle cup[a]	Beef, ground 80% lean/20% fat, raw[b] (4 oz; 113 g)	Pork, ground 84% lean/16% fat, raw[b] (4 oz; 113g)	Chicken, breast, meat only, raw[b] (4 oz; 113g)	Ramen Express noodle cup[a]
Protein (g)	20 *(36%)*	19.4 *(38%)*	20.3 *(40%)*	25.4 *(50%)*	5 *(9%)*
Total fat (g)	14 *(18%)*	22.6 *(29%)*	18 *(23%)*	3.0 *(4%)*	12 *(15%)*
Saturated fat (g)	1.5 *(8%)*	8.6 *(43%)*	5.6 *(28%)*	0.64 *(3%)*	5 *(25%)*
Cholesterol (mg)	0 *(0%)*	80 *(27%)*	76.8 *(3%)*	82.5 *(27%)*	0 *(0%)*
Sodium (mg)	1220 *(53%)*	75 *(3%)*	77 *(3%)*	51 *(2%)*	1160 *(50%)*
Total carbohydrate (g)	29 *(11%)*	0 *(0%)*	0.5 *(0%)*	0 *(0%)*	37 *(13%)*
Dietary fiber (g)	2 *(7%)*	0 *(0%)*	0 *(0%)*	0 *(0%)*	1 *(4%)*
Total sugars (g)	3	0	0	0	2
Iron (mg)	3 *(15%)*	2.19 *(12%)*	0.99 *(6%)*	0.42 *(2%)*	2 *(11%)*
Calcium (mg)	21 (2%)	20.3 *(2%)*	17 *(1%)*	5.7 *(0%)*	18 *(1%)*
Calories	330	287	246	136	280
Quantity to supply 20g protein	1 cup	116.3g	111.1g	88.9g	1 cup + 87g beef; 83g pork; 67g chicken

[a]from on-package nutrition facts

[b]from USDA FoodData Central SR Legacy foods: https://fdc.nal.usda.gov/index.html; % DV from https://nutritionvalue.org/

The novelty of CW ramen noodle is its supply of a full serving of nutritionally complete protein (having all essential amino acids). Therefore, for this study, protein provision will be considered the primary function, and the functional unit will be defined as "provision of 20g of protein to end consumer." Chef Woo is packaged in a paper cup for instant rehydration; one serving (one cup) supplies 20 g of protein; therefore, the reference flow in the CW LCA is 1 cup.

2.1.3. System Boundaries

Figure 1 provides a graphical representation of the system boundaries considered in this study. The study represents a cradle-to-grave assessment of the CW product chain. This cradle-to-grave boundary scope was chosen because it was anticipated that differences in energy use associated with home storage and preparation may be present between the products compared. Table 2 provides additional detail of items included and excluded from system boundaries.

Table 2. Description of items included and excluded from Chef Woo system boundary.

Included	excluded
• Raw material supply, including ingredients, primary, secondary and tertiary packaging • Processing and packaging operations • Facility-level utility requirements (includes overhead such as lighting and HVAC) • Transport of ingredients and packaging materials • Product to retailer/distributor • Food home storage and preparation • Packaging disposal	• Retail stage • Transport from retail to home • Food waste and food waste disposal • Capital goods and infrastructure • Employee travel

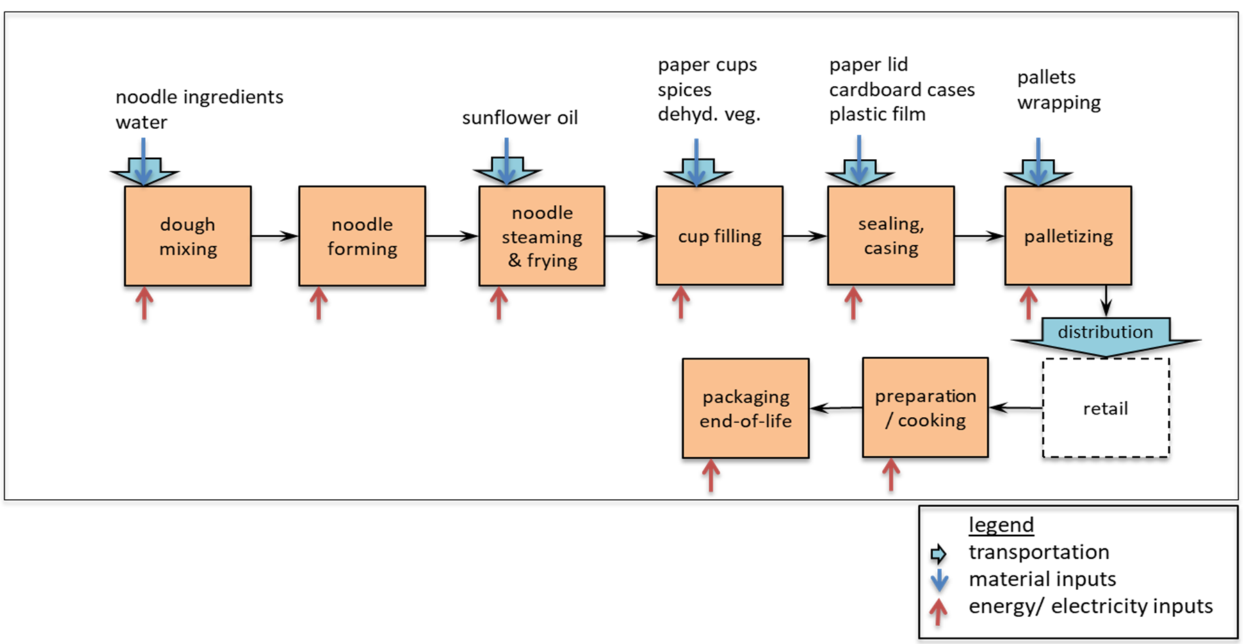


Figure 1. Life cycle stages included in cradle to grave system boundary of the Chef Woo product. The retail stage will not be included.

2.1.3.1. Time Coverage

Market-scale production of CW began in September of 2020. Therefore, a limited data history is available. For this study, ingredients and suppliers are representative of 2020 production and no significant formulation or supplier changes were made over the year. Production/processing utility demands were averaged across November, 2020 – April, 2021 production (see Section 3.2.3 for details).

2.1.3.2. Technology Coverage

The study is to represent production of CW in the U.S. in 2021. The age or modernization of processing equipment at the Palmetto Gourmet Foods facility, the sole location of CW production, is unknown.

2.1.3.3. Geographical Coverage

The study is to represent CW production in the continental US, with electricity grid data specific to the production location. Where known, ingredient production is representative of the place of origin, and transportation is included to the Palmetto Gourmet Foods production facilities. At this point, CW has only limited distribution in the U.S., and a projected average transport distance was calculated based on the states in which distribution currently occurs (see Section 3.2.4). Use (home consumption) impacts are representative of US average homes. Packaging disposal is representative of the U.S. average as described in Section 3.2.6.

2.1.4. Allocation principles

In choosing datasets for the CW LCA model, consistent allocation approaches were selected. For processes from Ecoinvent v. 3.4, the "Cut-off by classification" system model was chosen. The 'cut-off' model is based on the approach that primary production of materials is always allocated to the primary user of a material. If a material is recycled, the primary producer does not receive any credit for the provision of any recyclable materials. The consequence is that recyclable materials are available burden-free to recycling processes and secondary (recycled) materials bear only the impacts of the recycling processes. Also, producers of wastes do not receive any credit for the recycling or re-use of products resulting out of any waste treatment. The Agri-footprint database is built around a similar model; for Agri-Footprint v. 4.0 processes, economic allocation was consistently selected.

The LCA of pea protein isolate, developed with data from the manufacturer as described in Section 3.2.2.1, used an economic (revenue based) allocation assignment.

Allocation of energy consumption between parallel production lines in the Palmetto facility was according to ratios provided by the facility head of engineering (see Section 3.2.3 for details).

2.1.5. Cut-off Criteria

All efforts have been made to be as inclusive as possible, and no cut-off criteria are defined for this study. Instead, we use 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.

2.2. Life Cycle Impact Assessment Methodology and Impact Categories

The ideal in LCA is to report on a full array of potential environmental impacts in order to evaluate possible shifts or trade-offs in impact. In reality, however, the reliability of available data often requires limiting perspective to a select subset of relevant impact categories. Further, a limited number of impact categories were reported in the animal production system studies used as comparison. Thus, the impact categories chosen for this study were limited to: climate change (greenhouse gas emissions), fossil energy use, water use and land use. These four categories offer a valuable point of comparison for agriculture-dominated supply chains. Characterizations from IPCC 2013, 100 year time horizon were used for greenhouse gas emissions, whereas the ReCiPe 2016 Midpoint impact assessment method, Hierarchist version (Huijbregts et al. 2017) was used for other categories. Details for the categories reported in this study are given below:

- Greenhouse gas emissions – utilizes the global warming potentials from IPCC 2013, 100 year time horizon (IPCC 2013).
- Fossil energy use – ReCiPe reports "fossil resource scarcity," which at the midpoint is characterized by the ratio between the higher heating value of each fossil resource and the higher heating value of crude oil (43.2 MJ/kg). It is reported as "kg oil-eq". To express this in terms of fossil energy use, the value from ReCiPe is multiplied by 43.2 MJ/kg crude oil.
- Water use – ReCiPe reports "water consumption", which is the amount of water extraction from surface water bodies or ground water that is lost from the watershed of origin. This "loss" is commonly through evaporation, evapotranspiration, or incorporation into a product. For consumptive water flows, this midpoint indicator equals the inventory.
  While water scarcity characterized impacts (such as the AWARE method (Boulay et al. 2018)) are gaining prominence and acceptance in LCA, meaningful application of such methods requires appropriately regionalized water use data. Especially in the US, where water scarcity varies greatly in dominant agricultural regions, assessment at a "national average" level may not offer additional information or insight. Such a regionalized inventory was not available for the US livestock production systems used as the comparison here, meaning that "water use" for these livestock production systems would require assuming a US national average scarcity. Similarly, provenance of the CW agricultural supply chain is not well known. Thus, we conclude that applying a water scarcity impact category would not offer additional information or differentiation.
- Land use – The midpoint characterization is reported in m^2yr annual crop equivalents, and characterization factors are the relative species loss caused by a specific land use type (annual crops, permanent crops, forestry, urban land, etc). For typical agricultural land occupation with annual crops, the characterization factor is 1; the characterization factor is 0.55 for grasslands (including pastures and grazing), 0.3 for occupation by forest (e.g., for paper products) and 0.73 for most industrial or urban land occupations.

It shall be noted that the above impact categories represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) actually follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the functional unit (relative approach). LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

2.3. Data Quality Requirements

Data quality has been considered throughout the LCA process and has been qualitatively assessed in Section 5.4. In situations where data quality was questionable, sensitivity analysis has been performed to assess the influence of uncertainty on overall results.

2.4. 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.

2.5. Software and Database

The LCA model was created using SimaPro 8.5.2.0 software system, developed by PRé Sustainability. The accompanying databases, Ecoinvent 3.4 and Agri-Footprint 4.0 (AFP) were utilized for background materials and processes in the model. In addition, the World Food Life Cycle Database was used for one ingredient present in small quantities.

2.6. Critical Review

The ISO 14040/14044 standards require a critical review when the study results are intended to support comparative assertions intended to 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

- Thomas P. Gloria, PhD. Managing Director, Industrial Ecology Consultants (chair)
- Andrea L. Hicks, PhD. Associate Professor, University of Wisconsin, Madison
- Greg J. Thoma, PhD. Professor, University of Arkansas.

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. 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 B. 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. Data Collection Procedure

Most data were provided by Borealis Foods, including information on product formulation, processing, process energy use at the Palmetto Gourmet Foods facility in Saluda, SC, packaging, storage and distribution. Additional information on key ingredients, production consumables and packaging were collected from respective vendors.

3.2. Chef Woo Product System

3.2.1. Electricity generation

Electricity grid inventory data for the US were represented at the USEPA eGRID level for year 2019 mix of fuels. This required updating the mix of fuels with information from EPA's eGRID Data Explorer (https://www.epa.gov/egrid/data-explorer). While the 2010 USLCI eGRID datasets were used as the starting point, processes for production of electricity from different fuels were replaced with Ecoinvent equivalents as the USLCI database contains numerous "empty" and missing flows (for example, water and land use are generally not included). In addition, an assumed line loss of 5.1% was included in the modification (not previously accounted for in USLCI processes). The resulting LCIs for electricity grid mixes used in this study are given in Appendix A. When facility locations were known, electricity generation was modeled using a dataset representative of that eGRID region. The US average resource mix was used for unspecified locations.

3.2.2. Chef Woo noodle ingredients

The ingredients required to produce the CW noodle cake are listed in Table 3, along with the data approach used to model each. All ingredients were included in the LCA. Where indicated, information and/or data were gathered from the actual purveyor or manufacturer of the product, but these details are considered proprietary. Note that while primary ingredients of CW are organic, no corresponding datasets for organic production exist and agricultural production of these ingredients are modelled as conventional. Further details of prominent ingredients follow. In all cases where the manufacturing location was known, transportation legs from the place of manufacture to Saluda, SC (location for CW production) were also included using the Ecoinvent dataset [Transport, freight, lorry, unspecified {GLO}| market for | Cut-off, S].

Table 3. Summary of CW noodle ingredients and data used in modeling ingredient production*.

ingredient	data approach utilized [xxx] = process name in SimaPro {xxx} = source database	transport distance to Saluda, SC (km)
flour mix		
organic pea protein isolate	production data from supplier; see Section 3.2.2.1	1872
organic wheat flour	[Wheat flour, from dry milling, at plant, UK Economic]{AFP}; Process modified to RMPA eGRID; wheat grain mix supply to 50% CO, 25% MN, 25% ND (AFP5 wheat cultivation processes) based on information from supplier. Transport distance from production state to flour mill (known location) included.	2527
undisclosed proprietary protein	<8% total (dry) flour input. Modeled as pea protein isolate on recommendation from Borealis	1233
brine ingredients (totaling <2% of final noodle cake weight)		

water	[Tap water {RoW}| tap water production, conventional treatment | Cut-off]{Ecoinvent}	
fine salt	[Sodium chloride, powder {GLO}|market for | Cut-off]{Ecoinvent}	Unknown origins and very small quantities; transport not included
potassium carbonate	[Potassium carbonate {GLO} market for | Cut-off]	
sodium carbonate	[soda ash, light, crystalline, heptahydrate {GLO}| market for | Cut-off]{Ecoinvent}	
sodium tripolyphasphate	[Sodium tripolyphosphate {GLO} market for | Cut-off]{Ecoinvent}	
guar gum	[Germ, from guar seed, at plant (WFLDB 3.5)/IN]{WFLDB}	
frying oil		
organic sunflower oil	[Refined sunflower oil, from crushing (pressing) at plant]{AFP} modified to US grid, sunflower seed market mix to 60% Argentina market, 40% France market based roughly on info from supplier.	154
dried vegetables and seasoning		
air dried carrot	[Carrot, at farm/NL Economic]{AFP} w drying as in Section 3.2.2.2	25670 (barge ship) 1204 (truck)
air dried scallions	[Onion, at farm/FR Economic]{AFP} w drying as in Section 3.2.2.2	25670 (barge ship) 1204 (truck)
freeze dried sweet corn	[Maize, at farm/CN Economic]{AFP} w drying as in Section 3.2.2.2	25670 (barge ship) 1204 (truck)
freeze dried peas	*(proxy)* [Green bean, at farm/NL Economic]{AFP} w drying as in Section 3.2.2.2	25670 (barge ship) 1204 (truck)
air dried red bell pepper	GHGE, energy use and land use for field production in China from published LCA (Wang et al. 2018) w drying as in Section 3.2.2.2	26272 (barge ship) 1748 (truck)
seasoning	*(proxy)* [Sodium chloride, powder {GLO}|market for | Cut-off]{Ecoinvent}	1923

* Formulation composition provided, but not revealed here for proprietary reasons

3.2.2.1. Pea protein isolate

The primary protein source in CW is pea protein isolate, currently sourced from a US supplier. The manufacturer of the pea protein isolate provided under confidentiality their 2020 (full year of production) facility-level material and energy input and output data. These were built into pea milling and separation processes in SimaPro, using a default dataset from AFP for pea agricultural production from France, chosen because it had yields similar to what the manufacturer indicated their contracted farmers were reporting. Allocation of the pea separation processes was revenue based (price*volume), whereas energy requirements for drying were allocated by facility engineers to specific co-products. Transportation distances and modes for pea shipment from farms to mill and flour from mill to separation/processing were also provided by the manufacturer and included. The resulting impacts (at processor gate) for pea protein isolate production from this primary data were: GHGE: 6.5 kg CO_2eq/kg; fossil energy use: 78.3 MJ/kg; land use: 16.3 m^2/kg; water consumption: 0.18 m^3/kg.

3.2.2.2. Dried vegetables

The final CW cup contains small quantities of dried vegetables (total weight =2.9g) which all originate from China. Agricultural production of vegetables was modeled per the processes indicated in Table 3. The existing AFP dataset for bell pepper represented production in heated greenhouses, which would be extremely unlikely for a dried vegetable market, so LCA results from a published literature study were used (Wang et al. 2018).

The amount of dried vegetables that yield from a given quantity of raw vegetable is based on the raw vegetable moisture content, as in Table 4, and an assumed dry moisture content of 5%.

Table 4. Moisture content of raw vegetables, from USDA Food Data Central[1] SR Legacy Foods

	raw moisture content (%)
carrot	88.3
scallions	92.3
corn	76
peas	78.9
red bell pepper	92.2

For 1 kg raw vegetable:

$$dry\ weight\ (kg) = \frac{(1 - raw\ moisture\ content)}{1 - dry\ moisture\ content}$$

Empirical values found in the literature for the specific energy consumption (SEC, energy required per kg of water removed) for convective drying of vegetables vary tremendously, with values ranging from 4 to 140 MJ/kg water removed. Given this uncertainty, we contacted the current suppliers of the dried vegetable ingredients for estimates of energy demand. Responses are summarized in Table 5, and are used to represent vegetable drying in the baseline CW LCA.

Table 5. Information on vegetable drying provided via email by product suppliers

vegetable	dryer type	estimated energy demand	energy carrier	Energy modeling approach
carrots	bin dryers (air dried)	10 mt steam per 1 mt dried carrot	steam generated via biomass (wood chips)	[Heat, from steam, in chemical industry {RoW}| steam production, as energy carrier, in chemical industry | Cut-off, U] modified by replacing electricity demand with average Chinese grid and energy demand with biomass represented by [Heat, district or industrial, other than natural gas {RoW}| heat production, softwood chips from forest, at furnace 300kW | Cut-off, S]
scallions	bin dryers (air dried)	25 mt steam per 1 mt dried scallion	steam generated via	[Heat, from steam, in chemical industry {RoW}| steam production, as energy carrier, in chemical industry | Cut-off, U] modified

[1] https://fdc.nal.usda.gov/index.html

			biomass (wood chips	by replacing electricity demand with average Chinese grid and energy demand with biomass represented by [Heat, district or industrial, other than natural gas {RoW}| heat production, softwood chips from forest, at furnace 300kW | Cut-off, S]
green peas	freeze dryer (22 hr cycle)	10,000 kWh per cycle, yields 900 kg peas	(assuming average Chinese grid electricity)	[Electricity mix, AC, consumption mix, at consumer, < 1kV/CN Economic]
sweet corn	freeze dryer (22 hr cycle)	10,000 kWh per cycle, yields 650 kg corn	(assuming average Chinese grid electricity)	[Electricity mix, AC, consumption mix, at consumer, < 1kV/CN Economic]
red bell pepper	air dried	2500 cubic meters natural gas per 1 mt dried bell pepper	steam generated by natural gas	[Heat, district or industrial, natural gas {GLO}| market group for | Cut-off, S]

The influence of these drying energy estimates is tested in Section 5.3.3.

3.2.3. Chef Woo processing & packaging

Noodle manufacturing occurs as shown in the system diagram in Figure 1, and can be seen in the video at: https://palmettogf.com/facility-showcase/. Briefly, noodle dough is mixed in batches of 150 kg flour to supply a continuous process line. The dough is pressed and then cut into noodles. Noodles are steamed to cook, then fried (in sunflower oil) to dehydrate in a shape that fits the ready-to-eat cup. The resulting noodle cake is placed in the paper cup and spices and dehydrated vegetables are added. The cups are heat sealed with a lid and aggregated into cardboard cases of 12 cups and cases are shrink-wrapped. 110 cases are stacked per pallet and stretch-wrapped. Figure 2 offers an image of the Chef Woo primary packaging, and modeling details of primary and tertiary packaging are given in Table 6. Note that packaging material demands reflect material in finished package and do not include manufacturing inefficiencies (scrap from form cutting).

Figure 2. Photograph of Chef Woo in retail packaging. Note that the four flavors shown here differ only in the composition of seasoning, and are modeled identically in this LCA.

Table 6. Chef Woo packaging materials and modeling approaches

component	quantity	Modeling approach/ LCI processes utilized	Shrink rate (%)	transport distance to Saluda, SC (km)
Primary packaging				
500ml paper cup	14.1 g (12.8 g paper, 1.3g PE)	Paper cups coated on each side with 0.75 mil PE; weight of PE estimated based on cup surface area as 1.3g per cup. • [Solid bleached board {GLO}| market for | Cut-off] {Ecoinvent} • [Packaging film, low density polyethylene {GLO}\ market for | Cut-off] {Ecoinvent}	31.4	3452
lid	1.1 g	Diecut lids constructed of 48 gauge PET, 70# C1S Paper, 1.1 mil polyolefin sealant. Assumed that total weight is evenly distributed across 3 materials: • [Polyethylene terephthalate, granulate, amorphous {GLO} market for | Cut-off] {Ecoinvent} • [Printed paper {GLO}| market for | Cut-off] {Ecoinvent} • [Packaging film, low density polyethylene {GLO}\ market for | Cut-off] {Ecoinvent}	26.8	4109
Tertiary packaging				
Cardboard case tray	140.5 g (per 12 cups)	[Corrugated board box {GLO}| market for corrugated board box | Cut-off] {Ecoinvent}	8.7	164
Case shrink wrap	10.9 g per case	[Packaging film, low density polyethylene {GLO}\ market for | Cut-off] {Ecoinvent}	n/a	116
Pallet stretch wrap	108.9 g per pallet	[Packaging film, low density polyethylene {GLO}\ market for | Cut-off] {Ecoinvent}	n/a	
Wood pallet	1 per 110 cases (15.9kg ship weight)	[EUR-flat pallet {GLO}| market for | Cut-off] {Ecoinvent}		1386

Utility inputs into the manufacturing process include electricity, natural gas (used in steamers and fryers), and municipal water (mixing dough, washing). Facility-level utility requirements were allocated to individual Chef Woo cups in the following fashion: electricity, natural gas and water utilities bills were collected and compiled for the November, 2020 to April, 2021 time period. The Palmetto facility runs parallel processing lines, one producing ramen cups, the other ramen flats or "pillows" (for home preparation in a pot). Facility engineers indicated that resource consumption was allocated between the two lines as indicated in Table 7. As Chef Woo is currently only offered in cups, the compiled November to April utility demands were allocated to the cup line, and then divided by the *total* number of cups (Chef Woo, Ramen Express, and co-packing units) produced over the time period. Note that it is assumed that energy use per cup is the same regardless of whether the processing line is manufacturing high-protein ramen (Chef Woo) or typical wheat-based ramen.

Table 7. Utility consumption allocation between product lines at Palmetto Foods facility

	Electricity*	Natural gas‡	Water use‡
Cup noodle line	44%	45%	50%
Pillow noodle line	56%	55%	50%

* based on electricity current readings at main electrical panels for each line

‡ informed estimate by facility engineers

3.2.4. CW distribution

US distribution of Chef Woo is limited for financial reasons to the following states: Mississippi, Tennessee, Illinois, Kentucky, North Carolina, Virginia, West Virginia, Maryland, Ohio, Indiana, Missouri, Arkansas, Alabama, Georgia, Florida, and Pennsylvania. An average distribution distance was estimated by selecting locations in these states from a database[2] of distances between the top 1000 US population centers and then generating a population-weighted average distance between Columbia, SC (closest city in database, 53 miles from Saluda, SC) and these population centers. The resulting population-weighted distance, 977 km, was used to represent CW distribution in the base case. Sensitivity to distribution distance is considered in Section 5.3.1. Transport for this distribution phase was modeled with the Ecoinvent process, [Transport, freight, lorry, unspecified {GLO}| market for | Cut-off, S].

3.2.5. CW Preparation for consumption

This study excludes the retail stage of the CW supply chain. This exclusion is considered conservative as CW is shelf stable and does not require refrigeration, and therefore its allocation of retail-level energy consumption should be lower than that of fresh meats. However, representation of retail stages in LCA introduces a great deal of uncertainty and modeling challenges that were deemed unnecessary for the goals of this study.

However, the preparation stage was included in order to demonstrate differences arising from preparation of the "instant" ramen product compared to other protein sources that require cooking before consumption. Instant ramen is prepared simply by adding boiling water. The preparation stage impacts are therefore associated with the energy required to bring 250 mL of water to boiling, which, assuming a starting temperature of 68°F, equals 83.6 kJ. An energy transfer efficiency of 80% was assumed for heating water in an electric kettle[3]. Sensitivity to this energy transfer efficiency is considered in Section 5.3.1.

3.2.6. Packaging disposal modeling

End of life processes are *not* included for the main food product in this study, nor are the effects of food waste included. CW is shelf-stable and (as modeled here) is sold in single-serving units. Therefore it is anticipated that loss/waste rates through post-manufacturing stages will be low. No specific information was available on CW food waste rates, so food waste contributions were therefore excluded to avoid the additional uncertainty.

However, in order to facilitate future comparisons of different packaging formats, disposal of packaging materials is included.

Modeling of packaging disposal follows EPA's Waste Reduction Model (WARM, version 14) (US EPA 2016). The WARM model uses a life cycle approach to estimate energy use (or credit) and

[2] Database originally obtained from: http://www.mileage-charts.com/chart.php?p=chart&a=NA&b=US is no longer available at this location.

[3] http://insideenergy.org/2016/02/23/boiling-water-ieq/

GHGE associated with recycling, combustion, composting and landfilling of different materials. While the WARM model uses the avoided burden approach to credit recycling by the offset of virgin material, in our model we account for the influence of recycled content in material production via a recycled content (or cut-off) method. Thus, recycling aids the system by avoiding end-of-life burdens from landfill or incineration, but does not result in a material displacement credit at the end-of-life process.

We assume US average recycling rates of 68.2%[4] for the paper portion of the noodle cup as well as the case tray. As case shrink wrap PE, and pallet wrap PE will be generally removed at a distribution or retail hub, we assume 100% recycling of these films. The cup PE coating and lid (as well as the remaining 31.8% of paper) are landfilled.

3.3. U.S. meat production: baseline for comparison

The major US meat commodity groups have sponsored high-quality LCAs of US beef, pork, and chicken production in recent years, and these studies form the basis for comparison here. Building from previous LCAs of US beef production (Battagliese et al. 2013; Battagliese et al. 2015; Thoma et al. 2017), Rotz, et al. developed a comprehensive environmental footprint of US beef cattle production in the US that incorporates regional production practices and characteristics as well as the influence of cull animals from the dairy industry (Rotz et al. 2019). This study did not report land use impacts, so values from (Thoma et al. 2017) are used as placeholder, recognizing they introduce some inconsistency. The environmental footprint of US swine (pork) production was evaluated in a cradle-to-farm gate LCA also designed to reflect geographic and production practice variability (Putman et al. 2018). The most recent year presented (2015) was used here as the comparative benchmark. Further, a cradle-to-farm gate LCA of the US poultry industry offers a snapshot of the environmental footprint of chicken production (Putman et al. 2017), with 2010 used as the benchmark year here. A summary of the results from these three studies is presented in Table 8. While inconsistencies exist in the specific impact assessment methods utilized in these three studies, for the impact categories considered here, this is of minor consequence. Fossil energy use, blue water use, and land use are (largely) uncharacterized inventory indicators; the beef and pork study both utilize global warming potentials based on IPCC 2013 100 year time horizon. It is only the GHGE from the poultry study that uses somewhat outdated global warming potential characterization factors. Ideally, this could be corrected, but (Putman et al. 2017) do not report inventory results of individual greenhouse gases.

Table 8. Summary of LCA results for U.S. beef, pork and chicken production, at farm gate.

	source	Base year	weight basis	GHGE	Fossil energy use	blue water use	Land use
				kg CO_2-eq.	MJ	liter	m^2a
Beef (inc. dairy culls)	(Rotz et al. 2019)	2013-2017	kg carcass weight	21.3	50	2034	22.1*
pork	(Putman et al. 2018)	2015	kg live weight	3.1	22.5	180	3.7
poultry	(Putman et al. 2017)	2010	kg live weight	1.28	12.5	113	3.2

*value from (Thoma et al. 2017); includes contribution from "feed" and "cattle," corrected to remove influence of food waste, and multiplied by 0.667 to approximately convert back from boneless weight to carcass weight.

[4] https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/paper-and-paperboard-material-specific-data

3.3.1. Slaughter and processing

The results in Table 8 represent production of livestock animals at farm gate; to represent the slaughter and processing stage in the comparison cases, the following AFP processes were modified:

- [Beef meat, fresh, from beef cattle, at slaughterhouse, PEF compliant/IE Economic/Economic]
- [Pig meat, fresh, at slaughterhouse/NL Economic]
- [Chicken meat, fresh, at slaughterhouse/NL Economic]

In each case, a dummy process representing the results in Table 8 was created and substituted in place of the "at farm" input. In addition, electricity demand was substituted to be supplied by the US average grid. In addition, as the beef production study provided results at farm gate on a carcass weight basis whereas the inputs into the slaughter process were on a live weight basis, the beef slaughter process was further modified such that, as modeled at least, carcass beef is the input to the slaughter process. To do this, first, hides and skins, category 1/2 byproducts, and category 3 byproducts were eliminated as co-products, leaving only beef meat, food grade bones, and food grade fat. Second, the "at farm" input amount was reduced from 1 kg to 0.614 kg (weighted average of the dress percentages for beef cattle and Holstein steers) and minor adjustments were made to co-product outputs (bones from 0.08kg to 0.07kg, fat from 0.07kg to 0.054kg) to assure mass balance. Finally, the allocation percentages from the removed co-products were added to beef meat such that allocation was only between meat and food-grade bones and fat. These modifications to the beef slaughter process are summarized in Table 9.

Table 9. Summary of modifications made to AFP beef slaughter process in order to accommodate US beef "inputs" on carcass weight basis

(relevant) flows in beef slaughter process	Original process		Modified process	
	Quantity (kg)	Economic allocation factor	Quantity (kg)	Economic allocation factor
INPUT				
Beef cattle for slaughter, at beef farm	1	-	0.614	-
OUTPUTS				
Beef meat, fresh, from beef cattle, at slaughterhouse	0.49	92.9%	0.49	97%
Beef co-product, food grade bones, from beef cattle, at slaughterhouse	0.08	1%	0.07	1%
Beef co-product, food grade fat, from beef cattle, at slaughterhouse	0.07	1.8%	0.054	2%
Beef co-product, Cat.3 by-products, from beef cattle, at slaughterhouse	0.07	0.8%	0	
Beef co-product, hides and skins, from beef cattle, at slaughterhouse	0.07	3.5%	0	
Beef co-product, Cat.1/2 and waste, from beef cattle, at slaughterhouse	0.22	0%	0	

3.3.2. Packaging and distribution

Packaging for all meat products was modeled as a simple polystyrene tray wrapped with PE film. Packaging material weights were borrowed from a previous study (Heller et al. 2019). Plastics were assumed to be landfilled at end of life, whereas corrugated cardboard (tertiary packaging) was assumed to be recycled.

Distribution of meats was modeled using an identical distribution distance as that for CW (977 km). However, a different transport process was used to account for cold chain requirements during meat distribution: [Transport, freight, lorry with reefer, cooling {GLO}| market for | Cut-off, S]{Ecoinvent}.

3.3.3. Home storage and preparation

Meats require refrigeration and cooking before consumption. Energy consumption at this life cycle stage can vary widely depending on household behaviors, cooking styles and preferences, etc. Here, we use refrigeration and cooking energy consumption per kg reported in a full supply chain LCA of US dietary patterns (Kim et al. 2020), averaging values for the "red meat" and "poultry" food group. This resulted in home refrigeration energy demand of 1.65 kWh per kg and cooking energy demand of 2.45 kWh (delivered energy) per kg. While there may be small differences in energy demand depending on cooking process (frying vs. boiling, for example), this value is interpreted as an "average" of typical cooking. Average US grid electricity supplied refrigeration energy, whereas cooking was divided 65% to electricity, 35% to natural gas, based on average US household range ownership (EIA 2018).

3.4. Beyond Burger

A comparison with Beyond Burger (a pea-protein based beef analog burger) was included to facilitate comparison with other plant-based protein products. Results from Heller and Keoleian (2018) reflecting the production, packaging and pre-distribution cold storage of 1 kg Beyond Burger were built into a dummy process in SimaPro which was then linked to distribution and home storage and preparation stages modeled identically to those described for the meat products, above.

3.5. Ramen Express wheat-based ramen

The manufacturing of Ramen Express (wheat-based noodle) is essentially identical to that of CW, with the exception of the flour ingredients (wheat flour only), frying oil (palm oil instead of sunflower oil) and minor differences in the quantities of seasoning and dried vegetables used. Thus, a parallel model was developed for Ramen Express, making appropriate adjustments to ingredients. The AFP process: [Refined palm oil, at plant/NL Economic] was used for frying oil. Noodle processing was modeled identically to CW.

4. Life Cycle Impact Assessment Results

4.1. Chef Woo LCA results

The contribution from major stages/components in the CW life cycle to the four impact indicators is shown in Figure 3, followed by numerical results presented in Table 10. Noodle ingredients (which includes frying oil) is a significant contributor across all indicators. Land and water use is dominated by the agricultural production of CW ingredients. Downstream stages of distribution and preparation contribute minimally across all indicators.

In the following sections, we consider the environmental indicators independently in more detail.

Figure 3. Distribution of impacts across life cycle stages for CW noodle cup.

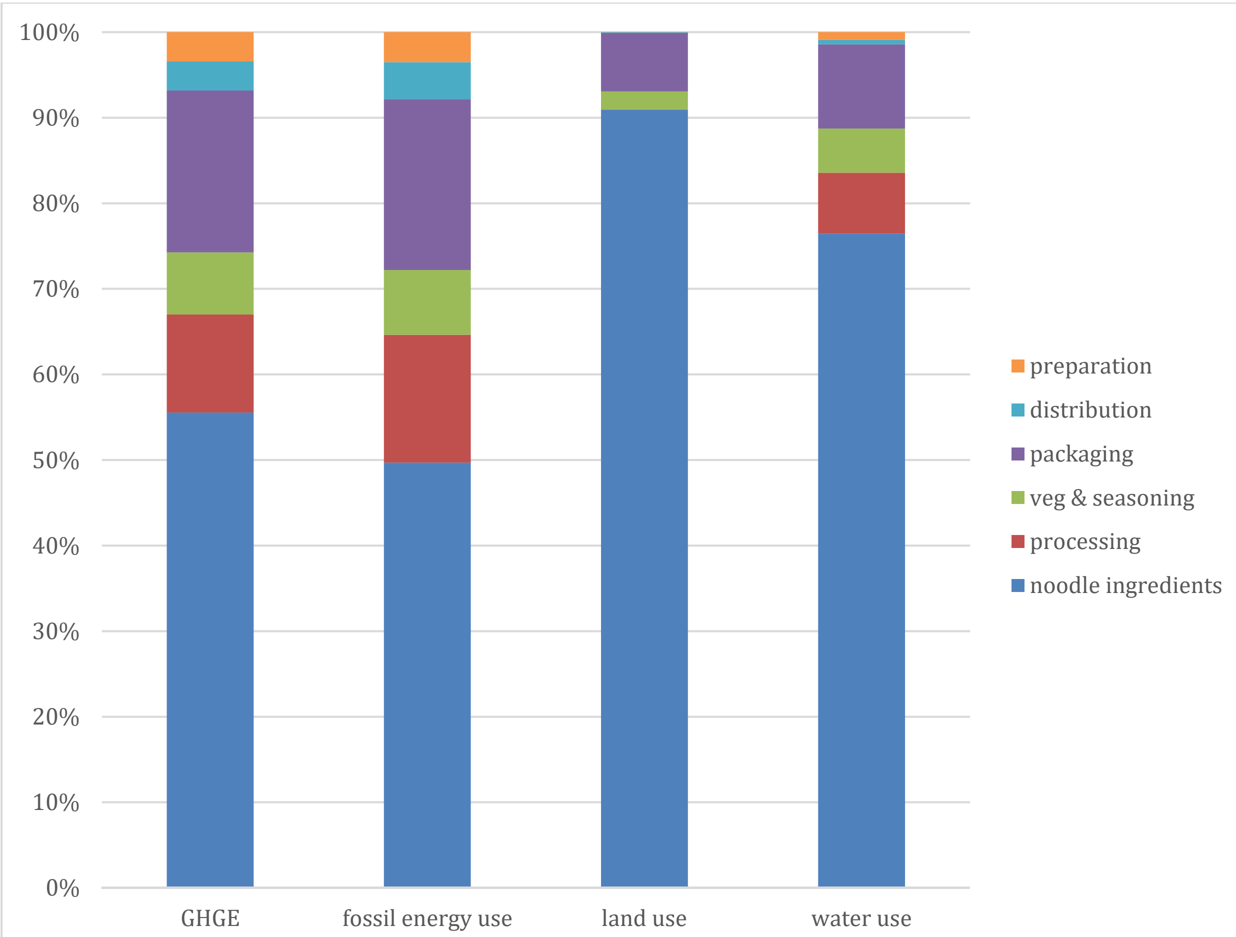


Table 10. LCA results for one Chef Woo noodle cup.

	Unit	Total	noodle ingredients	processing	veg & seasoning	packaging	distribution	preparation
GHGE	kg CO_2 eq	0.43	0.24	0.05	0.03	0.08	0.01	0.01
fossil energy use	MJ	5.08	2.52	0.76	0.38	1.01	0.22	0.18
land use	m^2a crop eq	0.91	0.83	0.00	0.02	0.06	0.00	0.00
water use	liter	8.18	6.25	0.58	0.42	0.80	0.04	0.08

4.1.1. Greenhouse gas emissions

The GHGE associated with producing, delivering and preparing a Chef Woo ramen noodle cup are 0.43 kg CO_2eq per cup. CO_2 emissions dominate the inventory (CO_2 = 79% of total global warming potential; methane = 12.3%, nitrous oxide = 8.6%). More than 60% of this impact is associated with producing and delivering ingredients (noodle + veg & seasoning); packaging represents 19%, and processing steps represent 12%. Additional details on the percent contributions to GHGE are given in Table 11.

Table 11. Percent contributions to GHGE from different stages and processes in the CW life cycle.

	% total	% of stage
noodle ingredients	55.5	
pea protein isolate	24.4	43.9
proprietary protein	7.0	12.6
wheat flour	5.8	10.5
sunflower oil	13.6	24.5
ingredient transport	4.6	8.3
processing	11.5	
natural gas	7.2	62.5
electricity	4.2	36.3
veg & seasoning	7.3	
raw veg	1.5	20.3
veg drying	4.5	62.4
seasoning	0.5	7.4
transport	0.3	4.6
packaging	18.9	
cup & lid	9.7	51.5
tertiary	5.9	30.9
disposal	3.3	17.6
distribution	3.4	
preparation	3.4	

4.1.2. Fossil energy use

Distribution of energy demand across life cycle stages follows that of GHGE fairly well, with the exception that processing and packaging represent somewhat larger shares. Ingredients contribute more than half of the fossil energy use, with pea protein isolate being the single greatest contributor, at 24.3% of total fossil energy use. Energy used directly in the CW processing line represents 15% of the life cycle total, with 68% of this from natural gas use and the remainder from electricity. Energy use in distribution of the CW product is only 4.3% of the total, whereas preparation for consumption constitutes 3.5%.

Producing and drying the included vegetables uses 6.6% of the total fossil energy consumed, with the freeze dried products contributing most notably (see Table 12). Contributions from carrot and scallions are particularly low as the supplier of these vegetables indicated that the energy used for drying is supplied by wood chips (i.e., non-fossil energy). Sensitivity of these results to the values supplied by suppliers are explored in Section 5.3.3.

Table 12. Contribution to energy use by different vegetables compared their mass in CW

	% of dried veg. fossil energy use	*% of dried veg. mass*
Air dried carrot	4%	34%
Air dried scallions	4%	20%
Freeze dried green pea	36%	14%
Air dried red bell pepper	15%	17%
Freeze dried sweet corn	42%	16%

4.1.3. Land use

As may be expected, agricultural production of ingredients dominates land use (93%, including noodle, oil and dried vegetables) with packaging representing the remainder. Contributors include sunflower oil (32%), pea protein isolate (31%), wheat flour (19%), proprietary protein (proxied by pea isolate) (9%), and all vegetables (2%). Paper products in packaging contribute 6% total, roughly half in primary packaging and half in tertiary packaging.

4.1.4. Water use

Agricultural production of ingredients also dominates water use, with noodle ingredients and oil contributing 73% and dried vegetables 5%. Packaging production represents 10% of total water use whereas the water used in the CW processing itself (making noodle dough) is 5% of the total. Upstream contributions from all transportation, electricity and natural gas use total an additional 5%. Individual ingredient contributions include: pea protein isolate (38%); wheat (15%); sunflower oil (10%); proprietary protein (proxied by pea) (11%); primary packaging (7%).

4.2. Comparisons with other protein sources

Table 13, Figure 4 and Figure 5 offer a summary of the comparison of CW with other protein sources; all entries represent the provision of 20g protein. In general, CW performs better than comparative protein sources on GHGE, energy use and water use, with some exceptions. Differences in GHGE between CW and chicken are less than 10%, which is not considered significant within the uncertainty of each study (potential variability in animal production values will be discussed in Section 5.2.3). Beyond Burger outperforms CW in terms of water use, likely driven by very low water use in the pea protein isolate dataset used in the Beyond Burger study (pea protein isolate is also the primary protein source in the Beyond Burger, and that study utilized yet another proprietary LCA result for pea protein isolate). Interestingly, CW has higher land use than all comparisons except beef. This is likely driven by the fact that CW relies on a number of ingredients requiring post-farm processing (pea protein isolate, sunflower oil, dried vegetables) which, due to mass reductions and co-product allocations, can amplify the land use impacts of agricultural production.

Table 13. Comparison of total impacts for supplying 20g protein from various sources.

	GHGE	fossil energy use	land use	water use
	kg CO_2eq	MJ	m^2a	liter
Chef Woo	0.43	5.08	0.91	8.18
beef	3.32	10.33	3.13*	289.01
pork	0.88	7.55	0.72	35.67
chicken	0.39	4.22	0.40	15.15
Beyond Burger	0.59	8.36	0.45	4.29
Ramen Express + beef	2.85	10.81	2.69	220.52
Ramen Express + pork	1.02	8.71	0.88	30.14
Ramen Express + chicken	0.64	6.22	0.64	14.76

*land use value is from a different US beef production LCA than other beef indicators; used here as proxy

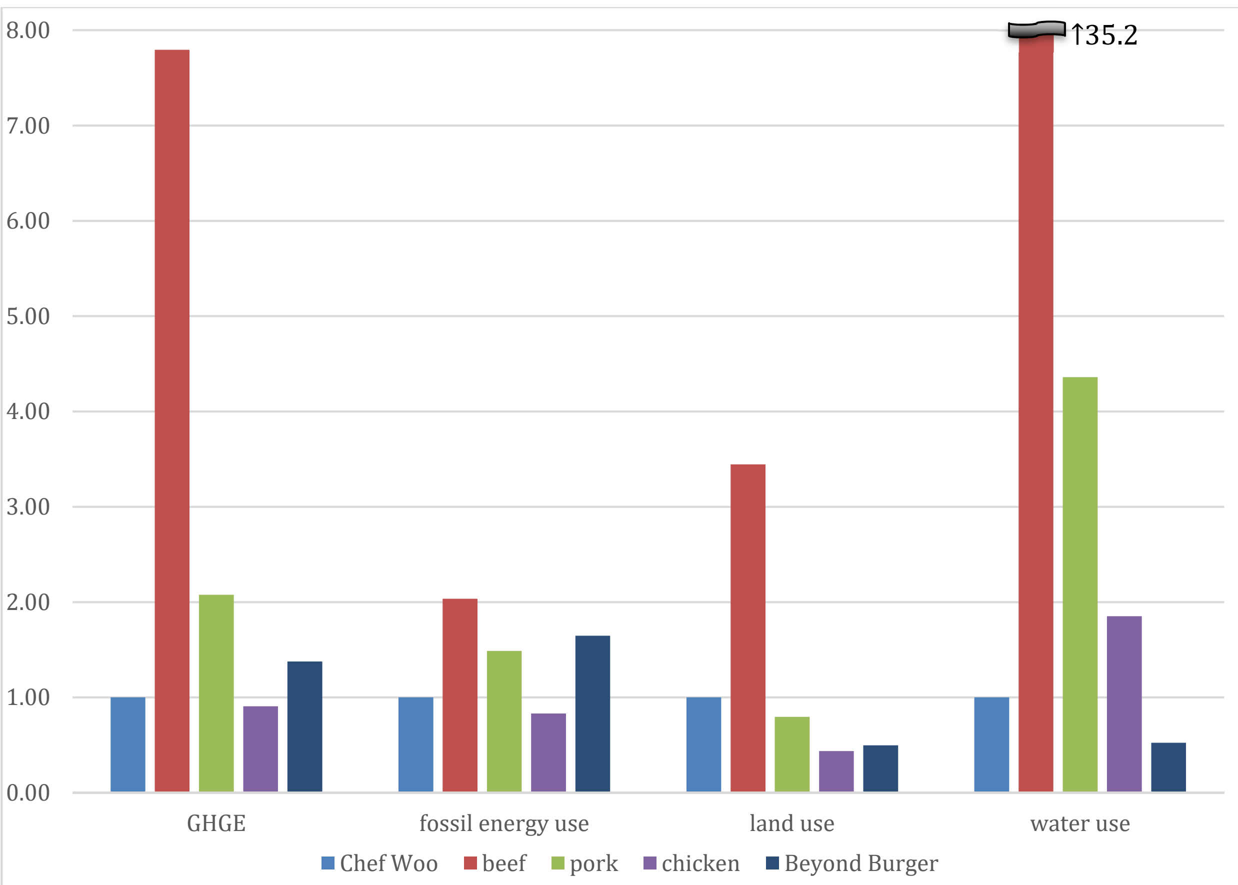


Figure 4. Relative comparison of supplying 20g protein from various sources. Chef Woo is set to 1.0.

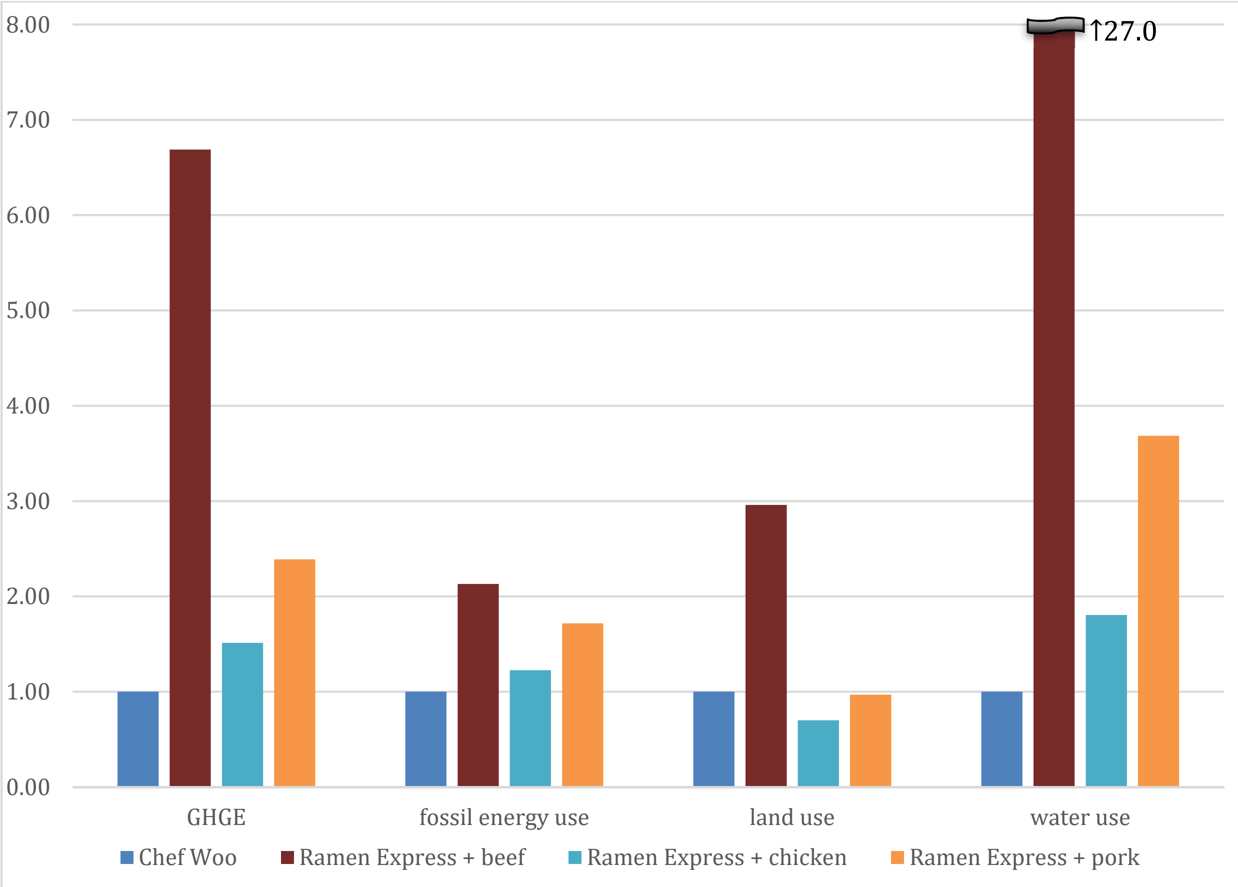


Figure 5. Relative comparison of Chef Woo noodle with regular noodle + meat. Chef Woo is set to 1.0

For reference, Figure 6 provides the distribution of impacts across life cycle stages for the comparative cases. In general, impacts are dominated by the production stage, but home storage and preparation impacts make notable contributions to fossil energy use in all cases and to GHGE for chicken and Beyond Burger. Figure 7 offers the distribution of impacts across life cycle stages for the wheat-based noodle, Ramen Express. This distribution is very similar to CW with somewhat larger percentages attributable to processing and packaging due to lower impacts from ingredients (wheat flour is less impactful than pea protein isolate, and Ramen Express contains smaller quantities of dried vegetables). Relative to CW, Ramen Express has lower environmental impacts per cup (29% less GHGE, 42% less fossil energy, 63% less land use, 60% less water use) but supplying an equivalent quantity of protein through Ramen Express plus meat (as may be a typical meal) is more impactful than CW in all categories except land use.

Figure 6. Distribution of impacts across life cycle stages for beef, pork, chicken and Beyond Burger.

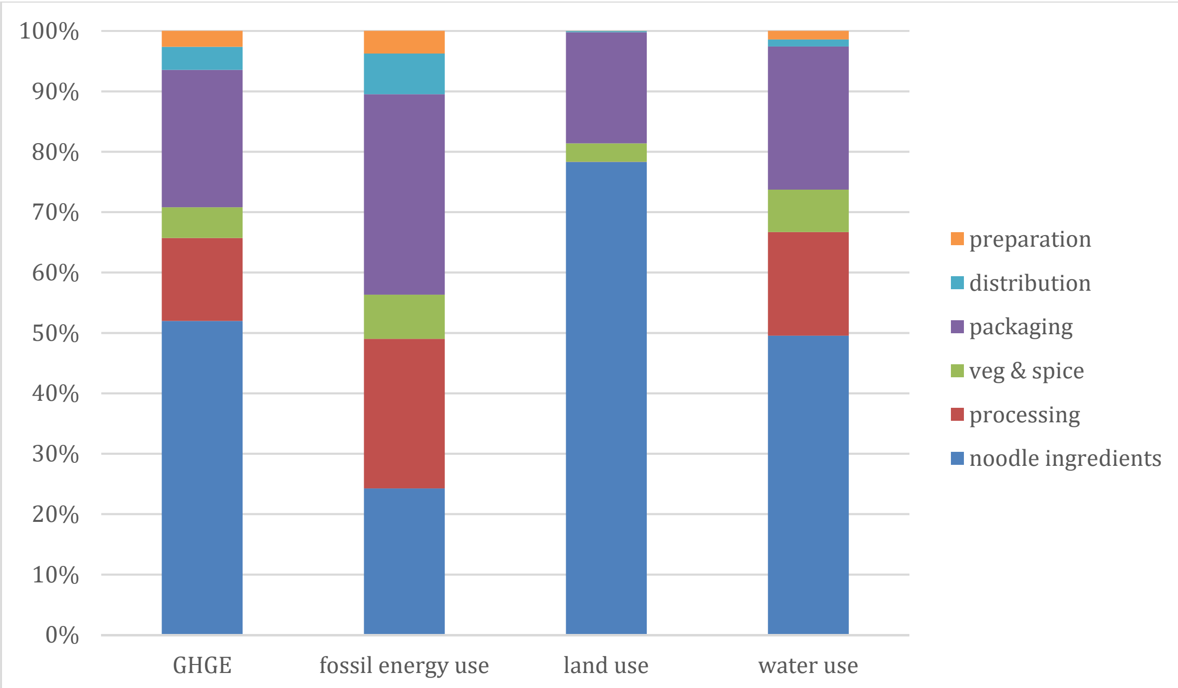


Figure 7. Distribution of impacts across stages for Ramen Express (wheat-based noodle)

5. Interpretation

5.1. Identification of Relevant Findings

Based on the LCA findings presented here, CW outperforms beef as a source of protein in all impact categories, and performs as good or better than pork or chicken in all categories except land use. Combining regular (wheat-based) ramen with enough beef, pork or chicken to supply 20g of protein also has higher GHGE, energy use, and water use than CW. Beyond Burger, also a processed, plant-based protein source, results in 27% more GHGE and 39% more fossil energy use than CW but about 50% less land and water use.

This study confirmed expected findings regarding "hotspots" in the CW life cycle. The production of ingredients made notable contributions to GHGE, energy use, land use and water use. Supplying protein is often resource intensive, and the primary CW protein source, pea protein isolate, is the top contributor across all impact categories, with the interesting exception of land use, where sunflower oil makes a comparable contribution. Packaging, distribution and at-home preparation make minor contributions across all categories.

The poorer performance relative to meats of CW land use compared to GHGE appears to, at least in part, be due to contributions from sunflower oil. Whereas the contribution from sunflower oil to overall CW GHGE is 14%, its contribution to land use is 32%. Figure 8 demonstrates that, while there can be notable variation in some impact categories due to country of origin and/or oil separation processes, alternative oils suitable for frying (e.g., rapeseed, soybean) could lead to notable reductions in environmental impact. Environmental impact, of course, must be balanced with other criteria in the selection of frying oils, and results in Figure 8 are illustrative only and will require further investigation to inform a selection. Still, this appears to be one area where CW environmental performance could be improved.

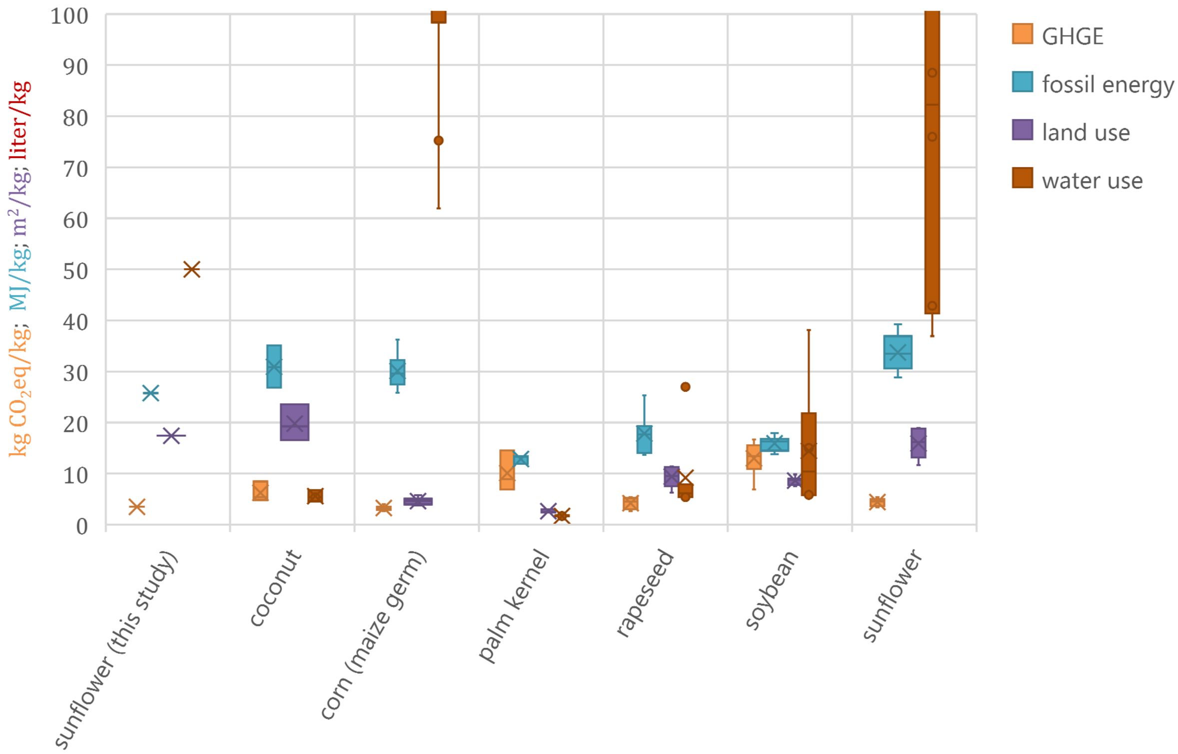


Figure 8. Example of variation in environmental impact intensity of refined vegetable oils. Included datapoints are from Agrifootprint v. 4.0, economic allocation, and include the following crop/country combinations: coconut ID, IN, PH; maize germ (both pressing and solvent extraction) DE, FR, NL, US; palm kernel ID, MY; rapeseed (both pressing and solvent) BE, DE, NL, US; soybean (both pressing and solvent) AR, BR, NL; sunflower (both pressing and solvent) AR, CN, UA   The "X" inside box represents averages, box and whiskers are upper and lower quartiles, circles are individual datapoints. Y-axis is cropped to improve resolution of other datapoints; the average water use for maize germ is 209.5 L/kg and sunflower is 403 L/kg.

5.2. Assumptions and Limitations

5.2.1. Boundary condition limitations

The boundary conditions employed in this study follow the products through distribution and also include the at-home use stage (storage and preparation). The retail stage, as well as potential contributions from food waste, are excluded. Both of these are expected to favor CW because it is shelf stable and does not require refrigeration, and is sold only in single serving units. However, no specific information was available on CW food waste rates, so food waste contributions were excluded to avoid the additional uncertainty.

5.2.2. Spatial and temporal assumptions

CW production was modeled based on current practices, including specific ingredient supply chains, where known. Such specifics could be subject to market shifts such as, for example, a shift in suppliers or agricultural production regions. In addition, CW processing efficiencies are based on current production practices, and efficiencies can be expected to improve as production volume increases, leading to decreasing impacts (Section 5.3.1considers result sensitivity to electrical use intensity). Further, future production scenarios may include more geographically distributed production, thus influencing transportation distances.

5.2.3. Variability in meat production systems

We have utilized what we feel to be LCA studies representative of contemporary US livestock production for the comparative cases here. However, there can be notable variability in LCA results due to differences in production practices, production regions, and in some cases, LCA methodological and modeling choices and underlying data availability. Therefore, it is useful to consider potential ranges in associated environmental impacts. Numerous "meta review" style databases have emerged in recent years to offer estimates to environmental impacts associated with foods, often with the distinct acknowledgement of the above-mentioned variability. Table 14 offers comparisons of the values used in this study with two such sources. Note that the boundary conditions with these sources differ, thus Table 14 offers two different corresponding reference points, although the numerical differences are minor. The data from Poore and Nemecek (Poore and Nemecek 2018) was weighted to represent global production and therefore skews considerably higher than both the US livestock production values used here as well as values from dataFIELD (which were intended to represent US consumption).

In general, the conclusions drawn from Table 14 are that the results used here for comparison to CW are low relative to the range of values seen more broadly. This means that conclusions drawn on CW performance in relation to these animal-based protein sources are conservative.

Table 14. Comparison of meat LCA results used in this study with other sources

	used in this study, cradle to farm gate	from dataFIELD (Heller et al. 2018) (Heller et al. 2021)‡			used in this study, cradle to distribution	from (Poore and Nemecek 2018)			
		average ± SD		n		mean	median	min	max
GHGE (kg CO_2eq / kg boneless meat)									
beef	25.9	33.1	±12.6	95	26.7	99.5	60.4	35.1	432.0
pork	5.3	5.6	±1.6	50	6.1	12.3	10.6	6.6	27.6
chicken	1.8	4.2	±2.3	32	2.5	9.9	7.5	4.0	47.7
energy use (MJ / kg boneless meat)									
beef	57.2	67.9	±39.1	19	65.1	N/A			
pork	36.2	28.6	±6.9	17	44.3				
chicken	16.5	27.3	±11.4	15	23.8				
land use (m^2 / kg boneless meat)									
beef	26.9	N/A			26.9	326.2	170.4	49.0	1971.9
pork	6.5				6.5	17.4	13.4	7.4	286.7
chicken	4.4				4.4	12.2	11.0	6.4	61.8
water use (L / kg boneless meat)									
beef	2472.3	1447			2476.5	1451	740	101	26951
pork	307.9	802			312.0	1796	1810	67	6318
chicken	158.1	876			161.9	660	370	19	4710

‡ GHGE and energy use based on meta-review methods described in (Heller et al. 2018); database available at: https://css.umich.edu/page/datafield ; SD = standard deviation; n = number of entries included in average and SD. Water use based on basin-level blue water use of US feed crops, production weight-averaged to national level, then combined via simplistic feed rations to animal production; method described in (Heller et al. 2021).

5.3. Results of Sensitivity Analysis

5.3.1. Modeling parameter sensitivity

The influence of a number of parameters on overall CW system environmental performance is shown in Table 15. Shrink rates (waste) for various material inputs were calculated based on production records; however, changes in production practices or efficiencies could affect these rates. Table 15 demonstrates the percent change to overall CW performance from a 20% increase in shrink rate. Note that these sensitivities are all linear: for examples, a 20% *reduction* in noodle shrink rate would result in a 1.99% *reduction* in CW carbon footprint, and a 10% increase would result in a 1.00% increase in carbon footprint (half of value reported in Table 15). While the influence of individual shrink rates is small, eliminating all waste results in a notable decrease (nearly 14% decrease in GHGE). The average distribution distance in the base case was calculated based on a population weighted average distance from the production location (Saluda, SC) to population centers in the 16 states in which CW is currently distributed. Assuming instead a distribution to all of the top 1000 population centers in the continental US (i.e., all states) results in a 4.6% increase in CW carbon footprint.

When calculating the energy required to boil water for CW rehydration, an energy transfer efficiency of 80% was assumed, typical for electric kettle heating. Assuming water is boiled instead in a microwave (with an assumed energy transfer efficiency of 50%) results in a 2.1% increase in carbon footprint. Often, more water is boiled in an electric kettle than is needed; Table 15 indicates the impact this has on CW LC performance. Finally, the "seasoning" used in CW, a complex blend of salts, herbs and spices, was modeled as sodium chloride. Arbitrarily increasing the impact of salt per kg by a factor of 5 (500%) to accommodate for other seasoning components – an unlikely high increase – results in a 2% or less increase across all indicators.

Recognizing that current production at the Palmetto Gourmet Foods facility is below capacity, we consider the sensitivity of environmental performance to a reduction in electricity intensity. The average production throughput over the 6 months of data used in this study was 29% of capacity. While increasing product throughput will likely lead to an increase in natural gas consumption (e.g., because additional water is evaporated from noodles in fryer), electricity demand largely covers overhead (lights, HVAC, processing line operation) that may remain roughly constant with increased product throughput. To demonstrate this effect, we divide the electricity intensity (kWh/cup produced) by 2.93 (ratio of 85% to 29% capacity). This results in a 2.7% decrease in overall CW GHGE and a 3.1% reduction in fossil energy demand.

Finally, the base case assumed that the case shrink wrap PE and pallet wrap PE was recycled. Assuming instead that these films are landfilled has a negligible effect on GHGE of 0.01% (not shown in Table 15.

Table 15. Sensitivity of CW LCA model to a variety of parameters. All values are shown relatve to the totals in Table 10.

	GHGE	energy use	land use	water use
	(%) percentage increase from total CW baseline impacts			
Noodle shrink rate (+20%)	1.99	1.92	2.71	2.49
Dried corn shrink rate (+20%)	0.06	0.07	0.01	0.04
Seasoning shrink rate (+20%)	0.02	0.02	0.00	0.01
Cup shrink rate (+20%)	0.50	0.50	0.16	0.33
Lid shrink rate (+20%)	0.05	0.08	0.00	0.03
Case tray shrink rate (+20%)	0.07	0.05	0.01	0.02
All shrink rates = 0	-13.53	-13.27	-14.50	-14.64
Average distribution distance (+20%)	0.68	0.87	0.00	0.10
Distribution distance = national weighted average (2308 km)	4.61	5.88	0.00	0.71
Boiling water in microwave (energy transfer efficiency = 50%)	2.06	2.11	0.00	0.55
Boiling extra 20% water	0.69	0.70	0.00	0.18
Boiling 100% extra water (2x necessary)	3.44	3.52	0.00	0.92
Seasoning impact 5x greater	2.08	2.13	0.01	1.56
Electricity intensity (per cup) reduced (/2.93)	-2.74	-3.13	0.01	-0.86

5.3.2. Pea protein isolate variability

Limited LCA data are available for the purified plant-based protein concentrates and isolates that are common in plant-based protein foods. The data used in the CW baseline came from Borealis' pea protein isolate supplier (Section 3.2.2.1). However these LCA results are notably different (GHGE 54% greater) than the pea protein isolate dataset available in AFP (Table 16). The AFP process is modeled for production in Europe, with 81.4% of peas from France (modeled with the identical agricultural production process used in our estimate) and the balance from Germany. The economic allocation to pea protein isolate is lower in AFP compared to data provided by the US supplier, suggesting that a healthier market for byproducts from this process may exist in Europe. The majority (60%) of the processing energy use in the US supplier case is associated with drying of the pea protein isolate (processing stages are not differentiated in the AFP dataset).

Table 16. Comparison of LCA datasets for pea protein isolate production

		total	pea ag. production	processing	intermediate transport
GHGE (kg CO2eq/kg)	pea protein isolate, US supplier	6.0	2.2	3.1	0.8
	pea protein isolate, AFP process	3.9	1.5	2.2	0.1
fossil energy use (MJ/kg)	pea protein isolate, US supplier	71.7	16.0	44.0	11.7
	pea protein isolate, AFP process	39.0	10.3	26.9	1.8
land use (m2a/kg)	pea protein isolate, US supplier	16.4	16.3	0.02	0.04
	pea protein isolate, AFP process	10.6	10.6	-	-
water use (liters/kg)	pea protein isolate, US supplier	187.1	169.2	15.7	2.2
	pea protein isolate, AFP process	109.6	84.5	1.7	0.1

At this stage, the source of the differences between these datasets remains unclear and needs to be treated as uncertainty within the CW model. Using the AFP pea protein isolate dataset reduces CW GHGE by 11.1%, fossil energy use by 14.3%, land use by 14.1%, and water use by 21.0%.

5.3.3. Vegetable drying variability

There is limited information in LCA databases and studies in the literature on vegetable drying, and an informal review of empirical values from the literature shows tremendous variation in energy demand. Anecdotal evidence suggests that conventional convective drying (hot air blown over cut samples) remains the industry standard and that significant improvement in drying energy efficiency can be achieved through alternative drying methods either in place of or in concert with convective drying (Menon et al. 2020). Early modeling exercises of the energy required to dry the vegetables in CW proved this parameter to be important to the overall noodle cup sustainability performance. Thus, we reached out to current suppliers for energy estimates (see Section 3.2.2.2) that are now used in the base case. However, we acknowledge that there may be variability in this vegetable drying energy demand, resulting in uncertainty in LCA results.

Table 17 offers an overview of the GHGEs associated with producing dried vegetables as modeled in this study, based on the energy demand estimates communicated by suppliers. Per information from the supplier, carrot and green onion were modeled with heat supplied by wood chips. For reference, Table 17 also includes values if heat were instead supplied by natural gas. This substitution (natural gas rather than biomass for drying carrot and onion) increases the carbon footprint of CW by 1.4%. Clearly, freeze drying (green pea and sweet corn) is more energy intensive than air drying, but these differences do not appear as great as the 4-10 times more intensive mentioned in a recent review article (Bhatta et al. 2020).

Table 17. GHG emission intensity of dried vegetable production as modeled in this study

GHGE (kg CO_2eq /kg dried product)	air dried carrot	air dried green onion	freeze dried green pea	air dried red bell pepper	freeze dried sweet corn
total	1.62	3.49	15.00	9.21	21.90
drying energy	0.56	1.41	12.90	4.25	17.80
raw veg production	0.66	1.68	1.74	4.48	3.64
transport	0.40	0.40	0.40	0.48	0.40
(assuming heat from natural gas rather than biomass)					
total	4.52	10.70			
drying energy	3.46	8.65			

Table 18 demonstrates how CW environmental performance responds to increases in vegetable drying energy demand, and that a 5-fold increase in energy for drying the small quantity of vegetables (2.9 g) can result in notable increases in CW GHGE and energy use. While a 5-fold increase may seem extreme, it does not appear to be out of the realm of possibility based on empirical values reported in the literature for convective drying of vegetables (Beigi 2016; Menon et al. 2020). Thus, vegetable drying remains an important parameter to consider in the environmental performance of CW.

Table 18. Percent increase in CW environmental performance (over Table 9 baseline) resulting from increases in vegetable drying energy demand

% Increase in drying energy demand	GHGE	energy use	land use	water use
10%	0.5%	0.5%	0.0%	0.0%
20%	0.9%	1.1%	0.1%	0.0%
50%	2.3%	2.7%	0.2%	0.0%
100%	4.5%	5.5%	0.4%	0.1%
500%	22.5%	27.3%	2.2%	0.4%

To further elucidate the contribution of dried vegetables to CW environmental performance, a scenario is considered without vegetables included (Table 19).

Table 19. CW scenario excluding vegetables

	Unit	Total	% reduction from basecase (Table 9)
GHGE	kg CO_2 eq	0.40	6.3%
fossil energy use	MJ	4.74	6.5%
land use	m^2a crop eq	0.89	2.1%
water use	liter	7.80	4.7%

5.3.4. Allocation choice

The ISO guidelines offer a preference to allocation choice in LCA, but leave much room for practitioner interpretation. In this study, end of life allocation follows the cut-off rule (impact of production falls to the primary user of recycled materials) and co-product allocation is revenue-based (economic). Ecoinvent processes are also available that use the "Allocation at the Point of Substitution" (APOS) model, which allocates end of life burdens based on market values. Utilizing APOS rather than cut-off allocation for all Ecoinvent processes (Ecoinvent processes contribute 61% of CW carbon footprint) makes no noticeable difference in the CW results.

Agrifootprint processes (contributing 35% of CW carbon footprint) are available with economic-, mass-, and energy-based allocation. Replacing all economic-based processes with mass-based processes, and also using mass allocation for the pea protein isolate processes leads to the following reductions in CW environmental impacts: GHGE, 16%; fossil energy, 14%; land use, 29%; water use, 36%. Such reductions are anticipated as mass allocation can shift more impact to the secondary co-product (e.g., pea starch, wheat bran, etc) and reduce the impact to the primary product. While clear standards for allocation are not available yet for this product type, economic allocation remains the preferred choice in this study as it maintains the greatest amount of internal consistency between mixed databases (Ecoinvent and Agrifootprint). Note that Ecoinvent does not provide choice of co-product allocation method.

5.4. Data Quality Assessment

5.4.1. Inventory data quality assessment

A qualitative analysis of the uncertainty due to variability of the inventory data was carried out using the pedigree matrix approach for groups of data, based on expert opinion of the study researchers. The significance of data quality scores in the pedigree matrix is presented in Table 20.

The data quality evaluation is presented in Table 21. The importance of data to the life cycle impacts was also evaluated by expert opinion based on contribution analysis and sensitivity analyses.

Table 20. Pedigree matrix used for data quality assessment derived from (Weidema and Wesnaes 1996)

Indicator score	1	2	3	4	5
Reliability	Verified data based on measurements	Verified data partly based on assumptions or non-verified data based on measurements	Non-verified data partly based on assumptions	Qualified estimate (e.g. by industrial expert)	Non-qualified estimate
Completeness	Representative data from a sufficient sample of sites over an adequate period to even out normal fluctuations	Representative data from a smaller number of sites over adequate periods	Representative data from an adequate number of sites over shorter periods	Representative data from a smaller number of sites and shorter periods or incomplete data from an adequate number of sites and periods	Representativeness unknown or incomplete data from a smaller number of sites and/or over shorter periods
Temporal correlation	Less than 3 years' difference to year of study	Less than 6 years' difference	Less than 10 years' difference	Less than 15 years' difference	Age of data unknown or more than 15 years' difference
Geographic correlation	Data from study area	Average data from larger area that includes the studied area	Data from areas with similar production conditions	Data from areas with slightly similar production conditions	Data from unknown areas or areas with very different production conditions
Further technological correlation	Data from studied businesses, processes and materials	Data from studied processes and materials from different businesses	Data on studied processes and materials from a different technology	Data on related processes or materials with the same technology	Data on related processes or materials with different technology

The analysis shows that, overall, the quality of the data used for the LCA modeling is of high to medium data quality. This conclusion derives from the fact that data of greatest importance to the results (i.e., to which the assessment is most sensitive) receives mostly low scores (i.e., higher quality) in the pedigree quality assessment. Descriptive data of the CW composition, processing, and packaging came directly from Borealis Foods, and is considered reliable. Utility demand during processing was averaged over a reasonable time period, though during a time when production efficiency was improving. However, these utility demands do not have large importance on overall system results, as is demonstrated in the sensitivity analysis. Vegetable production relies of proxy datasets in some instances, but drying data (to which environmental impact is more sensitive) was gathered from product suppliers.

A method for generating empirical uncertainty factors from the qualitative data quality pedigree matrix has been introduced (Ciroth et al. 2016), and in theory could be applied to generate quantitative uncertainty estimates for the primary data gathered in this study. These uncertainties could then be propagated through the LCA model via Monte Carlo analysis to arrive at a confidence interval for the results. The Ecoinvent and Agrifootprint databases utilized in this study, however, also are incomplete in supplying uncertainty estimates for underlying flows, and applying the pedigree matrix process to those flows is outside the scope of this project.

Table 21. Data quality evaluation and importance of data contribution to life cycle impacts.

	source	Importance (scale = 1-3)	Indicator score (1-5, see Table 20 for interpretation)				
			reliability	completeness	Temporal correlation	Geographic correlation	Further technological correlation
Ingredients							
CW formulation	B	1	1	1	1	1	1
Pea protein isolate production	S	1	1	4	1	1	1
Proprietary protein	P	2	4	5	1	5	4
Wheat flour production	D	2	2	1	2	1	1
sunflower oil production	D	2	2	1	2	2	1
Dried vegetable production	D, S	1	2	2	1	3	1
Minor ingredients	D, P	3	3	5	2	2	4
Processing							
Utility demand	B	2	2	2	1	1	1
Packaging							
Packaging weights /quantity	B	2	1	2	1	1	1
Packaging material composition	S, P	2	3	1	1	1	4
Other packaging production	P, D	3	3	5	3	3	4
Distribution transport							
distance	M	3	3	3	1	1	1
Modeled truck	D	3	2	1	3	2	3
Preparation							
	M	3	3	5	3	2	4
Comparison cases							
beef	L	1	2	1	2	1	2
Pork	L	1	2	1	2	1	2
Chicken	L	1	2	1	4	1	2
Ramen Express	B,M	2	2	2	1	1	1
Beyond Burger	L	2	2	2	2	1	1

Sources: B = Borealis Foods; S = supplier; D = databases; P = proxy; M = modeled; L = literature/published report

Importance: 1 = high; 2 = medium; 3 = low

5.5. Model Completeness and Consistency

All relevant process steps within the boundary conditions of the study were considered and modeled. The process chain is considered to be sufficiently complete and detailed with regard to the goal and scope of this study.

Assumptions and methods are consistent across the CW LCA. A combination of LCI databases were used due to limitations in process and geographical representation in any single database. This is not ideal, as combing databases can inadvertently introduce errors in analyses. The two databases used, however – Ecoinvent and Agrifootprint – are widely used and generally recognized to apply consistent methodological approaches. In some instances (such as transport and natural gas consumption) "global" datasets from Ecoinvent were chosen over geographically explicit datasets from USLCI due to incompleteness in the USLCI database (empty processes, missing water and land use flows).

To the extent possible based on the level of description of the studies used as comparison, boundaries and allocation rules have been applied consistently. Some inconsistency exists in the impact assessment methods employed in the studies used as comparison, but we judge this to be of minor consequence as it relates to indicators that are (primarily) based on inventories without impact characterization.

5.6. Conclusions, Limitations, and Recommendations

Part of the goal of this study was to provide an estimate of the environmental performance of replacing meat consumption with consumption of the plant-based Chef Woo ramen noodle. A robust LCA of the Chef Woo product was conducted and environmental impact results were compared with representative studies of beef, pork, chicken and a plant-based burger designed to cover an equivalent boundary condition (cradle to preparation/cooking, excluding retail). However, as is nearly always the case in LCA, uncertainties remain in underlying data, and these uncertainties are not readily quantifiable. We therefore reserve declaring differences in product performance to those where impacts differ by more than 25% (based on expert judgement). The resulting comparative statement from this study is as follows:

> *When comparing an equivalent provision of protein, Chef Woo greenhouse gas emissions are significantly less than beef or pork, and somewhat less than Beyond Burger. Chef Woo fossil energy use is significantly less than beef, and somewhat less than pork and Beyond Burger. Chef Woo land use is significantly less than beef, somewhat more than pork and significantly more than chicken or Beyond Burger. Chef Woo water use is significantly less than beef and pork, somewhat less than chicken, and significantly more than Beyond Burger. Differences in greenhouse gas emissions and fossil energy use between Chef Woo and chicken cannot be determined by this study, due to underlying uncertainties.*
>
> *Supplying 20 g of protein through CW rather than a traditional noodle meal (regular ramen supplemented with meat) leads to significantly less impacts across all categories when using beef, significantly less greenhouse gas emissions and water use when using pork, and somewhat less greenhouse gas emissions and water use when using chicken.*

Table 22. Relative comparison between CW and other protein sources. Negative percentages mean CW has lower impact. Colors (defined below) indicate differences in environmental performance.

	GHGE	fossil energy	land use	water use
Beef	-87%	-51%	-71%	-97%
Pork	-52%	-33%	26%	-77%
Chicken	10%	20%	129%	-46%
Beyond Burger	-27%	-39%	101%	91%
Ramen Express + beef	-85%	-53%	-66%	-96%
Ramen Express + pork	-58%	-42%	3%	-73%
Ramen Express + chicken	-34%	-18%	43%	-45%

Green	CW >50% reduction in impact; significantly reduced
Blue	CW between 25% and 50% reduction in impact; somewhat reduced
Grey	CW <25% different (+/-); unable to confidently determine difference
Yellow	CW between 25% and 50% greater impact; somewhat greater
Orange	CW >50% greater impact; significantly greater

The range of environmental impacts from meat production seen in studies of other modeling frameworks, geographic locations and production practices suggests that the comparison made here, using studies designed to represent US production, is conservative, and that other contexts would likely further favor Chef Woo. Sensitivity analysis of the Chef Woo LCA suggests that modeling assumptions and processing efficiency-related parameters have minor influence (less than 10%) on the reported baseline, but that data quality for the upstream production of ingredients could have a notable effect on the reported Chef Woo environmental performance. We feel that all reasonable efforts were made to gather appropriate and supply-chain specific data on these ingredients.

Limitations in this study include the following:

- The primary noodle ingredients in CW (wheat flower, pea protein isolate, sunflower oil) are organic. However, existing LCI databases do not include organic production, and collection of primary data was outside the scope of this study. Further, it is often difficult to predict the performance of organic production methods relative to their conventional counterparts. We have used LCIs representative of conventional processes as proxy throughout this study. While yields with organic production are often (but not always) somewhat lower than conventional, the balance of this with reduced inputs, primarily synthetic fertilizers, makes anticipating the effect on environmental performance difficult.
- A small quantity of a proprietary (undisclosed) protein flour is used in making CW noodle (less than 8% of dry flour input). This ingredient was modeled as pea protein isolate in this study. Without additional knowledge of this ingredient, it is impossible to know the validity of this proxy assumption. However, if the proprietary protein were to have a carbon footprint 2 times greater than pea protein isolate (an unlikely situation), it would lead to a 20% increase in CW carbon footprint.
- Energy demand for drying the vegetables included in the CW cup relied on unverified estimates from suppliers. The range of energy demands reported in literature reports of

vegetable drying suggest that uncertainty in these estimates could affect the conclusions of this study.

- Land and water use are reported here are uncharacterized inventory values. Ongoing development in impact assessment methods for characterizing water use impacts (for example, via water scarcity-weighted methods such as the AWARE method (Boulay et al. 2018)) and land use impacts (for example, with biodiversity-related characterization) demonstrate that such characterization can influence conclusions. However, given limitations in the comparative meat studies and uncertainties with CW ingredient production regions, we have chosen not to apply such characterization methods here.

Recommendations from the study include the following:

- Communication of the environmental performance of Chef Woo and the relative benefit with respect to comparative protein sources shall occur with acknowledgement of the uncertainties present in this study.
- Noodle ingredients (including frying oil) are a primary driver of impact across all indicators. Continued improvement in CW environmental performance can be achieved by substituting ingredients with less impactful alternatives. Based on the data used here, sunflower oil appears to have an outsized impact contribution, and less impactful substitutes may be possible. Important market-based signals in support of supply chain reductions in environmental impacts can also be sent by seeking suppliers with reduced product impact.
- Ongoing improvements in production efficiencies (reduced shrink rates, increased production throughput, energy efficiency measures) can lead to notable improvements in environmental performance, especially when stacked (combining multiple improvements).

6. References

Battagliese, T., J. Andrade, I. Schulze, B. Uhlman and C. Barcan (2013). More Sustainable Beef Optimization Project: Phase 1 Final Report. BASF: http://bit.ly/NCBA_Report.

Battagliese, T., J. Andrade, R. Vinas, K. Stackhouse-Lawson, C. A. Rotz and J. Dillon (2015). U.S. Beef - Phase 2 Eco-efficiency Analysis. BASF: https://goo.gl/LtqAsD.

Beigi, M. (2016). "Energy efficiency and moisture diffusivity of apple slices during convective drying." Food Science and Technology **36**: 145-150.

Bhatta, S., T. Stevanovic Janezic and C. Ratti (2020). "Freeze-drying of plant-based foods." Foods **9**(1): 87.

Boulay, A.-M., J. Bare, L. Benini, et al. (2018). "The WULCA consensus characterization model for water scarcity footprints: assessing impacts of water consumption based on available water remaining (AWARE)." The International Journal of Life Cycle Assessment **23**(2): 368-378.

Ciroth, A., S. Muller, B. Weidema and P. Lesage (2016). "Empirically based uncertainty factors for the pedigree matrix in ecoinvent." The International Journal of Life Cycle Assessment **21**(9): 1338-1348.

EIA (2018). 2015 Residential Energy Consumpsion Survey. US Energy Information Administration: https://www.eia.gov/consumption/residential/data/2015/.

Heller, M. C. and G. A. Keoleian (2018). Beyond Meat's Beyond Burger Life Cycle Assessment: A detailed comparison between a plantbased and an animal-based protein source. Center for Sustainable Systems, University of Michigan: http://css.umich.edu/sites/default/files/publication/CSS18-10.pdf.

Heller, M. C., S. E. M. Selke and G. A. Keoleian (2019). "Mapping the Influence of Food Waste in Food Packaging Environmental Performance Assessments." Journal of Industrial Ecology **23**(2).
Heller, M. C., A. Willits-Smith, T. Mahon, G. A. Keoleian and D. Rose (2021). "Individual US diets show wide variation in water scarcity footprints." Nature Food **2**(4): 255-263.
Heller, M. C., A. Willits-Smith, R. Meyer, G. A. Keoleian and D. Rose (2018). "Greenhouse gas emissions and energy use associated with production of individual self-selected U.S. diets." Environmental Research Letters **13**(4).
Huijbregts, M. A. J., Z. J. N. Steinmann, P. M. F. Elshout, et al. (2017). "ReCiPe2016: a harmonised life cycle impact assessment method at midpoint and endpoint level." The International Journal of Life Cycle Assessment **22**(2): 138-147.
IPCC (2013). Climate Change 2013. The Physical Science Basis. Working Group I contribution to the Fifth Assessment Report of the IPCC: http://www.ipcc.ch/.
ISO (2006). Environmental management - life cycle assessment - requirements and guidelines. International Organization for Standardization.
Kim, D., R. Parajuli and G. J. Thoma (2020). "Life Cycle Assessment of Dietary Patterns in the United States: A Full Food Supply Chain Perspective." Sustainability **12**(4): 1586.
Menon, A., V. Stojceska and S. A. Tassou (2020). "A systematic review on the recent advances of the energy efficiency improvements in non-conventional food drying technologies." Trends in Food Science & Technology **100**: 67-76.
Poore, J. and T. Nemecek (2018). "Reducing food's environmental impacts through producers and consumers." Science **360**(6392): 987-992.
Putman, B., J. Hickman, P. Bandekar, M. Matlock and G. Thoma (2018). A Retrospective Assessment of US Pork Production: 1960 to 2015. Final Report. University of Arkansas: https://porkcheckoff.org/wp-content/uploads/2021/02/16-214-THOMA-final-rpt.pdf.
Putman, B., G. Thoma, J. Burek and M. Matlock (2017). "A retrospective analysis of the United States poultry industry: 1965 compared with 2010." Agricultural Systems **157**: 107-117.
Rotz, C. A., S. Asem-Hiablie, S. Place and G. Thoma (2019). "Environmental footprints of beef cattle production in the United States." Agricultural Systems **169**: 1-13.
Schau, E. M. and A. M. Fet (2008). "LCA studies of food products as background for environmental product declarations." International Journal of Life Cycle Assessment **13**(3): 255-264.
Thoma, G., B. Putman, M. Matlock, J. Popp and L. English (2017). Sustainability Assessment of U.S. Beef Production Systems. Resilience Services, PLLC and the University of Arkansas: https://goo.gl/8ttBo6.
US EPA. (2016). "Waste Reduction Model (WARM), version 14." Retrieved August 12, 2017, from https://www.epa.gov/warm/versions-waste-reduction-model-warm.
Wang, X., C. Zou, Y. Zhang, et al. (2018). "Environmental impacts of pepper (Capsicum annuum L) production affected by nutrient management: A case study in southwest China." Journal of Cleaner Production **171**: 934-943.
Weidema, B. P. and M. S. Wesnaes (1996). "Data quality management for life cycle inventories—an example of using data quality indicators." Journal of cleaner production **4**(3-4): 167-174.

Appendix A: Modified electrical grid processes

The tables below detail the final inventories for the updated/modified electrical grid processes used in this study. The structure of these processes began with processes from USLCI, but the contributing electricity generation processes were replaced with (US specific) electricity generation processes from ecoinvent. This was done due to both the empty processes that exist in the USLCI network, as well as the lack of land and water use flows in USLCI processes. The only USLCI process to remain is "electricity, biomass", for which there was not an obvious substitution (the percent contribution from this process is small in all grids).

US average grid (2019)

Products		
Electricity, at grid, US, 2019 /kWh/RNA UPDATE	0.949*	kWh
Materials/fuels		
Electricity, high voltage {SERC}| electricity production, hard coal | Cut-off, S	0.233	kWh
Electricity, high voltage {NPCC, US only}| electricity production, oil | Cut-off, S	0.0061	kWh
Electricity, high voltage {SERC}| electricity production, natural gas, combined cycle power plant | Cut-off, S	0.3844	kWh
Electricity, high voltage {NPCC, US only}| electricity production, nuclear, boiling water reactor | Cut-off, S	0.1955	kWh
Electricity, high voltage {WECC, US only}| electricity production, hydro, run-of-river | Cut-off, S	0.03415	kWh
Electricity, high voltage {NPCC, US only}| electricity production, hydro, reservoir, alpine region | Cut-off, S	0.03415	kWh
Electricity, high voltage {SERC}| electricity production, oil | Cut-off, S	0.0032	kWh
Electricity, biomass, at power plant/US	0.0156	kWh
Electricity, high voltage {SERC}| electricity production, wind, 1-3MW turbine, onshore | Cut-off, S	0.0715	kWh
Electricity, low voltage {WECC, US only}| electricity production, photovoltaic, 570kWp open ground installation, multi-Si | Cut-off, S	0.0174	kWh
Electricity, high voltage {WECC, US only}| electricity production, deep geothermal | Cut-off, S	0.0037	kWh

*assuming 5.1% grid gross loss according to EPA eGRID

MROW eGRID (2019)

Products		
Electricity, at eGrid, MROW, 2019/kWh/RNA UPDATE	0.949*	kWh
Materials/fuels		
Electricity, high voltage {MRO, US only}| electricity production, hard coal | Cut-off, S	0.4391	kWh
Electricity, high voltage {MRO, US only}| electricity production, oil | Cut-off, S	0.0012	kWh
Electricity, high voltage {MRO, US only}| electricity production, natural gas, conventional power plant | Cut-off, S	0.1116	kWh
Electricity, high voltage {MRO, US only}| electricity production, nuclear, boiling water reactor | Cut-off, S	0.1125	kWh
Electricity, high voltage {MRO, US only}| electricity production, hydro, run-of-river | Cut-off, S	0.0685	kWh
Electricity, biomass, at power plant/US	0.0086	kWh
Electricity, high voltage {MRO, US only}| electricity production, wind, 1-3MW turbine, onshore | Cut-off, S	0.2507	kWh
Electricity, high voltage {MRO, US only}| electricity production, oil | Cut-off, S	0.0003	kWh
Electricity, low voltage {WECC, US only}| electricity production, photovoltaic, 570kWp open ground installation, multi-Si | Cut-off, S	0.0057	kWh

*assuming 5.1% grid gross loss according to EPA eGRID

RMPA eGRID (2019)

Products		
Electricity, at eGrid, RMPA, 2019/kWh/RNA UPDATE	0.949*	kWh
Materials/fuels		
Electricity, high voltage {WECC, US only}| electricity production, hard coal | Cut-off, S	0.4252	kWh
Electricity, high voltage {WECC, US only}| electricity production, oil | Cut-off, S	0.0001	kWh
Electricity, high voltage {WECC, US only}| electricity production, natural gas, conventional power plant | Cut-off, S	0.2652	kWh
Electricity, high voltage {WECC, US only}| electricity production, hydro, reservoir, alpine region | Cut-off, S	0.119	kWh
Electricity, biomass, at power plant/US	0.0024	kWh
Electricity, high voltage {NPCC, US only}| electricity production, wind, 1-3MW turbine, onshore | Cut-off, S	0.1687	kWh
Electricity, low voltage {WECC, US only}| electricity production, photovoltaic, 570kWp open ground installation, multi-Si | Cut-off, S	0.051679	kWh

*assuming 5.1% grid gross loss according to EPA eGRID

Appendix B: External Review Statement

Contents

Industrial Ecology Consultants

October 6, 2021

Martin C. Heller
Senior Research Specialist
Center for Sustainable Systems
University of Michigan

Critical Review Report: Chef Woo High-Protein LCA

The Life Cycle Assessment (LCA) Practitioner, Center for Sustainable Systems at the University of Michigan, commissioned a panel of experts to perform an external independent critical review of the **Chef Woo high-protein ramen noodle Life Cycle Assessment: A detailed comparison with animal-based protein sources** study on behalf of the commissioning organization, Borealis Foods.

The review of the study was performed to demonstrate conformance with the following standards:

International Organization for Standardization. (2006). *Environmental management -- Life cycle assessment – Principles and framework* (ISO 14040:2006).

International Organization for Standardization. (2006). *Environmental management -- Life cycle assessment -- Requirements and guidelines* (ISO 14044:2006).

International Organization for Standardization. (2014). *Environmental management -- Life cycle assessment -- Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006*. (ISO/TS 14071:2014).

The independent third-party critical review was conducted by the following panel of experts per ISO 14044:2006 Section 6.2: Critical review:

Thomas P. Gloria, Ph.D.
Founder, Chief Sustainability Engineer
Industrial Ecology Consultants

Greg Thoma, Ph.D., P.E.
Managing Director
Resilience Services, PLLC.
Fayetteville, AR

Andrea L. Hicks, Ph.D.
Associate Professor
Department of Civil and Environmental Engineering
Hanson Family Fellow in Sustainability
Director of Sustainability Education and Research
University of Wisconsin Madison

REVIEW SCOPE

The intent of this review was to provide an independent third-party external critical review of a LCA study report in conformance with the aforementioned ISO standards. This review did not include an assessment of the Life Cycle Inventory (LCI) model however, it did include a critical review of the general approach to complete the study and a detailed analysis of the individual datasets applied.

REVIEW PROCESS

The critical review process of the LCA study was conducted to ensure conformance to the International Organization for Standardization (ISO) 14040/44 LCA standards following the review processes and procedures per ISO 14071. The primary task of the review process per ISO 14044 review requirements is to ensure the general requirements for conducting LCA studies are met:

- Are methods used to carry out the LCA consistent with ISO 14040/14044 standards?
- Are methods used to carry out the LCA scientifically and technically valid?
- Are data used appropriate and reasonable in relation to the goal of the study?
- Do interpretations reflect limitations identified and the goal of the study?
- Was the study report transparent and consistent?

The review process involved the review of all requirements set forth by the applicable ISO standards cataloged in comprehensive review table along with editorial comments. There were two rounds of comments by the reviewers submitted to the LCA practitioner. Responses by the LCA practitioner to each issue raised were resolved and acknowledged by the review panel to have been satisfactorily addressed.

CRITICAL REVIEW STATEMENT

Based on the independent critical review objectives, the **Chef Woo high-protein ramen noodle Life Cycle Assessment: A detailed comparison with animal-based protein sources, October 6, 2021,** was determined to be ***in conformance*** with the applicable ISO standards. The plausibility, quality, and accuracy of the LCA-based data and supporting information are confirmed.

As the Chair of the External Independent Third-Party Review Panel, I confirm that the members of the panel have sufficient scientific knowledge and experience of food systems and their related upstream production and agricultural processes and the applicable ISO standards to carry out this critical review.

Sincerely,

Thomas P. Gloria, Ph.D.
Founder, Chief Sustainability Engineer
Industrial Ecology Consultants

Date: 9/10/21	Doc.: Chef Woo high-protein ramen noodle Life Cycle Assessment: A detailed comparison with animal-based protein sources, v0.1, 10/6/21, by the Regents of the University of Michigan on behalf of Borealis Foods.
Reviewer(s):	Thomas Gloria, Andrea Hicks, and Greg Thoma

(1) Com-ment Type & No.	(2) Page No.	(3) Para/ Fig/ Tbl/ Note	(4) ISO/PCR Requirement	(5) Comment (justification for change)/Proposed change	(6) Decisions on each comment submitted	(7) Status Open/ Closed
			Are the methods used to carry out the study consistent with the ISO 14040/14044 standards?			
TE1			**ISO 14044 Requirement (§4.1):** *General Requirements - LCA studies shall include the goal and scope definition, inventory analysis, impact assessment and interpretation of results.*	Requirement met		Closed.
TE2			**ISO 14044 Requirement (§4.1):** *General Requirements - LCI studies shall include definition of the goal and scope, inventory analysis and interpretation of results. The requirements and recommendations of this International Standard, with the exception of those provisions regarding impact assessment, also apply to life cycle inventory studies.*	Not applicable as this is an LCA		Closed.
TE3			**ISO 14044 Requirement (§4.1):** *General Requirements - An LCI study alone shall not be used for comparisons intended to be used in comparative assertions intended to be disclosed to the public.*	Not applicable		Closed.
TE4			**ISO 14044 Reporting Requirements (§5.1) and (§5.1.1):** *General Requirements and Considerations - The type and format of the report shall be defined in the scope phase of the study.* *The results and conclusions of the LCA shall be completely and accurately reported without bias to the intended audience. The results, data, methods, assumptions and limitations shall be transparent and presented in sufficient detail to allow the reader to comprehend the complexities and trade-offs inherent in the LCA. The report shall also allow the results and interpretation to be used in a manner consistent with the goals of the study.*	Requirement met.		Closed.
TE5			**ISO 14044 Reporting Requirements (§5.2)** *Additional Requirements and Guidance* *When results of the LCA are to be communicated to any third party (i.e. interested party other than the commissioner or the practitioner of the study), regardless of the form of communication, a third-party report shall be prepared. The third-party report can be based on study documentation that contains confidential information that may not be included in the third-party report.*	Requirement met		Closed.
TE6			**ISO 14044 Reporting Requirements (§5.2)** *Additional Requirements and Guidance* *The third-party report constitutes a reference document, and shall be made available to any third party to whom the communication is made.*	Requirement will presumably be met as inclusion of an appendix in the final document.	Yes, this review matrix and the review statement will be included as appendix. **Acknowledged**	Closed
TE7			**ISO 14044 Reporting Requirements (§5.2)** *Additional Requirements and Guidance* *The third-party report shall cover the following aspects:* ***a) General aspects:*** *1) LCA commissioner, practitioner of LCA (internal or external);* *2) date of report;* *3) statement that the study has been conducted according to the requirements of this International Standard (ISO 14044).*	Requirement met		Closed.

Type of comment: **GE** = general **TE** = technical **ED** = editorial

Date: 9/10/21	Doc.: Chef Woo high-protein ramen noodle Life Cycle Assessment: A detailed comparison with animal-based protein sources, v0.1, 10/6/21, by the Regents of the University of Michigan on behalf of Borealis Foods.
Reviewer(s):	Thomas Gloria, Andrea Hicks, and Greg Thoma

(1) **Com-ment Type & No.**	(2) **Page No.**	(3) **Para/ Fig/ Tbl/ Note**	(4) **ISO/PCR Requirement**	(5) **Comment (justification for change)/Proposed change**	(6) **Decisions on each comment submitted**	(7) Status Open/ Closed
TE8			**ISO 14044 Requirement (§4.2.1):** *Goal and Scope Definition General – The goal and scope of an LCA shall be clearly defined and shall be consistent with the intended application. Due to the iterative nature of LCA, the scope may have to be refined during the study.*	Requirement met		Closed.
TE9			**ISO 14044 Requirement (§4.2.2):** *Goal of the study – In defining the goal of an LCA, the following items shall be unambiguously stated:* *– the intended application;* *– the reasons for carrying out the study:* *– the intended audience, i.e. to whom the results of the study are intended to be communicated:* *– whether the results are intended to be used in comparative assertions intended to be disclosed to the public.*	Requirement met		Closed.
TE10			**ISO 14044 Reporting Requirements (§5.2)** *Additional Requirements and Guidance* *The third-party report shall cover the following aspects:* ***b) Goal of the study**:* *1) reasons for carrying out the study;* *2) its intended applications;* *3) the target audiences;* *4) statement as to whether the study intends to support comparative assertions intended to be disclosed to the public.*	Requirement met		Closed.
TE11			**ISO 14044 Requirement (§4.2.3.1):** ***Scope of the study - General**.* *In defining the scope of an LCA, the following items shall be considered and clearly described:* *– the product system to be studied;* *– the functions of the product system or, in the case of comparative studies, the systems;* *– the functional unit;* *– the system boundary;* *– allocation procedures;* *– LCIA methodology and types of impacts;* *– interpretation to be used;* *– data requirements;* *– assumptions;* *– value choices and optional elements;* *– limitations;* *– data quality requirements;* *– type of critical review, if any;* *– type and format of the report required for the study.* *In some cases, the goal and scope of the study may be revised due to unforeseen limitations, constraints or as a result of additional information. Such modifications, together with their justification, should be documented.*	Requirement met.		Closed.

Type of comment: **GE** = general **TE** = technical **ED** = editorial

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Com-ment Type & No.	**Page No.**	**Para/ Fig/ Tbl/ Note**	**ISO/PCR Requirement**	**Comment (justification for change)/Proposed change**	**Decisions on each comment submitted**	Status Open/ Closed
TE12			**ISO 14044 Requirement (§4.2.3.2): *Scope of the study - Function and functional unit*** *The scope of an LCA shall clearly specify the functions (performance characteristics) of the system being studied. The functional unit shall be consistent with the goal and scope of the study. One of the primary purposes of a functional unit is to provide a reference to which the input and output data are normalized (in a mathematical sense). Therefore, the functional unit shall be clearly defined and measurable.* *Having chosen the functional unit, the reference flow shall be defined. Comparisons between systems shall be made on the basis of the same function(s), quantified by the same functional unit(s) in the form of their reference flows. If additional functions of any of the systems are not taken into account in the comparison of functional units, then these omissions shall be explained and documented. As an alternative, systems associated with the delivery of this function may be added to the boundary of the other system to make the systems more comparable. In these cases, the processes selected shall be explained and documented.*	Requirement met		Closed.
TE13			**ISO 14044 Requirement (§4.2.3.3.1): *Scope of the study - System boundary*** *The system boundary determines which unit processes shall be included within the LCA. The selection of the system boundary shall be consistent with the goal of the study. The criteria used in establishing the system boundary shall be identified and explained.* *Decisions shall be made regarding which unit processes to include in the study and the level of detail to which these unit processes shall be studied.* *The deletion of life cycle stages, processes, inputs or outputs is only permitted if it does not significantly change the overall conclusions of the study. Any decisions to omit life cycle stages, processes, inputs or outputs shall be clearly stated, and the reasons and implications for their omission shall be explained.* *Decisions shall also be made regarding which inputs and outputs shall be included and the level of detail of the LCA shall be clearly stated.*	Requirement met requirement met the exclusion of retail is not discussed until the limitations section 5.2.1; it would be useful to mention the rationale earlier in the document as well. Requirement met	This rationale for exclusion of retail and losses have been added to Section 3.2.5 **Acknowledged**	Closed
TE14			**ISO 14044 Requirement (§4.2.3.3.2): *Scope of the study - System boundary*** *It is helpful to describe the system using a process flow diagram showing the unit processes and their inter-relationships. Each of the unit processes should be initially described to define:* *– where the unit process begins, in terms of the receipt of raw materials or intermediate products,*	Requirement met		Closed

(1) Com-ment Type & No.	(2) Page No.	(3) Para/ Fig/ Tbl/ Note	(4) ISO/PCR Requirement	(5) Comment (justification for change)/Proposed change	(6) Decisions on each comment submitted	(7) Status Open/ Closed
			– the nature of the transformations and operations that occur as part of the unit process, and *– where the unit process ends, in terms of the destination of the intermediate or final products.* *Ideally, the product system should be modelled in such a manner that inputs and outputs at its boundary are elementary and product flows. It is an iterative process to identify the inputs and outputs that should be traced to the environment, i.e. to identify which unit processes producing the inputs (or which unit processes receiving the outputs) should be included in the product system under study. The initial identification is made using available data. Inputs and outputs should be more fully identified after additional data are collected during the course of the study, and then subjected to a sensitivity analysis (see 4.3.3.4).* *For material inputs, the analysis begins with an initial selection of inputs to be studied. This selection should be based on an identification of the inputs associated with each of the unit processes to be modelled. This effort may be undertaken with data collected from specific sites or from published sources. The goal is to identify the significant inputs associated with each of the unit processes.* *Energy inputs and outputs shall be treated as any other input or output to an LCA. The various types of energy inputs and outputs shall include inputs and outputs relevant for the production and delivery of fuels, feedstock energy and process energy used within the system being modelled.*	For the non-CW products, this requirement is not precisely met because the "dummy processes", as described, appear to only contain information regarding literature-based impacts of the respective products. While technically this is not compliant, I think that it is acceptable given the goal of the study. Requirement met Requirement met	This decision – to represent livestock production as LCA results rather than a system model of elementary flows – was made after spending many days unsuccessfully attempting to import the animal production system LCAs, which are available through USDA LCA Digital Commons in OpenLCA format, into SimaPro format. It was anticipated when scoping the project that this would be possible, but it proved to be quite difficult. However, the LCA models do exist as system models of elementary flows, and a member of this review panel was involved in all animal production LCAs utilized and therefore should be able to flag any potential concerns with this approach. **Acknowledged**	
TE15			**ISO 14044 Requirement (§4.2.3.3.3):** ***Scope of the study – Cut-off Criteria*** *The cut-off criteria for initial inclusion of inputs and outputs and the assumptions on which the cut-off criteria are established shall be clearly described. The effect on the outcome of the study of the cut-off criteria selected shall also be assessed and described in the final report.* *Several cut-off criteria are used in LCA practice to decide which inputs are to be included in the assessment, such as mass, energy and environmental significance. Making the initial identification of inputs based on mass contribution alone may result in important inputs being omitted from the study. Accordingly, energy and environmental significance should also be used as cut-off criteria in this process.* *a)* ***Mass****: an appropriate decision, when using mass as a criterion, would require the inclusion in the study of all inputs that cumulatively contribute more than a defined percentage to the mass input of the product system being modelled.*	Requirement met		Closed.

(1) Com-ment Type & No.	(2) Page No.	(3) Para/ Fig/ Tbl/ Note	(4) ISO/PCR Requirement	(5) Comment (justification for change)/Proposed change	(6) Decisions on each comment submitted	(7) Status Open/ Closed
			*b) **Energy**: similarly, an appropriate decision, when using energy as a criterion, would require the inclusion in the study of those inputs that cumulatively contribute more than a defined percentage of the product system's energy inputs.* *c) **Environmental significance**: decisions on cut-off criteria should be made to include inputs that contribute more than an additional defined amount of the estimated quantity of individual data of the product system that are specially selected because of environmental relevance.* *Similar cut-off criteria may also be used to identify which outputs should be traced to the environment, e.g. by including final waste treatment processes.* *Where the study is intended to be used in comparative assertions intended to be disclosed to the public, the final sensitivity analysis of the inputs and outputs data shall include the mass, energy and environmental significance criteria so that all inputs that cumulatively contribute more than a defined amount (e.g. percentage) to the total are included in the study.* *All of the selected inputs identified through this process should be modelled as elementary flows.* *It should be decided which inputs and outputs data have to be traced to other product systems, including flows subject to allocation. The system should be described in sufficient detail and clarity to allow another practitioner to duplicate the inventory analysis.*			
TE16			**ISO 14044 Requirement (§4.2.3.4): *Scope of the study – LCIA methodology and types of impacts*** *It shall be determined which impact categories, category indicators and characterization models are included within the LCA study. The selection of impact categories, category indicators and characterization models used in the LCIA methodology shall be consistent with the goal of the study and considered as described in 4.4.2.2.*	Provide justification for not using the AWARE method. See comment in document.	AWARE is a very useful methodology for understanding the impact of water use in regions with differing water scarcity. However, for the method to be meaningful, it requires regionalized data for water flows. If the animal production systems utilized as the comparisons were built in a way that represented the regionalized production of crops within the US, applying AWARE may be useful. As it is, assuming that ALL water use associated with animal production occurs in the US, then applying AWARE (with a US average characterization) really only multiplies the water use through by a constant, resulting in a result that no longer has a physical interpretation. As this study primarily focuses on US production and since the	Closed

(1) Com-ment Type & No.	(2) Page No.	(3) Para/ Fig/ Tbl/ Note	(4) ISO/PCR Requirement	(5) Comment (justification for change)/Proposed change	(6) Decisions on each comment submitted	(7) Status Open/ Closed
					US has such large differences in water scarcity and since the model as implemented does not include sub-national accounts of water use, we feel that the use of AWARE characterization does not provide useful additional information. Out of curiosity, I did run the current models with AWARE as implemented in SimaPro. The "water scarcity footprint" for CW increases (from water use) by a factor smaller than the animal production systems (presumably due to non-domestic supply of sunflower oil and dried veg), but all 3 meat production systems increase by exactly the same factor (again, because they are all assuming "average US" water use). **Acknowledged**	
TE17			**ISO 14044 Requirement (§4.2.3.6): *Scope of the study – Data quality requirements*** ***4.2.3.6.1*** *Data quality requirements shall be specified to enable the goal and scope of the LCA to be met.* ***4.2.3.6.2*** *The data quality requirements should address the following:* *a) time-related coverage: age of data and the minimum length of time over which data should be collected;* *b) geographical coverage: geographical area from which data for unit processes should be collected to satisfy the goal of the study;* *c) technology coverage: specific technology or technology mix;* *d) precision: measure of the variability of the data values for each data expressed (e.g. variance);* *e) completeness: percentage of flow that is measured or estimated;* *f) representativeness: qualitative assessment of the degree to which the data set reflects the true population of interest (i.e. geographical coverage, time period and technology coverage);* *g) consistency: qualitative assessment of whether the study methodology is applied uniformly to the various components of the analysis;* *h) reproducibility: qualitative assessment of the extent to which information about the methodology and data values would allow an independent practitioner to reproduce the results reported in the study;* *i) sources of the data;* *j) uncertainty of the information (e.g. data, models and assumptions).*	Data quality has been addressed using pedigree matrix. However, from the discussion of bed quality is not entirely clear how the data quality evaluation has been used to characterize the robustness of conclusions. Differences between alternatives are, apparently, based on expert opinion, but the same ranges are applied across all impact categories, and it is not immediately obvious that the data quality and other factors are, in fact, equivalent across all impact categories.		Closed

(1) **Com-ment Type & No.**	(2) **Page No.**	(3) **Para/ Fig/ Tbl/ Note**	(4) **ISO/PCR Requirement**	(5) **Comment (justification for change)/Proposed change**	(6) **Decisions on each comment submitted**	(7) Status Open/ Closed
			Where a study is intended to be used in comparative assertions intended to be disclosed to the public, the data quality requirements stated in a) to j) above ***shall*** *be addressed.* ***4.2.3.6.3*** *The treatment of missing data shall be documented. For each unit process and for each reporting location where missing data are identified, the treatment of the missing data and data gaps should result in* *– a "non-zero" data value that is explained,* *– a "zero" data value if explained, or* *– a calculated value based on the reported values from unit processes employing similar technology.*	Requirement partially met. The use of proxy data where required is described and justified and included in sensitivity testing.		
TE18			**ISO 14044 Requirement (§4.2.3.7):** ***Scope of the study – Comparisons between systems*** *In a comparative study, the equivalence of the systems being compared shall be evaluated before interpreting the results. Consequently, the scope of the study shall be defined in such a way that the systems can be compared. Systems shall be compared using the same functional unit and equivalent methodological considerations, such as performance, system boundary, data quality, allocation procedures, decision rules on evaluating inputs, and outputs and impact assessment. Any differences between systems regarding these parameters shall be identified and reported. If the study is intended to be used for a comparative assertion intended to be disclosed to the public, interested parties shall conduct this evaluation as a critical review.* *A life cycle impact assessment shall be performed for studies intended to be used in comparative assertions intended to be disclosed to the public.*	There are a few minor points where, for example different databases were chosen for an essentially equivalent transportation stage (US LCI data sets for CW and ecoinvent datasets for refrigerated transport) Requirement met	Due to challenges with the USLCI database (empty processes, missing water and land use flows), USLCI processes have been substituted throughout the model with equivalent (although in some cases with less geographic specificity)processes from Ecoinvent. Now, transport for both CW and meat are from Ecoinvent (with meat using refrigerated transport). This substitution resulted in small changes in values (updated throughout report) but not changes in study conclusions. Note that the different databases were selected initially because USLCI does not have a refrigerated transport process. **Acknowledged**	Closed
TE19			**ISO 14044 Requirement (§4.2.3.8):** ***Scope of the study – Critical review considerations*** *The scope of the study shall define* *– whether a critical review is necessary and, if so, how to conduct it,* *– the type of critical review needed (see Clause 6), and* *– who would conduct the review, and their level of expertise.*	Requirement met		Closed.
TE20			**ISO 14044 Reporting Requirements (§5.2)** *Additional Requirements and Guidance* *The third-party report shall cover the following aspects:* ***c) Scope of the study:*** *1) function, including* *i) statement of performance characteristics, and* *ii) any omission of additional functions in comparisons;* *2) functional unit, including*	Requirement met		Closed.

(1) **Com-ment Type & No.**	(2) **Page No.**	(3) **Para/ Fig/ Tbl/ Note**	(4) **ISO/PCR Requirement**	(5) **Comment (justification for change)/Proposed change**	(6) **Decisions on each comment submitted**	(7) Status Open/ Closed
			i) consistency with goal and scope, *ii) definition,* *iii) result of performance measurement;* *3) system boundary, including* *i) omissions of life cycle stages, processes or data needs,* *ii) quantification of energy and material inputs and outputs, and* *iii) assumptions about electricity production;* *4) cut-off criteria for initial inclusion of inputs and output, including* *i) description of cut-off criteria and assumptions,* *ii) effect of selection on results,* *iii) inclusion of mass, energy and environmental cut-off criteria.*			
TE21			**ISO 14044 Requirement (§4.3.2.1):** *Life Cycle Inventory Analysis – Collecting Data* *The qualitative and quantitative data for inclusion in the inventory shall be collected for each unit process that is included within the system boundary. The collected data, whether measured, calculated or estimated, are utilized to quantify the inputs and outputs of a unit process.* *When data have been collected from public sources, the source shall be referenced. For those data that may be significant for the conclusions of the study, details about the relevant data collection process, the time when data have been collected, and further information about data quality indicators shall be referenced. If such data do not meet the data quality requirements, this shall be stated.* *To decrease the risk of misunderstandings (e.g. resulting in double counting when validating or reusing the data collected), a description of each unit process shall be recorded.* *Since data collection may span several reporting locations and published references, measures should be taken to reach uniform and consistent understanding of the product systems to be modelled.*	Requirement met		Closed.
TE22			**ISO 14044 Requirement (§4.3.3.1):** ***Life Cycle Inventory Analysis – Calculating Data - General*** *All calculation procedures shall be explicitly documented and the assumptions made shall be clearly stated and explained. The same calculation procedures should be consistently applied throughout the study.* *When determining the elementary flows associated with production, the actual production mix should be used whenever possible, in order to reflect the various types of resources that are consumed. As an example, for the production and delivery of electricity, account shall be taken of the electricity mix, the efficiencies of fuel combustion, conversion, transmission and distribution losses.*	Requirement Requirement met		Closed.

(1) Com-ment Type & No.	(2) Page No.	(3) Para/ Fig/ Tbl/ Note	(4) ISO/PCR Requirement	(5) Comment (justification for change)/Proposed change	(6) Decisions on each comment submitted	(7) Status Open/ Closed
			Inputs and outputs related to a combustible material (e.g. oil, gas or coal) can be transformed into an energy input or output by multiplying them by the relevant heat of combustion. In this case, it shall be reported whether the higher heating value or the lower heating value is used. *Several operational steps are needed for data calculation. These are described in 4.3.3.2 to 4.3.3.4 and 4.3.4.*	Requirement met		
TE23			**ISO 14044 Requirement (§4.3.3.2): *Life Cycle Inventory Analysis – Calculating Data – Validation of data*** *A check on data validity shall be conducted during the process of data collection to confirm and provide evidence that the data quality requirements for the intended application have been fulfilled.* *Validation may involve establishing, for example, mass balances, energy balances and/or comparative analyses of release factors. As each unit process obeys the laws of conservation of mass and energy, mass and energy balances provide a useful check on the validity of a unit process description. Obvious anomalies in the data resulting from such validation procedures require alternative data that comply with the data selection as established according to 4.2.3.5.*	requirement met		Closed.
TE24			**ISO 14044 Requirement (§4.3.3.3): *Life Cycle Inventory Analysis – Calculating Data – Relating Data to Unit Processes and Functional Unit*** *An appropriate flow shall be determined for each unit process. The quantitative input and output data of the unit process shall be calculated in relation to this flow.*	requirement met		Closed.
TE25			**ISO 14044 Requirement (§4.3.3.4): *Life Cycle Inventory Analysis – Calculating Data – Refining the system boundary*** *Reflecting the iterative nature of LCA, decisions regarding the data to be included shall be based on a sensitivity analysis to determine their significance, thereby verifying the initial analysis outlined in 4.2.3.3. The initial system boundary shall be revised, as appropriate, in accordance with the cut-off criteria established in the definition of the scope. The results of this refining process and the sensitivity analysis shall be documented.* *The sensitivity analysis may result in* *– exclusion of life cycle stages or unit processes when lack of significance can be shown by the sensitivity analysis,* *– exclusion of inputs and outputs that lack significance to the results of the study, or* *– inclusion of new unit processes, inputs and outputs that are shown to be significant in the sensitivity analysis.* *This analysis serves to limit the subsequent data handling to those input and output data that are determined to be significant to the goal of the LCA.*	Requirement met		Closed.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Com-ment Type & No.	**Page No.**	**Para/ Fig/ Tbl/ Note**	**ISO/PCR Requirement**	**Comment (justification for change)/Proposed change**	**Decisions on each comment submitted**	Status Open/ Closed
TE26			**ISO 14044 Requirement (§4.3.4.1):** ***Life Cycle Inventory Analysis – Calculating Data – Allocation - General*** *The inputs and outputs shall be allocated to the different products according to clearly stated procedures that shall be documented and explained together with the allocation procedure.* *The sum of the allocated inputs and outputs of a unit process shall be equal to the inputs and outputs of the unit process before allocation.* *Whenever several alternative allocation procedures seem applicable, a sensitivity analysis shall be conducted to illustrate the consequences of the departure from the selected approach.*	The description of allocation among the coproducts of slaughtering for meat products could be a little more clearly described-perhaps with a diagram indicating how the burdens were assigned.	A table (Table 9) was added to demonstrate how the slaughter process was modified to account for the fact that the beef production LCA results as provided are on a carcass weight basis. **Acknowledged**	Closed
TE27			**ISO 14044 Requirement (§4.3.4.2):** ***Life Cycle Inventory Analysis – Calculating Data – Allocation Procedures*** *The study shall identify the processes shared with other product systems and deal with them according to the stepwise procedure presented below.* *a)* ***Step 1****: Wherever possible, allocation should be avoided by* *1) dividing the unit process to be allocated into two or more sub-processes and collecting the input and output data related to these sub-processes, or* *2) expanding the product system to include the additional functions related to the co-products, taking into account the requirements of 4.2.3.3.* *b)* ***Step 2****: Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them; i.e. they should reflect the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system.* *c)* ***Step 3****: Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way that reflects other relationships between them. For example, input and output data might be allocated between co-products in proportion to the economic value of the products.* *Some outputs may be partly co-products and partly waste. In such cases, it is necessary to identify the ratio between co-products and waste since the inputs and outputs shall be allocated to the co-products part only.* *Allocation procedures shall be uniformly applied to similar inputs and outputs of the system under consideration. For example, if allocation is made to usable products (e.g. intermediate or discarded products)* *leaving the system, then the allocation procedure shall be similar to the allocation procedure used for such products entering the system.* *The inventory is based on material balances between input and output. Allocation procedures should therefore approximate as much as possible such fundamental input/output relationships and characteristics.*	As mentioned in the comments, there are a couple of, likely minor, points where additional clarification would be valuable.		Closed

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Com-ment Type & No.	**Page No.**	**Para/ Fig/ Tbl/ Note**	**ISO/PCR Requirement**	**Comment (justification for change)/Proposed change**	**Decisions on each comment submitted**	Status Open/ Closed
TE28			**ISO 14044 Requirement (§4.3.4.3):** *Life Cycle Inventory Analysis – Calculating Data – Allocation Procedures – resuse and recycling* *4.3.4.3.1 The allocation principles and procedures in 4.3.4.1 and 4.3.4.2 also apply to reuse and recycling situations.* *Changes in the inherent properties of materials shall be taken into account. In addition, particularly for the recovery processes between the original and subsequent product system, the system boundary shall be identified and explained, ensuring that the allocation principles are observed as described in 4.3.4.2.* *4.3.4.3.2 However, in these situations, additional elaboration is needed for the following reasons:* *– reuse and recycling (as well as composting, energy recovery and other processes that can be assimilated to reuse/recycling) may imply that the inputs and outputs associated with unit processes for extraction and processing of raw materials and final disposal of products are to be shared by more than one product system;* *– reuse and recycling may change the inherent properties of materials in subsequent use;* *– specific care should be taken when defining system boundary with regard to recovery processes.* *4.3.4.3.3 Several allocation procedures are applicable for reuse and recycling. The application of some procedures is outlined conceptually in Figure 2 and is distinguished in the following to illustrate how the above constraints can be addressed.* *a) A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials. However, the first use of virgin materials in applicable open-loop product systems may follow an open-loop allocation procedure outlined in b).* *b) An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties.* *4.3.4.3.4 The allocation procedures for the shared unit processes mentioned in 4.3.4.3 should use, as the basis for allocation, if feasible, the following order:* *– physical properties (e.g. mass);* *– economic value (e.g. market value of the scrap material or recycled material in relation to market value of primary material); or* *– the number of subsequent uses of the recycled material (see ISO/TR 14049).*	As mentioned in comments, the use of flows Appears Inconsistent with the Use of the APOS System Model from ecoinvent.	The APOS system model was substituted with Ecoinvent "cutoff" model throughout in order to improve consistency of allocation approaches through the model. This substitution resulted in virtually no changes in the CW results. **Acknowledged**	Closed
TE29			**ISO 14044 Reporting Requirement (§5.2):** *Additional Requirements and Guidance*	Requirement met		Closed.

Type of comment: **GE** = general **TE** = technical **ED** = editorial

(1) Com-ment Type & No.	(2) Page No.	(3) Para/ Fig/ Tbl/ Note	(4) ISO/PCR Requirement	(5) Comment (justification for change)/Proposed change	(6) Decisions on each comment submitted	(7) Status Open/ Closed
			The third-party report shall cover the following aspects: *d)* ***Life cycle inventory analysis****:* *1) data collection procedures;* *2) qualitative and quantitative description of unit processes;* *3) sources of published literature;* *4) calculation procedures;* *5) validation of data, including* *i) data quality assessment, and* *ii) treatment of missing data;* *6) sensitivity analysis for refining the system boundary;* *7) allocation principles and procedures, including* *i) documentation and justification of allocation procedures, and* *ii) uniform application of allocation procedures.*			
TE30			**ISO 14044 Requirement (§4.4.1):** *Life Cycle Impact Assessment – General* *The LCIA phase shall be carefully planned to achieve the goal and scope of an LCA study. The LCIA phase shall be coordinated with other phases of the LCA to take into account the following possible omissions and sources of uncertainty:* *a) whether the quality of the LCI data and results is sufficient to conduct the LCIA in accordance with the study goal and scope definition;* *b) whether the system boundary and data cut-off decisions have been sufficiently reviewed to ensure the availability of LCI results necessary to calculate indicator results for the LCIA;* *c) whether the environmental relevance of the LCIA results is decreased due to the LCI functional unit calculation, system wide averaging, aggregation and allocation.*	A and B are met; sensitivity assessment did not include evaluation of allocation decisions.	A section (5.3.4) has been added which considers the sensitivity of major allocation choices. **Acknowledged**	Closed
TE31			**ISO 14044 Requirement (§4.4.2.1):** *Life Cycle Impact Assessment – General* *The LCIA phase shall include the following mandatory elements:* *– selection of impact categories, category indicators and characterization models;* *– assignment of LCI results to the selected impact categories (classification);* *– calculation of category indicator results (characterization).*	Requirement met		Closed.
TE32			**ISO 14044 Requirement (§4.4.2.2.1):** *Life Cycle Impact Assessment – Selection* *Whenever impact categories, category indicators and characterization models are selected in an LCA, the related information and sources shall be referenced. This also applies when new impact categories, category indicators or characterization models are defined.* *NOTE Examples of impact categories are described in ISO/TR 14047.* *Accurate and descriptive names shall be provided for the impact categories and category indicators.*	Requirement met through the use of standard LCIA framework		Closed.

(1) Com-ment Type & No.	(2) Page No.	(3) Para/ Fig/ Tbl/ Note	(4) ISO/PCR Requirement	(5) Comment (justification for change)/Proposed change	(6) Decisions on each comment submitted	(7) Status Open/ Closed
			The selection of impact categories, category indicators and characterization models shall be both justified and consistent with the goal and scope of the LCA. *The selection of impact categories shall reflect a comprehensive set of environmental issues related to the product system being studied, taking the goal and scope into consideration.* *The environmental mechanism and characterization model that relate the LCI results to the category indicator and provide a basis for characterization factors shall be described.* *The appropriateness of the characterization model used for deriving the category indicator in the context of the goal and scope of the study shall be described.* *LCI results other than mass and energy flow data included in an LCA (e.g. land use) shall be identified and their relationship to corresponding category indicators shall be determined.* *For most LCA studies, existing impact categories, category indicators or characterization models will be selected. However, in some cases existing impact categories, category indicators or characterization models are not sufficient to fulfil the defined goal and scope of the LCA, and new ones have to be defined. When new impact categories, category indicators or characterization models are defined, the recommendations in this sub-clause also apply..* *Figure 3 illustrates the concept of category indicators based on an environmental mechanism. The impact category "acidification" is used in Figure 3 as an example. Every impact category has its own environmental mechanism.* *Characterization models reflect the environmental mechanism by describing the relationship between the LCI results, category indicators and, in some cases, category endpoint(s). The characterization model is used to derive the characterization factors. The environmental mechanism is the total of environmental processes related to the characterization of the impacts.*			
TE33			**ISO 14044 Requirement (§4.4.2.2.2):** *Life Cycle Impact Assessment – Selection* *For each impact category, the necessary components of the LCIA include* *– identification of the category endpoint(s),* *– definition of the category indicator for given category endpoint(s),*	Requirement met		Closed.

Type of comment: **GE** = general **TE** = technical **ED** = editorial

(1) Com-ment Type & No.	(2) Page No.	(3) Para/ Fig/ Tbl/ Note	(4) ISO/PCR Requirement	(5) Comment (justification for change)/Proposed change	(6) Decisions on each comment submitted	(7) Status Open/ Closed
			– identification of appropriate LCI results that can be assigned to the impact category, taking into account the chosen category indicator and identified category endpoint(s), and *– identification of the characterization model and the characterization factors.* *This procedure facilitates the collection, assignment and characterization modelling of appropriate LCI results.* *This also helps to highlight the scientific and technical validity, assumptions, value-choices and degree of accuracy in the characterization model.*			
TE34			**ISO 14044 Requirement (§4.4.2.2.2):** *Life Cycle Impact Assessment - The method of calculating indicator results shall be identified and documented, including the value-choices and assumptions used.*	Requirement met		Closed.
TE35			**ISO 14044 Requirement (§4.4.3.1):** *Life Cycle Impact Assessment - The [optional] application and use of normalization, grouping and weighting methods shall be consistent with the goal and scope of the LCA and it shall be fully transparent. All methods and calculations used shall be documented to provide transparency.*	Not applicable		Closed.
TE36			**ISO 14044 Requirement (§4.4.5):** *Life Cycle Impact Assessment –* **LCIA intended to be used in comparative assertions intended to be disclosed to the public** *An LCIA that is intended to be used in comparative assertions intended to be disclosed to the public shall employ a sufficiently comprehensive set of category indicators. The comparison shall be conducted category indicator by category indicator.* *An LCIA shall not provide the sole basis of comparative assertion intended to be disclosed to the public of overall environmental superiority or equivalence, as additional information will be necessary to overcome some of the inherent limitations in the LCIA. Value-choices, exclusion of spatial and temporal, threshold and dose-response information, relative approach, and the variation in precision among impact categories are examples of such limitations. LCIA results do not predict impacts on category endpoints, exceeding thresholds, safety margins or risks.* *Category indicators intended to be used in comparative assertions intended to be disclosed to the public shall, as a minimum, be* *– scientifically and technically valid, i.e. using a distinct identifiable environmental mechanism and/or reproducible empirical observation, and* *– environmentally relevant, i.e. have sufficiently clear links to the category endpoint(s) including, but not limited to, spatial and temporal characteristics.* *Category indicators intended to be used in comparative assertions intended to be disclosed to the public should be internationally accepted.*	The category indicators match the goal and scope. A statement Indicating the nature of the LCIA is needed. Requirement met for the use of standard impact assessment framework.	The following statement has been added to Section 2.2: It shall be noted that the above impact categories represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) actually follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the functional unit (relative approach). LCIA results are therefore	Closed

Type of comment: **GE** = general **TE** = technical **ED** = editorial

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Com-ment Type & No.	**Page No.**	**Para/ Fig/ Tbl/ Note**	**ISO/PCR Requirement**	**Comment (justification for change)/Proposed change**	**Decisions on each comment submitted**	Status Open/ Closed
			Weighting, as described in 4.4.3.4, shall not be used in LCA studies intended to be used in comparative assertions intended to be disclosed to the public. *An analysis of results for sensitivity and uncertainty shall be conducted for studies intended to be used in comparative assertions intended to be disclosed to the public.*		relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks. **Acknowledged**	
TE37			**ISO 14044 Reporting Requirements (§5.2)** ***Additional Requirements and Guidance -*** *The third-party report shall cover the following aspects:* *e)* ***Life cycle impact assessment****, where applicable:* *1) the LCIA procedures, calculations and results of the study;* *2) limitations of the LCIA results relative to the defined goal and scope of the LCA;* *3) the relationship of LCIA results to the defined goal and scope, see 4.2;* *4) the relationship of the LCIA results to the LCI results, see 4.4;* *5) impact categories and category indicators considered, including a rationale for their selection and a* *reference to their source;* *6) descriptions of or reference to all characterization models, characterization factors and methods used,* *including all assumptions and limitations;* *7) descriptions of or reference to all value-choices used in relation to impact categories, characterization models, characterization factors, normalization, grouping, weighting and, elsewhere in the LCIA, a justification for their use and their influence on the results, conclusions and recommendations;* *8) a statement that the LCIA results are relative expressions and do not predict impacts on category* *endpoints, the exceeding of thresholds, safety margins or risks.* *and, when included as a part of the LCA, also* *i) a description and justification of the definition and description of any new impact categories, category indicators or characterization models used for the LCIA,* *ii) a statement and justification of any grouping of the impact categories,* *iii) any further procedures that transform the indicator results and a justification of the selected references, weighting factors, etc.,* *iv) any analysis of the indicator results, for example sensitivity and uncertainty analysis or the use of environmental data, including any implication for the results, and* *v) data and indicator results reached prior to any normalization, grouping or weighting shall be made available together with the normalized, grouped or weighted results.*	Requirement generally met. Specific items need to be addressed as commented elsewhere.		Closed
TE38			**ISO 14044 Requirement (§4.5.1.1):** ***Life Cycle Interpretation*** *– General*	Requirement met		Closed.

(1) Comment Type & No.	(2) Page No.	(3) Para/ Fig/ Tbl/ Note	(4) ISO/PCR Requirement	(5) Comment (justification for change)/Proposed change	(6) Decisions on each comment submitted	(7) Status Open/ Closed
			The life cycle interpretation phase of an LCA or an LCI study comprises several elements as depicted in Figure 4, as follows: *– identification of the significant issues based on the results of the LCI and LCIA phases of LCA;* *– an evaluation that considers completeness, sensitivity and consistency checks;* *– conclusions, limitations, and recommendations.* *The relationship of the interpretation phase to other phases of LCA is shown in Figure 4.* *The goal and scope definition and interpretation phases of life cycle assessment frame the study, whereas the other phases of LCA (LCI and LCIA) produce information on the product system.* *The results of the LCI or LCIA phases shall be interpreted according to the goal and scope of the study, and the interpretation shall include an assessment and a sensitivity check of the significant inputs, outputs and methodological choices in order to understand the uncertainty of the results.*			
TE39			**ISO 14044 Requirement (§4.5.1.2):** ***Life Cycle Interpretation*** *– General* *The interpretation shall also consider the following in relation to the goal of the study:* *– the appropriateness of the definitions of the system functions, the functional unit and system boundary;* *– limitations identified by the data quality assessment and the sensitivity analysis.* *The documentation of the data quality assessment, sensitivity analyses, conclusions and any recommendations from the LCI and LCIA results shall be checked.* *The LCI results should be interpreted with caution because they refer to input and output data and not to environmental impacts. In addition, uncertainty is introduced into the results of an LCI due to the compounded effects of input uncertainties and data variability. One approach is to characterize uncertainty in results by ranges and/or probability distributions. Whenever feasible, such analysis should be performed to better explain and support the LCI conclusions.*	Requirement met		Closed.
TE40			**ISO 14044 Requirement (§4.5.2.3):** ***Life Cycle Interpretation*** *– Identification of Significant Issues.* *There are four types of information required from the preceding phases of the LCA:* *a) the findings from the preceding phases (LCI, LCIA) that shall be assembled and structured together with information on data quality;* *b) methodological choices, such as allocation rules and system boundary from the LCI and category indicators and models used in LCIA;*	Some further justification of the 25% difference criterion would strengthen the conclusions and interpretation section.	Due to lack of uncertainty data for much of the underlying databases, as well as a lack of uncertainties communicated in the comparison livestock production studies, establishing quantitative confidence intervals was not possible. The (yes, arbitrary) 25% criterion seemed appropriate given the level of variability	Closed

(1) Com-ment Type & No.	(2) Page No.	(3) Para/ Fig/ Tbl/ Note	(4) ISO/PCR Requirement	(5) Comment (justification for change)/Proposed change	(6) Decisions on each comment submitted	(7) Status Open/ Closed
			c) the value-choices used in the study as found in the goal and scope definition; *d) the role and responsibilities of the different interested parties as found in the goal and scope definition in relation to the application, and also the results from a concurrent critical review process, if conducted.* *When the results from the preceding phases (LCI, LCIA) have been found to meet the demands of the goal and scope of the study, the significance of these results shall then be determined. All relevant results available at the time shall be gathered and consolidated for further analysis, including information on data quality.*		introduced by some (albeit extreme and unlikely) sensitivity scenarios. Further, we have changed the language in the comparative statement, so that differences of less than 25% are designated as “unable to confidently determine difference” rather than saying that they’re about the same. **Acknowledged**	
TE41			**ISO 14044 Requirement (§4.5.3.1):** ***Life Cycle Interpretation*** – *Evaluation - General* *The objectives of the evaluation element are to establish and enhance confidence in, and the reliability of, the results of the LCA or the LCI study, including the significant issues identified in the first element of the interpretation. The results of the evaluation should be presented in a manner that gives the commissioner or any other interested party a clear and understandable view of the outcome of the study.* *The evaluation shall be undertaken in accordance with the goal and scope of the study.* *During the evaluation, the use of the following three techniques shall be considered:* *– completeness check (see 4.5.3.2);* *– sensitivity check (see 4.5.3.3);* *– consistency check (see 4.5.3.4).* *The results of uncertainty analysis and data quality analysis should supplement these checks.*	With regard to consistency check, and assessment of the use of multiple databases should be addressed.	In addition to reducing the number of databases used, also Added the following to Section 5.5: “ A combination of LCI databases were used due to limitations in process and geographical representation in any single database. This is not ideal, as combing databases can inadvertently introduce errors in analyses. The two databases used, however – Ecoinvent and Agrifootprint – are widely used and generally recognized to apply consistent methodological approaches. In some instances (such as transport and natural gas consumption) “global” datasets from Ecoinvent were chosen over geographically explicit datasets from USLCI due to incompleteness in the USLCI database (empty processes, missing water and land use flows).” **Acknowledged**	Closed
TE42			**ISO 14044 Requirement (§4.5.3.2):** ***Life Cycle Interpretation*** – *Evaluation - Completeness* *The objective of the completeness check is to ensure that all relevant information and data needed for the interpretation are available and complete.*	Requirement met		Closed.

(1) **Com-ment Type & No.**	(2) **Page No.**	(3) **Para/ Fig/ Tbl/ Note**	(4) **ISO/PCR Requirement**	(5) **Comment (justification for change)/Proposed change**	(6) **Decisions on each comment submitted**	(7) Status Open/ Closed
			If any relevant information is missing or incomplete, the necessity of such information for satisfying the goal and scope of the LCA shall be considered. This finding and its justification shall be recorded. *If any relevant information, considered necessary for determining the significant issues, is missing or incomplete, the preceding phases (LCI, LCIA) should be revisited or, alternatively, the goal and scope definition should be adjusted. If the missing information is considered unnecessary, the reason for this should be recorded.*			
TE43			**ISO 14044 Requirement (§4.5.3.3):** ***Life Cycle Interpretation*** – *Evaluation - Sensitivity* *The objective of the sensitivity check is to assess the reliability of the final results and conclusions by determining how they are affected by uncertainties in the data, allocation methods or calculation of category indicator results, etc.* *The sensitivity check shall include the results of the sensitivity analysis and uncertainty analysis, if performed in the preceding phases (LCI, LCIA).* *In a sensitivity check, consideration shall be given to* *– the issues predetermined by the goal and scope of the study,* *– the results from all other phases of the study, and* *– expert judgements and previous experiences.* *When an LCA is intended to be used in comparative assertions intended to be disclosed to the public, the evaluation element shall include interpretative statements based on detailed sensitivity analyses.* *The level of detail required in the sensitivity check depends mainly upon the findings of the inventory analysis and, if conducted, the impact assessment.* *The output of the sensitivity check determines the need for more extensive and/or precise sensitivity analysis as well as shows apparent effects on the study results.* *The inability of a sensitivity check to find significant differences between different studied alternatives does not automatically lead to the conclusion that such differences do not exist. The lack of any significant differences may be the end result of the study.*	Requirement met		Closed.
TE44			**ISO 14044 Requirement (§4.5.3.3):** ***Life Cycle Interpretation*** – *Evaluation - Consistency* *The objective of the consistency check is to determine whether the assumptions, methods and data are consistent with the goal and scope.* *If relevant to the LCA or LCI study the following questions shall be addressed.* *a) Are differences in data quality along a product system life cycle and between different product systems consistent with the goal and scope of the study?* *b) Have regional and/or temporal differences, if any, been consistently applied?*	Again, the use of multiple databases needs to be addressed.	This concern has been addressed (as described elsewhere) by replacing the Ecoinvent APOS model with the Cutoff model and minimizing the number of databases used by eliminating the use of USLCI (due to data quality challenges with this database). **Acknowledged**	Closed

(1) Com-ment Type & No.	(2) Page No.	(3) Para/ Fig/ Tbl/ Note	(4) ISO/PCR Requirement	(5) Comment (justification for change)/Proposed change	(6) Decisions on each comment submitted	(7) Status Open/ Closed
			c) Have allocation rules and the system boundary been consistently applied to all product systems? *d) Have the elements of impact assessment been consistently applied?*			
TE45			**ISO 14044 Requirement (§4.5.4): *Life Cycle Interpretation* – *Conclusions, limitations and recommendations*** *The objective of this part of the life cycle interpretation is to draw conclusions, identify limitations and make recommendations for the intended audience of the LCA.* *Conclusions shall be drawn from the study. This should be done iteratively with the other elements in the life cycle interpretation phase. A logical sequence for the process is as follows:* *a) identify the significant issues;* *b) evaluate the methodology and results for completeness, sensitivity and consistency;* *c) draw preliminary conclusions and check that these are consistent with the requirements of the goal and scope of the study, including, in particular, data quality requirements, predefined assumptions and values, methodological and study limitations, and application-oriented requirements;* *d) if the conclusions are consistent, report them as full conclusions; otherwise return to previous steps a), b) or c) as appropriate.* *Recommendations shall be based on the final conclusions of the study and shall reflect a logical and reasonable consequence of the conclusions. Whenever appropriate to the goal and scope of the study, specific recommendations to decision-makers should be explained.* *Recommendations should relate to the intended application.*	Requirement met		Closed.
TE46			**ISO 14044 Reporting Requirements (§5.2) *Additional Requirements and Guidance -*** *The third-party report shall cover the following aspects:* *f) Life cycle interpretation:* *1) the results;* *2) assumptions and limitations associated with the interpretation of results, both methodology and data related;* *3) data quality assessment;* *4) full transparency in terms of value-choices, rationales and expert judgements.*	Requirement met		Closed.
TE47			**ISO 14044 Requirement (§6.1):** *Critical Review - General* *The scope and type of critical review desired shall be defined in the scope phase of an LCA, and the decision on the type of critical review shall be recorded.* *In order to decrease the likelihood of misunderstandings or negative effects on external interested parties, a panel of interested parties shall conduct critical*	Requirement met		Closed.

(1) Com-ment Type & No.	(2) Page No.	(3) Para/ Fig/ Tbl/ Note	(4) ISO/PCR Requirement	(5) Comment (justification for change)/Proposed change	(6) Decisions on each comment submitted	(7) Status Open/ Closed
			reviews on LCA studies where the results are intended to be used to support a comparative assertion intended to be disclosed to the public.			
TE48			**ISO 14044 Requirement (§6.2):** *Critical Review -* ***Critical review by internal or external expert*** *A critical review may be carried out by an internal or external expert. In such a case, an expert independent of the LCA shall perform the review. The review statement, comments of the practitioner and any response to recommendations made by the reviewer shall be included in the LCA report.*	Not applicable		Closed.
TE49			**ISO 14044 Requirement (§6.1):** *Critical Review -* ***Critical review by panel of interested parties*** *A critical review may be carried out as a review by interested parties. In such a case, an external independent expert should be selected by the original study commissioner to act as chairperson of a review panel of at least three members. Based on the goal and scope of the study, the chairperson should select other independent qualified reviewers. This panel may include other interested parties affected by the conclusions drawn from the LCA, such as government agencies, non-governmental groups, competitors and affected industries.* *For LCIA, the expertise of reviewers in the scientific disciplines relevant to the important impact categories of the study, in addition to other expertise and interest, shall be considered.* *The review statement and review panel report, as well as comments of the expert and any responses to recommendations made by the reviewer or by the panel, shall be included in the LCA report*	Requirement met		Closed.
TE50			**ISO 14044 Reporting Requirements (§5.2) Additional Requirements and Guidance -** *The third-party report shall cover the following aspects:* *g) Critical review, where applicable:* *1) name and affiliation of reviewers;* *2) critical review reports;* *3) responses to recommendations.*	Requirement met		Closed.
TE51			**ISO 14044 Reporting Requirements (§5.3) Further reporting requirements for comparative assertion intended to be disclosed to the public.** **5.3.1 For LCA studies supporting comparative assertions intended to be disclosed to the public, the following issues shall also be addressed by the report in addition to those identified in 5.1 and 5.2:** *a) analysis of material and energy flows to justify their inclusion or exclusion;* *b) assessment of the precision, completeness and representativeness of data used;* *c) description of the equivalence of the systems being compared in accordance with 4.2.3.7;* *d) description of the critical review process;* *e) an evaluation of the completeness of the LCIA;*	See comment regarding the use of AWARE vs. consumptive water use in liters.	The following paragraph has been added to Section 2.2 to address the choice of water use over AWARE scarcity characterization: " While water scarcity characterized impacts (such as the AWARE method {Boulay, 2018 #1030}) are gaining prominence and acceptance in LCA, meaningful application of such methods requires appropriately regionalized water use data. Especially in the US, where water scarcity varies greatly in dominant	Closed

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Com-ment Type & No.	**Page No.**	**Para/ Fig/ Tbl/ Note**	**ISO/PCR Requirement**	**Comment (justification for change)/Proposed change**	**Decisions on each comment submitted**	Status Open/ Closed
			f) a statement as to whether or not international acceptance exists for the selected category indicators and a justification for their use; *g) an explanation for the scientific and technical validity and environmental relevance of the category indicators used in the study;* *h) the results of the uncertainty and sensitivity analyses;* *i) evaluation of the significance of the differences found.*		agricultural regions, assessment at a “national average” level may not offer additional information or insight. Such a regionalized inventory was not available for the US livestock production systems used as the comparison here, meaning that “water use” for these livestock production systems would require assuming a US national average scarcity. Similarly, providence of the CW agricultural supply chain is not well known. Thus, we conclude that applying a water scarcity impact category would not offer additional information or differentiation.” **Acknowledged**	
TE52			**ISO 14044 Reporting Requirements (§5.3) Further reporting requirements for comparative assertion intended to be disclosed to the public.** **5.3.2 If grouping is included in the LCA, add the following:** *a) the procedures and results used for grouping;* *b) a statement that conclusions and recommendations derived from grouping are based on value-choices;* *c) a justification of the criteria used for normalization and grouping (these can be personal, organizational or national value-choices);* *d) the statement that “ISO 14044 does not specify any specific methodology or support the underlying value choices used to group the impact categories”;* *e) the statement that “The value-choices and judgements within the grouping procedures are the sole responsibilities of the commissioner of the study (e.g. government, community, organization, etc.)”*	N/A		Closed.
			ISO 14044:2006/Amd 1:2017 Annex C - Footprints			
TE53			**ISO 14044:2006/Amd 1:2017 Annex C - C.2 Reporting** *Further to the requirements specified in Clause 5 on the reporting of LCA, this annex provides clarification about the interface between footprint quantification and communication. Footprint reports should include a statement indicating, for example, that the analysis is limited and does not address other impacts, which can be as important. If any footprint information is not communicated to third parties, the reporting requirements of 5.1.1 shall apply. If any footprint information is intended to be communicated to third parties, a third-party report in accordance with 5.1.2 and 5.2 c) shall be prepared and shall become the footprint study report, regardless of the chosen footprint communication. This third-party report shall serve as an input for the development of any footprint*	While the goal and scope identifies the principal impact categories for the study, a statement regarding the exclusion of other categories seems to be needed in order to satisfy this requirement.	The following statement has been added to Section 2.2: “ The ideal in LCA is to report on a full array of potential environmental impacts in order to evaluate possible shifts or trade-offs in impact. In reality, however, the reliability of available data often requires limiting perspective to a select subset of relevant impact categories. Further, a	Closed

(1) **Com-ment Type & No.**	(2) **Page No.**	(3) **Para/ Fig/ Tbl/ Note**	(4) **ISO/PCR Requirement**	(5) **Comment (justification for change)/Proposed change**	(6) **Decisions on each comment submitted**	(7) Status Open/ Closed
			communication formats that might have to fulfil additional requirements in accordance with the relevant International Standards on environmental labels and declarations developed by ISO/TC 207/SC 3. *Footprints are limited to only one environmental aspect or a limited set of impact category indicators. Footprints shall be named in a way that accurately reflects the area of concern or reflects the potential environmental impacts assessed. Where an area of concern has only been partially assessed, an alternative name descriptive of the narrower scope shall be applied.* *A footprint addresses one area of concern. This can conflict with the comprehensiveness principle of LCA. Therefore, the report of the footprint quantification shall document the limitations with regard to selected environmental impact categories in a transparent manner. While the selected footprint study can quantify an important environmental aspect or a potential environmental impact of a product or an organization, the LCIA profile, as specified in 4.4.1, includes results for a broader set of other impact category indicators. An objective of LCA is to allow an informed decision regarding a comprehensive set of potential environmental impacts. As a result, footprints shall not be used in comparative assertions intended to be disclosed to the public. A comprehensive evaluation of environmental performance of a product or an organization cannot be achieved through an analysis that considers only a single area of concern or a non-comprehensive set of potential environmental impacts or aspects. Decisions about product or organizational impacts that are only based on a single or few environmental issue(s) can conflict with goals and objectives related to other environmental issues.*		limited number of impact categories were reported in the animal production system studies used as comparison. Thus, the impact categories chosen for this study were limited to: greenhouse gas emissions (global warming potential), fossil energy use, water use and land use. These four categories offer a valuable point of comparison for agriculture-dominated supply chains." **Acknowledged**	
TE54			**ISO 14044:2006/Amd 1:2017 Annex C - C.3 Critical Review** *Further to the requirements specified in Clause 6 on the critical review of LCA, this annex provides clarification about the interface between footprint quantification and communication.* *When an organization decides to use a footprint study report as a basis of a footprint communication, this footprint study report shall be publicly available in accordance with 5.2.* *When a critical review is performed, it shall be in accordance with Clause 6 or ISO/TS 14071.*	Requirement met.		Closed
			ISO 14044:2006/Amd 2:2020 Annex D – Allocation Procedures			
TE55			**ISO 14044:2006/Amd 2:2020 Annex D – D.2 Expanding the product system** *Expanding the product system to include additional functions related to the co-products (see 4.3.4.2, step 1, option 2) can be a means of avoiding allocation.*	Not applicable		Closed

Type of comment: **GE** = general **TE** = technical **ED** = editorial

(1) Com-ment Type & No.	(2) Page No.	(3) Para/ Fig/ Tbl/ Note	(4) ISO/PCR Requirement	(5) Comment (justification for change)/Proposed change	(6) Decisions on each comment submitted	(7) Status Open/ Closed
			NOTE 1 The concept of expanding the product system to include additional functions related to the co-products can also be referred to as system expansion or expanding the system boundary. *Therefore, the product system that is substituted by the co-product is integrated in the product system under study. In practice, the co-products are compared to other substitutable products, and the environmental burdens associated with the substituted product(s) are subtracted from the product system under study (see Figure 1). The identification of this substituted system is done in the same way as the identification of the upstream system for intermediate product inputs. See also ISO/TR 14049:2012, 6.4.* *The application of system expansion involves an understanding of the market for the co-products. Decisions about system expansion can be improved through understanding the way co-products compete with other products, as well as the effects of any product substitution upon production practices in the industries impacted by the co-products.* *Important considerations relating to the identification of product systems substituted by co-products include whether:* *— specific markets and technologies are affected;* *— the production volume of the studied product systems fluctuates in time;* *— a specific unit process is affected directly.* *If applicable, when the inputs are delivered through a market, it is also important to know:* *— whether any of the processes or technologies supplying the market are constrained, in which case their output does not change in spite of changes in demand;* *— which of the unconstrained suppliers/technologies has the highest or lowest production costs and, therefore, is the supplier/technology affected when the demand for the supplementary product is generally decreasing or increasing, respectively.* *EXAMPLE A fuel combustion process produces co-products of heat that is used for district heating as well as electricity. The inventory, i.e. inputs and outputs, of the avoided electricity can be subtracted from the inventory of the fuel combustion process to determine the inventory of the heat.* *System expansion avoids allocation by integrating a functionally equivalent product system, that is assumed to be substituted by the co-product (product B), within the system boundary. The inputs and outputs associated with the substituted product system are assumed to be avoided by the production of the co-product (product B), as illustrated by the example in Figure D.1.*			

(1) Com-ment Type & No.	(2) Page No.	(3) Para/ Fig/ Tbl/ Note	(4) ISO/PCR Requirement	(5) Comment (justification for change)/Proposed change	(6) Decisions on each comment submitted	(7) Status Open/ Closed
			Since the substituted system has a negative sign, the addition of this system is mathematically the same as a subtraction. There is an additional example of this in ISO/TR 14049:2012, Figures 15 and 16. *NOTE 2 Figure D.1 shows how to avoid allocation when the investigated product system has two products: product A (the product system under study) and product B (here, an energy product).* *In the case of recycling, one way to avoid allocation can be by calculating a recycling credit based on the technical substitutability of the secondary material(s), i.e., taking into account any changes to the inherent properties and quality of the secondary material versus the substituted primary material. If the secondary material X from the product system under study substitutes a primary material Y, then the recycling credit corresponds to subtracting the inventory associated with the acquisition of the primary material Y from the inventory calculated for the product system under study. If an input to a product system is a recycled material that has previously implied a credit to the product system that the recycled material comes from, such recycled material carries the credit as a potential environmental impact to the product system that it enters.*			
TE56			**ISO 14044:2006/Amd 2:2020 Annex D – D.3 Allocation that reflects the underlying physical relationships** **D.3.1 General** *Physical allocation can be applied when a physical, i.e. causal, relationship can be identified between the inputs, outputs and co-products of the multifunctional process. Such a relationship exists when the amounts of the co-products can be independently varied. How the amounts of inputs and outputs (emissions and waste) change following such a variation can be used to allocate the inputs and outputs to the varied co-product.* *This allocation procedure (step 2, 4.3.4.2) is applicable when: a) the relative production of co-products can be independently varied through process management, and b) this has causal implications for the inputs required, emissions released or waste produced.* *EXAMPLE 1 When aqueous ammonia (NH3) reacts with ethylene oxide (C2H4O), three co-products are produced: monoethanolamine (H2NCH2CH2OH), diethanolamine (HN(CH2CH2OH)2) and triethanolamine (N(CH2CH2OH)3). The relative production volume of the three co-products can be controlled by changing the proportion of the reactants in the solution, which means the amounts of the co-products can be varied independently, and all products are therefore determining products, independently of each other. Therefore, this combined production can be described for each product separately based on the stoichiometric requirements of each product, with the limiting group being hydroxyl (OH). To make 1 kg monoethanolamine, 0,279 kg*	Not applicable		Closed

(1) Com-ment Type & No.	(2) Page No.	(3) Para/ Fig/ Tbl/ Note	(4) ISO/PCR Requirement	(5) Comment (justification for change)/Proposed change	(6) Decisions on each comment submitted	(7) Status Open/ Closed
			ammonia and 0,721 kg ethylene oxide are needed. To identify these masses, the following formula is used: *m = n×M* *where* *m mass (in kg);* *n amount of substance (in mol);* *M molar mass (in kg/mol).* *EXAMPLE 2 ISO/TR 14049:2012, 7.3.1, provides another example where transportation fuel consumption is allocated between a packaging material and a commodity based on the proportion of payload used.*			
TE57			**ISO 14044:2006/Amd 2:2020 Annex D – D.4 Allocation methods reflecting other relationships** **D.4.1 General** *According to 4.3.4.2, step 3, inputs and outputs can also be allocated between co-products reflecting other relationships between them, e.g. in proportion to the economic value of co-products (economic allocation).* *The most common form of economic allocation is based on the revenue obtained from the co-products.* *EXAMPLE 1 A dairy cow produces 70 % of its revenue through milk and 30 % through animals sold (calves and dairy cow at the end of life). This ratio can be used to allocate all inputs and outputs that can neither be directly attributed to the milk nor to the animals sold.* *EXAMPLE 2 Another example is given in ISO/TR 14049:2012, 7.3.2.*	Revenue allocation is the predominant mechanism used in the study; although, a cut off approaches used for consideration of recycling of one material.	Have adjusted model to use cut-off throughout. **Acknowledged**	Closed
			Are the methods used to carry out the study scientifically and technically valid?			
GE 1			**Consideration of using the cut-off method and then APOS is warranted given the diversity of datasets and models used for the analysis.** **The final version of the study report is scientifically and technically valid.**		This substitution of cut-off for APOS was executed. **Acknowledged**	Closed
			Are the data used appropriate and reasonable in relation of the goal of the study?			
GE 2			The data used are appropriate and reasonable. Again, please examine issues related to the multiple databases used to conduct the study. **The data used in the final version of the study are appropriate and reasonable in relation to the goal of the study.**		The number of databases have been reduced and consistency of DBs has been improved. **Acknowledged**	Closed
			Do the interpretations reflect the limitations identified and the goal of the study			
GE 3			**The interpretations reflect the limitations and goal of the study.**			Closed.

Type of comment: **GE** = general **TE** = technical **ED** = editorial

Date: 9/10/21	Doc.: Chef Woo high-protein ramen noodle Life Cycle Assessment: A detailed comparison with animal-based protein sources, v0.1, 10/6/21, by the Regents of the University of Michigan on behalf of Borealis Foods.
Reviewer(s):	Thomas Gloria, Andrea Hicks, and Greg Thoma

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Com-ment Type & No.	**Page No.**	**Para/ Fig/ Tbl/ Note**	**ISO/PCR Requirement**	**Comment (justification for change)/Proposed change**	**Decisions on each comment submitted**	Status Open/ Closed
			Is the report transparent and consistent?			
GE 4			The are several editorial issues to address. Please see comments in track changes in the document. **The final version of the report is transparent and consistent.**		All comments and suggested edits provided in the document have been addressed.	Closed
			Editorial Comments			
			Comments have been provided as track changes in the draft document.		**All responses and revisions have been accepted.**	Closed

Type of comment: **GE** = general **TE** = technical **ED** = editorial

CENTER FOR SUSTAINABLE SYSTEMS
UNIVERSITY OF MICHIGAN

School for Environment and Sustainability, 440 Church Street, 3012 Dana Building, Ann Arbor, MI 48109-1041
734-764-1412 | css.umich.edu