ISO-COMFORMANT LCA REPORT

COMPARATIVE CHICKEN NUGGET LIFE CYCLE ASSESSMENT (LCA)

CLIENT:

IMPOSSIBLE™

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ISO-CONFORMANT LIFE CYCLE ASSESSMENT REPORT

Comparative LCA of Impossible™ Chicken Nugget Made From Plants and Chicken-based Chicken Nugget

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EXECUTIVE SUMMARY

Impossible Foods Inc. (Impossible Foods) aims to restore biodiversity and mitigate the impact of climate change by transforming the global food system. To do this, Impossible Foods makes meat, fish, and dairy analogues from plants. Impossible Foods has developed a new plant-based meat alternative (PBMA), the Impossible™ Chicken Nugget Made From Plants (ICN), that aims to mimic the flavour and texture of a chicken-based nugget (CBN)[1]. The company has undertaken work to calculate four specific life cycle potential impact categories (global warming potential, freshwater eutrophication potential, land occupation, and water consumption) of two different versions of the product distributed within the United States (US). These impact categories were chosen because they will provide the most business value to Impossible Foods in their discussions with customers and other clients and are the most salient to animal agricultural environmental impacts. As a result, in this report, four life cycle potential impact categories of two ICN products (ICN1 for retail consumption and ICN2 for restaurant-type food service), manufactured and distributed within the US are compared against functionally equivalent CBNs (CBN1 for retail consumption and CBN2 restaurant-type food service) produced, manufactured and distributed within the US.

Boundary and scope

The type of inventory is cradle-to-gate of the initial purchaser of finished product, whether a distributor, food service operator, or traditional retailer, prior to purchase by an end consumer; the retail, use and end-of-life stages are excluded from the boundary because they are assumed to be identical for the respective comparative scenarios (i.e., the ICN has similar cooking time, specific heating capacity, shelf-life and distribution systems to the CBN). As noted above, the gate of the retailer for the ICN1, ICN2, CNB1, and CBN2, is located in the US (generic location) (thus, there are four total scenarios).

The four impact categories for all scenarios are considered on a per kilogram (kg) of delivered final product basis. ReCiPe Midpoint (H) v1.12/World Recipe H was used to quantify all indicators. These four impact categories were quantified using primary data from Impossible Foods manufacturing facilities and secondary data from literature, industry sources and commercial databases. Only the results for the four impact categories were quantified because these are the key environmental areas of concern for Impossible Foods; this specific reporting of impact categories is also consistent with previous PBMA life cycle assessments (LCAs) subject to critical review (Dettling, Tu, Faist, DelDuce, & Mandlebaum, 2016; Khan, Loyola, Dettling, & Hester, 2019) as well as other meat-based LCAs.

This study was conducted with the intention to communicate the LCA results and conclusions internally and externally. Internal communication will aid in internal decision-making and provide information to the company's stakeholders who are interested in the impacts associated with producing the ICN. Since the results are intended to be communicated externally, the study was critically reviewed by a three-person panel of independent experts in conformance with ISO 14044 (ISO, 2006); see Section 6 for more information. The reviewers' findings are summarized in a statement at the end of this report.

Results

In general, the four impact categories of the ICN are lower than the CBN. The following are the key findings from this work, generalized for all ICN and CBN results:

- 1 kg of ICN shows a global warming potential result 36% lower than 1 kg of CBN, with little difference between ICN1 and ICN2 because the recipes differ so little.
- 1 kg of ICN shows a freshwater eutrophication potential result 47% less than 1 kg of CBN, as it avoids some crop fertilizer and manure application emissions present in chicken production.

[1] A note that this LCA does not assess the flavour nor texture of the particular products under study.

- 1 kg of ICN shows a land occupation result between 48% to 49% less than 1 kg of CBN, as it required fewer land-intensive crops.
- 1 kg of ICN shows a water consumption result between 44% to 43% less than 1 kg of CBN due to lower demand for agricultural irrigation for the ICN ingredients than for the CBN ingredients and high-water withdrawal for the chicken production and slaughterhouse stages More detailed results are provided in the report.

The ICN studied in this work has lower impact categories than CBN because of a lower quantity of crops and energy consumption in the in-scope life cycle of the products.

The application of the results, interpretation, and conclusions of this study are limited to the products considered in this study. Furthermore, the results calculated for the ICN1 and ICN2 are limited to the unique recipe and cannot be extrapolated or applied to the production of other PBMAs by other means.

In summary, the study has found that there are clear potential environmental benefits in the impact categories of concern discussed in this study, to using ICN1 and ICN2 examined in this work compared to CBN1 and CBN2.

Critical review

A critical review was performed by a third-party panel (Critical Review Panel) directed by the International Reference Centre for the Life Cycle of Products, Processes and Services (CIRAIG). The panel concluded that methods used to carry out the LCA are consistent with the ISO-14044 standard and are scientifically and technically valid and that the data used is appropriate and reasonable for public reporting. Some of the data that was deemed to be proprietary for Impossible Foods and/or its suppliers may have been redacted from this report. However, this data was not redacted for the Critical Review Panel. WSP has not audited or otherwise verified the information supplied to us in connection with this engagement.

Assessment Summary

Life Cycle Assessment (LCA)	
Life Cycle Assessment over select potential impact categories for Impossible Foods	
Parameter	**Description**
Company Name and Contact Information	*Study Commissioner:* Impossible Foods Inc. Redwood City, California, USA *Client Contact:* Arjun Pillai Hausner arjun.hausner@impossiblefoods.com *Study Practitioners:* WSP Canada Inc. Colin Powell Colin.powell@wsp.com Jenn Packer Jenn.packer@wsp.com
Standards Used	ISO 14040 2006: Environmental management – Life cycle assessment – Principals and framework ISO 14044 2006: Environmental management – Life cycle assessment – Requirements and guidelines
Product Name	The product under study is the Impossible Chicken Nugget Made From Plants. Four versions are studied here: two for retail consumption (ICN1) sent to the US retailers and two for distribution to food service/restaurants (ICN2) in the US.
Product Description	The ICN1 and ICN2 products are a pre-cooked, frozen plant-based meat alternative (PBMA) meant to mimic ground chicken nuggets and to be used in place of chicken nuggets as a plant-based substitute.
Functional Unit (study basis)	The function of the product is food for human consumption. The functional unit is one kilogram (kg) of product manufactured in the US in 2021 and delivered to the retailer in the US for ICN1, CBN1 and to the food service provider in the US for ICN2, CBN2.
Temporal Boundary	Data from Impossible Foods are up to date and relevant for the current year. Secondary data from Ecoinvent v3.6 cut-off databases have a validity range up to 2021. The time period in which the results should be considered valid is five years from publication date of this study.
Country/Region of Product Consumption	The ICN1 and ICN2 are produced in the Midwest US. Then, they are distributed to the US (ICN1, ICN2). The chicken and chicken nugget processes studied in this work comparatively take place in the US and distributed to the US.
Version and Date of Issue	Final version – November 5, 2021.

Glossary of Terms

CBN1 and 2: Ground chicken nugget functionally equivalent to ICN1 and 2, respectively

GaBi®: Life cycle assessment software program

GWP: Global Warming Potential

ICN: Impossible™ Chicken Nugget Made From Plants

ICN1 and 2: Specific recipe formulations of the ICN

ISO: International Organization for Standardization

kg: kilogram

LCI: Life Cycle Inventory

LCIA: Life Cycle Impact Assessment

PBMA: Plant-based meat alternative

US: United States

1 GOAL OF THE STUDY

Impossible Foods Inc. (Impossible Foods) has developed a new plant-based meat alternative (PMBA), called the Impossible™ Chicken Nugget Made From Plants (ICN), that aims to mimic the flavour and texture of a chicken-based chicken nugget (CBN)[2]. The ICN is made primarily from plant-based proteins, fats, oils, and binders and formed into a nugget shape, breaded, fried, frozen, and then packaged for distribution to retailers and food-service providers.

Impossible Foods commissioned WSP Canada Inc. (WSP) to develop a life cycle assessment (LCA). The LCA was carried out using characterization factors programmed into GaBi[3]. ReCiPe Midpoint (H) v1.12/World Recipe H (RIVM, 2018) was used to quantify four impact categories: global warming potential (GWP), freshwater eutrophication potential, land occupation, and water consumption (depletion). The reader is directed to RIVM (2018) for more detailed discussion of the ReCiPe methodology, the definition of midpoint categories, as well as the specific definitions within the impact categories. As a note, using the ReCiPe Midpoint (H) method (World H), water depletion was quantified; water depletion is defined in Goedkoop et al. (2009) as freshwater withdrawal (from irrigation sources, for example) minus freshwater return (to a body of water, for example).

The nature of this study is current as the ICN is currently being produced in the United States (US).

The goal of this study is twofold:

- Determine the absolute values of the above four impact categories of the ICN scenarios; and,
- Calculate the difference in the above four impact categories between the ICN scenarios and the CBN scenarios.

This study analyzes only the recipes and products used by Impossible Foods for the ICN and cannot be applied to that of other PBMAs or Impossible Foods products. Only the results for the four impact categories were quantified because these are the key environmental areas of concern for Impossible Foods; this specific reporting of impact categories is also consistent with previous PBMA life cycle assessments (LCAs) subject to critical review (Dettling, Tu, Faist, DelDuce, & Mandlebaum, 2016; Heller & Keoleian, 2018; Khan, Loyola, Dettling, & Hester, 2019) as well as other meat-based LCAs. We recognize this as a limitation to the overall results presentation, but are confident that these four impact categories are most relevant for food products and there is precedent for disclosure over only these impact categories.

1.1 REASONS FOR CARRYING OUT THE STUDY

This study was conducted to inform internal decision-making and to provide information to the public who are interested in the potential environmental impacts of Impossible Foods' products. These four potential impact categories are of interest to Impossible Foods and their stakeholders. Only the results for the four impact categories were quantified because these are the key environmental areas of concern for Impossible Foods; this specific reporting of impact categories is also consistent with previous PBMA life cycle assessments (LCAs) subject to critical review.

[2] A note that this LCA does not evaluate flavour nor texture.

[3] https://gabi.sphera.com/america/index/

The company commissioned this study to determine the absolute values of four potential impact categories from the life cycle of their company's ICN product and compare those values against animal meat-based benchmarks. Therefore, the results of this study include absolute and comparative values that are intended to be communicated externally.

1.2 INTENDED APPLICATIONS

This project report is intended to support Impossible Foods in quantifying those four particular impact categories associated with ICN ingredients, production, and distribution and in supporting the comparative assertions of those four particular impact categories associated with the ICN products studied here against the functionally equivalent CBN, intended to be disclosed to the public.

1.3 TARGET AUDIENCE

Specific audiences may include the company's employees, business partners, customers, and the general public. The study results are prepared for both Impossible Foods' internal use and to be communicated externally in conformance with ISO 14040, 14044, and 14062 (ISO, 2018).

1.4 COMPARATIVE ASSERTION FOR PUBLIC DISCLOSURE

This LCA is intended to be conformant with the requirements of ISO 14044 (ISO, 2006), which governs the requirements for public product-to-product comparisons for LCAs. A comparative assertion is intended to be made with the products described in this report. A Critical Review Panel was convened; details of the panel members and qualifications are described later in this report. The results of that review are also provided later in this report.

2 SCOPE OF THE STUDY

2.1 FUNCTION

The primary functions of the ICN and CBN are to provide food for consumers to eat.

2.2 FUNCTIONAL UNIT

In order to maintain functional equivalence, the functional unit is one kilogram (kg) of product manufactured in the US in 2021 and delivered to the retailer in the US for ICN1, CBN1 and to the food service provider in the US for ICN2, CBN2.

The following pairs are intended to be functional equivalents:

- ICN1 and CBN1; and,
- ICN2 and CBN2;

No other comparisons are meant to be made.

While it is acknowledged that there is not a single measurement on which to set a functional basis for food consumed due to the multiple reasons people eat food (i.e., for nutrition, to reduce or mitigate hunger, social gathering, etc., which are not addressed in this study), the ICN was designed to be nutritionally and aesthetically similar to a ground chicken nugget. Table 1 provides the nutritional data for the ICN and CBN with a comparable protein, fat, and calories amount per mass.

Table 1 – Nutritional data for ICN and CBN

Nutrient	Units	ICN* 100 g (provided by Impossible Foods)	Chicken-based chicken nugget 100 g
Calories	kcal	251.14	300
Fat	g	14.56	18.89
Saturated fat	g	1.64	4.44
Trans fat	g	0	0
Cholesterol	mg	0	44.44
Sodium	mg	581.63	522.22
Total carbohydrate	g	17.54	16.67
Total dietary fiber	g	4	0

Total sugars	g	0.59	0
Protein	g	14	15.56

*The recipes for ICN1 and ICN2 only differ slightly and the nutritional values do not differ significantly. **It is recognized that nutritional information for market chicken nuggets may vary, but this product is seen as representative for these purposes.

The products are compared in this LCA on a per-mass basis, as was done in the other LCAs for Impossible Foods (Impossible Foods, 2020). It is noted, though, that human bodies digest animal proteins differently than vegetables and thus the specific digestion of the PBMA and the chicken-based nugget may differ; this effect was not examined in this specific study. An additional limitation to using the per-weight basis to examine the impact categories would be the fact that some people eat to satiate specific dietary needs, for example, protein intake. An analysis is completed in Section 5.3.2.1 to examine the impact categories on a caloric and protein functional-unit basis to understand if the conclusions change based on a different functional unit.

2.3 DESCRIPTIONS OF THE SYSTEMS

As noted above, the ICN is compared against a functionally equivalent CBN. The systems studied are discussed in this section. As a note, the ICN and CBN have similar breading, and cooking. This is also borne out in practice where chicken-based and plant-based nuggets are prepared and made using similar processes in similar facilities.

2.3.1 IMPOSSIBLE CHICKEN MADE FROM PLANTS – ICN

There are two varieties of the ICN under study in this LCA differentiated by the target customer (retail and food service):

- ICN1: a PBMA that mimics the taste and texture of a chicken-based chicken nugget, that is delivered pre-cooked and frozen to a distributor, with a recipe and packaging that is designed to be sold directly to consumers at retail locations; and,
- ICN2: a PBMA that mimics the taste and texture of a chicken-based chicken nugget, that is delivered pre-cooked and frozen to a distributor, with a recipe and packaging that is designed to be sold directly to food service establishments for consumption by consumers in food service establishments.

The differences in the ICN1 and ICN2 are related to (1) breading inputs to account for the different cooking conditions typically used by in-home consumers and restaurant operators, and (2) the quantity of packaging.

The ICN is intended to be included in recipes and meals as a direct and equivalent substitute for chicken-based chicken nuggets. It consists of ingredients sourced globally, including plant-based proteins, fats, oils, and binders.

The boundary of the system studied includes all activities necessary to produce the ICN1 and ICN2 from cradle-to-gate of the initial purchaser of finished product, whether a distributor, food service operator, or traditional retailer, prior to purchase by an end consumer. Retail, use and end-of-life stages are excluded from the study as these do not differ significantly between the ICN and the reference CBN products. Overhead services (e.g., lighting and heating of buildings on site) are considered a non-attributable process (i.e., processes that are not directly connected to the studied product) but are included because they are typically provided with the total electricity and fuel consumption data. Other non-attributable processes such as infrastructure and equipment, corporate activities, transport of employees to and from work, etc. are excluded as either the information is not available or, while it is recognized that these non-attributable processes may have some environmental impacts that can be quantified using hybrid LCA methodologies, they are not in-scope for this type of LCA.

Figure 1 further details the system under study, including raw materials production, the ICN primary and secondary production processes, packaging and then distribution to retailer. As noted prior, the use and end-of-life stages are not included here because they are not considered to differ between the ICN and CBN processes.

Figure 1 – Inventory boundary for the ICN scenarios (WSP analysis) – REDACTED FOR PROPRIETARY REASONS

The in-scope life cycle stages of the ICN, with the specific sub stages that are relevant to the potential environmental impact calculations, are described briefly in Table 2.

Table 2 – In-scope life cycle stages of ICN

Stages	Sub stages	Description
Base meat production	Bulk ICN raw material production	The ingredients in the ICN include organic and inorganic chemicals, plant fats, proteins and carbohydrates. The organic and inorganic chemical production may require electricity, natural gas and other fossil fuel inputs, as well as other primary chemical inputs. Crop production to obtain the plant fats, proteins and carbohydrates generally includes soil preparation, which includes applying fertilizer or manure to add nutrients, and tillage and plowing to remove unwanted weeds or grass. Once the soil is prepared, the seeds are sowed, followed by irrigation and further application of fertilizers and/or manure. Once the crops reach maturity, they are harvested using a combine and dried, packaged and stored until ready for shipment. Impacts from this substage primarily arise from fossil fuel use to produce fertilizer and run farm equipment; nitrate and nitrogen emissions from the application of fertilizers and lime; water withdrawal and return for irrigation; and land occupation for the cropland itself (Chicken Farmers of Canada, 2018; Dalgaard, Halberg, & Hermansen, 2007; Putman, 2017).
	Transport from site to processing facility	The raw materials and crops, for the ICN are delivered via truck to the Impossible Foods production plant in the Midwest US from regions that produce and distribute large volumes of the specific ingredients (exact locations not provided publicly for proprietary reasons).
Processing	ICN bulk formation	The production process for the ICN involves first the development of a bulk product.
	Transport to finishing and cooking facility	The bulk ICN product is then delivered to a finishing and cooking facility at another location in the Midwest US using a refrigerated truck.
	Finishing and cooking	After delivery of the bulk ICN product to the finishing and cooking facility, the product is breaded, fried, baked and then packaged. The breading stages use a variety of wheat-, corn-, potato-based flours and starches. The frying stage uses soybean oil as a cooking oil. The frying and baking stages use natural gas and electricity to heat. This is the same finishing and cooking step as the CBN to ensure comparability. This is also borne out in practice where chicken-based and plant-based nuggets are prepared and made using the same processes in the same facilities.
Packaging	Packaging	The ICN packaging consists of a plastic bag that contains the nuggets. These bags are then packed in corrugated cardboard. Packaging and nugget production are co-

		located. No other packaging is used. The amount of the plastic and the corrugated cardboard used for ICN1 and ICN2 differs and is discussed later in this document.
Distribution to retailer	Transport from secondary processing to retail (ICN1) and food-service (ICN2)	The packaged ICN products are then delivered to the US, via truck, to retailers: grocery stores for ICN1 and restaurants for ICN2.

2.3.2 CHICKEN NUGGET BOUNDARY DESCRIPTION

For CBN, chickens are produced in conventional farms (not organic farms) in the US and processed to ground chicken and nuggets for domestic consumption. The products are meant to mimic the ICN, to be sold frozen and in the form of a chicken nugget. There are two varieties of the CBN under study in this LCA:

- CBN1: a chicken-based chicken nugget is delivered pre-cooked and frozen to a distributor for a retail customer; and,
- CBN2: a chicken-based chicken nugget is delivered pre-cooked and frozen to a distributor for food service establishments.

Consistent with the ICN1 and ICN2, the differences in the CBN1 and CBN2 are related to (1) the specific ingredients that make up the bulk product prior to breading and dusting steps, and (2) the quantity of packaging.

Figure 2 further details the system under study, including feed production, chicken production (i.e., the chicken production process and slaughter), chicken processing, forming, breading, and cooking (meant to produce functional equivalence to the ICN varieties), and then distribution to retailer/food-service. As noted prior, the use and end-of-life stages are not included here because they are not considered to differ from the ICN equivalent.

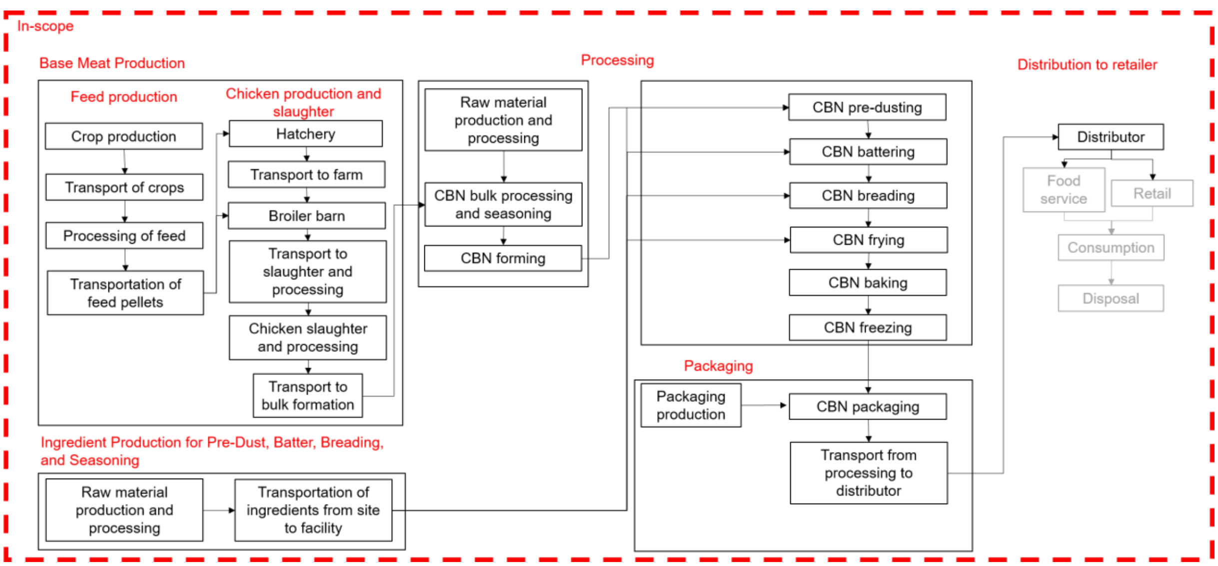

Figure 2 – Inventory boundary for CBN scenarios (WSP analysis)

As noted above, overhead services are considered non-attributable but are included because they are typically included in the total electricity and fuel consumption data. Other non-attributable processes such as infrastructure and equipment, corporate activities, transport of employees to and from work, etc. are excluded.

Based on WSP analysis, the in-scope life cycle stages of the CBN, with the specific sub stages that are relevant to environmental impact calculations, are described briefly in Table 3.

Table 3 – Boundary descriptions for chicken nuggets (WSP analysis)

Stages	Sub stages	Description
Base meat production - Feed production	Cultivation and harvesting of crops	The poultry and egg industry are a major user of feed grains (US Economic Research Service, 2021). Crop production generally includes soil preparation, which includes applying fertilizer or manure to add nutrients, and tillage and plowing to remove unwanted weeds or grass. Once the soil is prepared, the seeds are sowed, followed by irrigation and further application of fertilizers and/or manure. Once the crops reach maturity, they are harvested using a combine and dried, packaged and stored until ready for shipment. Impacts from this substage primarily arise from fossil fuel use to produce fertilizer and run farm equipment; nitrate and nitrogen emissions from the application of fertilizers and lime; leaching of manure causing potential eutrophication; water withdrawal and return for irrigation; and land occupation for the cropland itself. (Chicken Farmers of Canada, 2018; Dalgaard, Halberg, & Hermansen, 2007; Putman, 2017). It is noted that this comparison will only consider the conventional chicken industry not organic chicken.
	Transport of crops to processing plant	Once ready for shipment, the harvested crops are transported to the feed mill. The primary emissions relating to transportation are from the use of diesel (Dalgaard, Halberg, & Hermansen, 2007).
	Processing of crops (crushing, screening, milling and concentration)	The harvested crops must first be processed to be converted to feed and to a form that is easily consumed by the chickens. The feed mill is responsible for preparing finished feed. Different feed rations are used for newly hatched chicks (starter), birds in the development phase (developer) and mature birds (grower). Because of fossil fuel and electricity use during the processing stage, greenhouse gas (GHG) emissions are the primary source of environmental impacts from this substage (US Poultry & Egg Association, nd).
	Transport of crops to hatchery and broiler barn	Once ready for shipment, the processed feed is transported to the hatchery or broiler barn to be used as feed typically using trucks or trains. The primary emissions relating to transportation are from the use of diesel (Dalgaard, Halberg, & Hermansen, 2007).
Base meat production - Chicken production and slaughter	Live poultry production (broilers)	Poultry production generally includes egg production, pullet production, and broiler production. Pullet rearing and laying houses are typically on the same farm. Hatcheries are responsible for the incubation and hatching of chicks from fertile eggs. The grow-out farm or broiler farm is where the broiler chickens are raised. Activities include feeding, watering, cleaning, and management of waste. Primary sources of energy consumption include electricity, heating fuel, and diesel usage (US Poultry & Egg Association, nd; Putman, 2017; Skunca, Tomasevic, Nastasijevic, Tomovic, & Djekic, 2018). In the US, chicken production is concentrated in Georgia, Arkansas and Kentucky, as is modelled in Putman (2017).
	Manure management and application	Excreta from broiler and pullet operations are deposited on floors lined with wood shavings and collected then transported off-farm. The remaining floor space is covered by the nesting area, which has permeable flooring, allowing excreta to collect underneath. Excreta and bedding (collectively called litter) from all poultry operations are transported off- farm and applied as fertilizer to nearby farms (Putman, 2017).

	Slaughtering and processing	Activities which take place in a slaughterhouse include the reception of live chickens, livestock handling and animal welfare, slaughtering (stunning, bleeding, scalding and defeathering, evisceration, removing of head and feet) and chilling and freezing. Following slaughter, the chicken is processed including preparation activities, thermal processing, packaging, storage of final products and waste handling. Cleaning and carcass transportation from slaughterhouse to meat processing plant is also included (Skunca, Tomasevic, Nastasijevic, Tomovic, & Djekic, 2018; Putman, 2017).
Processing	Primary processing and forming	After the slaughter and processing, the fresh chicken meat is ground and seasoned as necessary. This primary process of bulk formation is assumed to occur in the same geographic region of the US as for the ICN for direct comparison to the ICN.
	Transport to finishing and cooking facility	The bulk CBN product is then delivered to a finishing and cooking facility also in the Midwest US as for the ICN for direct comparison to the ICN.
	Finishing and cooking	The secondary processing stage includes the finishing and cooking activities. The ground chicken is formed into nuggets, breaded, fried, baked, and packaged. The breading stages use a variety of wheat-, corn-, potato- and rice-based flours and starches. The frying stage uses soybean oil as a cooking oil. The frying and baking stage uses natural gas and electricity to heat. Secondary processing is assumed to occur in the same location as for the ICN for direct comparison to the ICN. This is the same finishing and cooking step as the ICN to ensure comparability. This is also borne out in practice where chicken-based and plant-based nuggets are prepared and made using the same processes in the same facilities.
Packaging	Packaging	Finished chicken nuggets are packaged for sale using similar packaging to that of the ICN1 and 2: plastic film and corrugated cardboard for retail and food service.
Transportation to retailer	Transport from secondary processing to retail (CBN1) and food service (CBN2)	The packaged CBN products are then delivered to the US, via truck, to retailers: grocery stores for CBN1 and restaurants for CBN2.

2.4 CUT-OFF APPROACH

It is noted that for all scenarios, a mass-based cut-off criterion for the foreground processes was used, where those cumulative inputs that comprised less than 0.5% of the total mass of the final products were not included in the quantification of the impact categories. This is consistent with the previous LCA studies for Impossible Foods (Impossible Foods, 2020). For the background processes, the ecoinvent 3.6 cut-off database was used. The authors recognize that this may introduce some issues related to consistency among the cut-off approaches, but that primarily, the foreground processes where the 0.5% cut off was used were more relevant to the overall magnitude of impacts.

For processes that were above that threshold where no modelled processes were available, proxies were used. Inputs where proxies were used are identified in Table 6.

2.5 INVENTORY DATE AND VERSION

This is the first version of the inventory comparing the ICN1 and ICN2 scenarios against CBN1 and CBN2, respectfully. The ICN production data are based on the most recent design and production data provided by Impossible Foods. For the CBN, the inventories are based on representative industrial, market and literature data, where available.

2.6 TIME PERIOD AND GEOGRAPHIES OF THE INVENTORIES

This assessment is intended to be representative of the ICN and CBN production in the US during the year that the study is conducted (2020[4]-and 2021). Data and assumptions are intended to reflect current equipment, processes and market conditions. Data has been selected where possible to best match these geographic and temporal conditions, and the data quality of significant inputs is evaluated using Table 4. Information sources for this report were evaluated as relevant and considered to represent the best available data and conditions in the industry. While certain processes may generate emissions over a longer period than the current year, all data has been selected to represent current conditions, where practical.

For the global warming potential indicator, the 100-year time horizon global warming potentials (GWPs) without carbon feedback from AR5 (CH_4 = 28 and N_2O = 265) are utilized (IPCC, 2014).

2.7 LAND USE CHANGE IMPACTS

Direct land-use changes from the use of crop lands to produce PBMA ingredients and crops for chicken feed production may be significant (Reckmann, Blank, Traulsen, & Krieter, 2016). The quantification of GHG emissions for specific ingredients is sourced from the ecoinvent v3.6 cut-off database (Wernet, et al., 2016) and all crop-based ingredients include direct land occupation change impacts in their processes. Regardless, direct land-use change emissions may differ depending on the previous land occupation, the type of crop and the region in which the crops are grown.

2.8 ALLOCATION

Allocation or system expansion may be required when a single process has multiple valuable products as outputs (e.g., the refining of crude oil into various petroleum co-products). In these situations, inputs and emissions for the whole process need to be allocated to the various co-products following appropriate methods.

For all existing ecoinvent v3.6 processes, no modifications to the allocations embedded were performed. For processes that were modified, existing allocations were maintained. For oils, such as sunflower and coconut, allocation was conducted on an economic basis and this approach was applied from Impossible Foods (2020) in order to maintain consistency.

At a chicken farm, prior to slaughter, live chickens are the main product and manure is produced as a co-product. In such production, it is not possible to allocate precisely what feed use, land occupation or emissions are related to

[4] 2020 created some operational impacts globally due to the global COVID-19 pandemic, but Impossible Foods' production was not impacted and this represents a typical year of operation for Impossible Foods.

chicken or the manure and therefore system expansion must be used. The manure production replaces fertilizer on the market, resulting in avoided production of fertilizer (that was used in the ecoinvent processes), and thereby a negative contribution to the potential environmental impact from the life cycle of the chicken. In this study, manure that was produced in the chicken production process was applied to the crop production processes. The reduced fertilizer requirements as a result were modelled using the manure application process as detailed in this work.

For the chicken products in this study during slaughter, an economic allocation procedure was used because chicken products have such widely different values in the market. In this study, the chicken parts that are available for human consumption (i.e., fresh meat and food grade parts) are allocated 96% of the impacts, whereas those available for other products are allocated 4%, as per Quantis (2019).

2.9 DATA QUALITY REQUIREMENTS

The life cycle data used in this LCA relies upon the primary data from Impossible Foods and Putman (2017) and secondary data sources such as the ecoinvent v3.6 database where appropriate.

Data quality for each process in the inventory boundary that contributed 5% or more of the potential environmental impact were evaluated and the efforts to improve data quality are reported later in the paper, where necessary. The data was assessed using the data quality indicators described in Table 4 (Weidema, et al., 2013).

Table 4 – Data quality indicators

Data quality indicators	Description
Reliability	The degree to which the sources, data collection methods and verification procedures used to obtain the data are dependable.
Completeness	The degree to which the data is statistically representative of the relevant activity. Completeness depends on many factors including the percentage of sites for which data is used out of the total number of relevant sites, coverage of seasonal and other fluctuations in data, etc.
Temporal representativeness	The degree to which the data reflects the actual time (e.g., year) or age of the activity.
Geographical correlation	The degree to which the data reflects the actual geographic location of the activity (e.g., country or site).
Technological representativeness	The degree to which the data reflects the actual technologies used.

The qualitative evaluation for each data quality indicator will be based on the scoring scheme presented in Table 5. (Weidema, et al., 2013).

Table 5 - Pedigree scoring quality criteria

Score	Technology	Temporal	Geography	Completeness	Reliability
Very good (1)	Data for the same technology	Data with less than 3 years of difference	Data from the same area	Data from all relevant sites over an adequate time period	Verified data based on measurements

Good (2)	Data for a similar but different technology	Data with less than 6 years of difference	Average data from larger area in which the area under study is included	Data from more than 50% of sites over an adequate time period	Verified data partly based on assumptions or non-verified data based on measurements
Fair (3)	Data for a different technology	Data with less than 10 years of difference	Data from an area with similar production conditions	Data from less than 50% of sites over an adequate time period or from more than 50% of sites for a short time period	Non-verified data partly based on assumptions or a qualified estimate
Poor (4)	Data from processes and materials under study but from different enterprises	Data with less than 15 years of difference	Data from area with slightly similar production conditions	Data from only one site relevant for the market or some sites but from shorter periods	Qualified estimate
Very poor (5)	Data for an unknown technology	Data with more than 15 years or unknown difference to the time period of the data set	Data from an area that is unknown or distinctly different area	Data from a small number of sites and from shorter periods	Non-qualified estimate

It is excepted that the majority of significantly contributing (i.e. more than 5% to an indicator total value) processes will have very good or good data quality.

3 LIFE CYCLE INVENTORY ANALYSIS

3.1 DATA SOURCES FOR ICN

Depending on its source, data can either be classified as primary or secondary:

- Primary data is specific to the processes included in the product's life cycle boundary. It can be collected in the reporting company or from its suppliers; and
- Secondary data is not specific to the product under study and is taken from commercial databases, industry reports, literature, etc.

When modeling the two product systems under study, the ecoinvent v3.6 cut-off (Wernet, et al., 2016) database was used as the sole source for background data, with infrastructure processes excluded as noted above. There were cases where an Agri-footprint v1.0 foreground process (Blonk Agri-footprint BV, 2014) was used (economical allocation), as was the case in previous Impossible Foods LCAs (Impossible Foods, 2020) but the background processes were replaced with ecoinvent v3.6 processes; whenever possible, appropriate country inventories were selected. When neither country-specific nor region-specific inventories were available, global or "rest of work" ("RoW" in ecoinvent) inventories were used. For agricultural processes, local and recent crop yields were used to update inventories and make them more reflective of local conditions (see Impossible Foods (2020)). Global inventories are typically average datasets of all the country- or region-specific datasets available in the database for the specific product/process. This is assumed to be a reasonable alternative in the absence of country- or region-specific datasets (Khan, Loyola, Dettling, & Hester, 2019).

3.1.1 ICN – RAW MATERIALS PRODUCTION

Primary data for the stages controlled by Impossible Foods, such as the mixing of the base meat to go into the nugget and then further processing, breading, and cooking, were provided by Impossible Foods and their suppliers/manufacturers. WSP has not audited the data in any way and relies on Impossible Foods to provide accurate data. For processes not controlled by Impossible Foods, such as transportation, secondary data were used from commercial databases and literature.

A list of the ingredients and the associated modelled processes and databases for the ICN is provided in Table 6. While only the broad categories of ingredients are shown here to ensure the privacy of proprietary information, the actual ingredients, or equivalent proxies, were used to model the ICN1 and ICN2 in the GaBi software. Specific ingredient contributions (i.e., amounts of each ingredient) are not provided to protect proprietary recipes. The Critical Review Panel had access to the specific amounts of each ingredient and processes used to model those ingredients but these were removed for proprietary reasons from the public version. All ingredients contributing less than 0.5% to the total mass of the product are excluded from the analysis, as per the cut-off approach.

Table 6 – List of ICN ingredients

ICN Ingredient	Modelled dataset*					Database
	Base Meat	Seasoning	Breading	Frying		
Water	x				Tap water production, conventional treatment {US} – agg****	ecoinvent v3.6
Soy protein concentrate	x				Used Agri-footprint v1.0 dataset for foreground process but replaced all background processes with ecoinvent v3.6 processes (Blonk Agri-footprint BV, 2014)	ecoinvent v3.6 See Impossible Foods (2020) for process
Sunflower oil	x				Used Agri-footprint v1.0 dataset for foreground process but replaced all background processes with ecoinvent v3.6 processes (Blonk Agri-footprint BV, 2014)	ecoinvent v3.6 See Impossible Foods (2020) for processes and updated crop yields
Salt	x	x			Salt (GLO), production	ecoinvent v3.6
Wheat flour			x		Wheat (US), production	ecoinvent v3.6
Potato starch			x		Potato starch {US}, market for	ecoinvent v3.6
Corn flour			x		Sweet corn {US}, production	ecoinvent v3.6
Sugar			x		Sugar, from sugarcane {US}, production	ecoinvent v3.6
Soybean oil				x	Soybean oil {US}, production	ecoinvent v3.6

*All processes were default allocation. ****We recognize that there may be region-specific differences in the way that water is conveyed and the energy sources used to do so and this changes the emissions profile. As such, using a US representative water process may not describe specifically the water distribution in the manufacturing area. However, due to a lack of available data in ecoinvent, we have decided to use the US-process.

The ingredients above made from crops were produced using conventional methods (i.e. non-organic) that consume fertilizers, fossil fuels, water, etc. as is typical for crop production in the region of production. It is noted that yields for the relevant crops (i.e. corn, potato, etc.) were modified according to Impossible Foods (2020). The reader is also directed to the specific ecoinvent processes identified above for more information on specific inputs. It is noted that the same processes used above to produce corn-based products are also used (and similarly yield is modified) for the chicken feed.

A fixed distance of 1,500 km by diesel truck was used for each US-based product transported to the Midwest US ICN production facility. We note that this distance may be conservative as some crops, such as corn, for example, would be produced closer to the manufacturing location than 1,500 km, but it is also assumed that this transport distance is not a significant contributor to the overall impact categories. The impact of sourcing ingredients was modeled using applicable truck and ocean transport using actual road and sea distances.

3.1.2 ICN – BASE MEAT FORMING

The ICN ingredients undergo a forming stage in the Midwest US to obtain the base meat; this includes the use of pumps, liquefiers, motors, refrigerators and other equipment to prepare the base meat for further processing.

The data for this stage were collected by the manufacturer and is based on total facility usage normalized by the mass of functional unit produced. As noted prior, WSP has not audited this data and relies on Impossible Foods and their suppliers to ensure accuracy of provided data. The electricity grid for the manufacturing location was modelled using the utility provider for that location based on eGRID2019 data (US EPA, 2021) using a modified ecoinvent v3.6 process.

It is assumed, as well, there is a loss of 5% by weight of the ICN from this processing stage. Thus, the process was modelled with 5% of the output going to landfill. This is a conservative assumption as all efforts are made to conserve the product mass. Regardless, this approach was also used by Dettling, Tu, Faist, DelDuce, & Mandlebaum (2016) and in previous Impossible Foods LCAs (Impossible Foods, 2020).

3.1.3 ICN – FINISHING AND COOKING

The ICN base meat undergoes a finishing (i.e., seasoning) and cooking stage in the Midwest US which includes the use of conveyer belts and mixers for breading stages and ovens, frying vats, motors, refrigerators and other equipment to cook the nugget and prepare the nugget for distribution and sale.

The data for this stage were collected by the manufacturer and is based on total facility usage normalized by the mass of functional unit produced by Impossible Foods. As noted prior, WSP has not audited this data and relies on Impossible Foods and their suppliers to ensure accuracy of provided data. The electricity grid for the location where secondary manufacturing occurs was modelled using the energy mix data provided by the utility provider for that location using a modified ecoinvent v3.6 process.

It is assumed, as well, there is a loss of 5% by weight of the ICN from this processing stage.

3.1.4 ICN – PACKAGING

The ICN1 and 2 are packed using a flexible plastic pouch, suitable for use for frozen food applications, and this packaging is marketed to retail locations and restaurants using corrugated cardboard secondary packaging. The amount of plastic film and corrugated cardboard used for the packaging in ICN1 is 33.9 g and 182.1 g, respectively, per kg of ICN1, with approximately 383 g of ICN1 in each pouch and 3,064 g of product overall in one corrugated cardboard case. The amount of plastic film and corrugated cardboard used for the packaging in ICN2 is 16.5 g and 98.0 g, respectively, per kg of ICN2, with approximately 908 g of ICN2 in each pouch and 4,540 g of product overall in one corrugated cardboard case.

3.1.5 ICN – TRANSPORTATION TO DISTRIBUTOR

Both the ICN1 and 2 are distributed to distributors, where the study boundary is drawn, using a fixed distance of 1,500 km of freezer truck travel to the distributor gate. It is noted that the in-scope life cycle stages stop at the gate of the distributor; they do not include any activity beyond the gate of the distributor as that is expected to be equivalent between the ICN and CBN scenarios.

3.2 DATA SOURCES FOR CBN

For chicken production and slaughter processes within the CBN scenarios, chicken feed and chicken production data from Putman (2017) as well as additional data from Skunca et al. (2018) were used. Manure management activity and emissions data were calculated using Global Livestock Environmental Assessment Model (GLEAM) for broilers for North America (FAO, 2017).

It is noted here that the model may not be fully representative of the full spectrum of chicken production processes in the US, but is meant to be representative at least partially of the US industry in 2017. This is certainly a limitation of the work; however, it is considered the best available approach. It is recognized that there may be variation in resource intensity for the inputs within the US (i.e., the amount of water or fertilizer used for feed production in certain regions of the country), which is not considered here. To recognize the limitations, an analysis of more up to date chicken performance factors are conducted in Section 5.3.1.2.

3.2.1 CBN– FEED PRODUCTION

In chicken rearing for food, the chickens are fed different feed over the course of their lives, depending on the age of the chicken. Specific feed compositions for the US are provided in Putman (2017). The primary ingredients of chicken feed (over 85%) include grains and grain by-products, protein-producing seeds, and fish meal (Chicken Farmers of Canada, 2021). Leveraging the cut-off approach described previously, only the crop ingredients are modelled for the feed, specifically corn, soybean meal, and wheat (Putman, 2017). The average feed composition used in this study to model the feed delivered to chickens throughout their different stages of development is provided in Table 7.

Table 7 - Compound feed composition* (Putman, 2017)

Feed constituent	Chicken feed in the US
Corn (kg corn/ kg feed)	0.69
Soybean (kg soybean/ kg feed)	0.28
Wheat** (kg wheat/ kg feed)	0.03

*Other constituents in the feed include fish meal, amino acids, fats and vitamins. The cut-off approach was leveraged to eliminate some of the smaller contributing constituents (all amino acids, fats, and vitamins) and where the ecoinvent v3.6 database lacked proxies to model ingredients (fish meal), the share of the feed related to these constituents is modelled as the feed itself. **Wheat is less than 5% of the reported feed composition from (Putman, 2017), however based on 1965 broiler feed data (wheat is 29.7%) and other sources of data, the wheat ratio in broiler feed is significantly varied and therefore included and further discussed in the uncertainty analysis.

Feed constituents were modelled using US-based processes in the ecoinvent v3.6 database, but modified to reflect 2017 US census-based yield (USDA, 2020) (the best available data), the average fertilizer use between 2014 and 2018 (FAO, 2019), and the 2019 US grid (all are available in Impossible Foods (2020)). The limitations of using country-wide yields for crops in specific crops are recognized here and it is noted that differences in regional irrigation demands, for example, can have impacts on water use and energy use and then subsequent global warming potential, but due to a lack of region-specific data, country-wide, and sometimes global, data for crops were used where necessary. Energy for on-farm operations and drying and mixing the feed was obtained from secondary data in feed processes within ecoinvent v3.6. Transportation by truck from the farms to the feed processing facility was included in this stage. A fixed distance of 200 km by truck was used to model feed transportation.

1.1.1 CBN– CHICKEN PRODUCTION

As noted above, broiler performance data for the US was modelled using data from Putman (2017). The reader is directed to this resource for more specific data on broiler performance.

The primary sources of environmental impact in this stage are on-farm operations and manure management (enteric fermentation is not of concern for non-ruminants). Methane and direct nitrous oxide emissions from manure management were calculated using GLEAM for broilers for North America (FAO, 2017). Default values, based on the IPCC (2006) worksheets for nitrogen excretion, were used to calculate indirect nitrous oxide and ammonia emissions from manure management in absence of more specific data available.

For on-farm operations, the contributions to the impact categories are associated with energy use for climate control, cleaning and other uses, as well as water withdrawal. On-farm operations contributions to the impact categories, including water use, were also taken from Putman (2017). Emissions and activity data for the chicken production stage are provided in Table 8.

Table 8 – Emission and activity factors used for chicken manure management activities

Emission/activity	Amount (per kg live weight chicken)	Reference/guideline
CH_4, manure management	1.76 g	FAO – GLEAM (FAO, 2017)
Direct nitrous oxide (N_2O), manure management	0.555 g	FAO – GLEAM (FAO, 2017)
Indirect N_2O from volatisation, manure management	0.325 g	IPCC (2006a) – Tier 1 emission factor
Indirect N_2O from leaching, manure management	0.039 g	IPCC (2006a) – Tier 1 emission factor
Ammonia emissions, manure management	18.6 g	IPCC (2006a) – Tier 1 emission factor and 90%/10% estimate split between ammonia and NOx
NO_2 emissions, manure management	2.1 g	IPCC (2006a) – Tier 1 emission factor and 90% /10% estimate split between ammonia and NOx

Electricity	0.087 kWh	Putman (2017)
Diesel	0.074 MJ	Putman (2017)
Propane	0.303 MJ	Putman (2017)
Water	3.88 kg	Putman (2017)
Wood shavings (for litter)	0.08 kg	Putman (2017)

1.1.2 CBN – MANURE APPLICATION

The manure collected during the rearing phases is spread on adjacent fields for crop production; the farm and chicken rearing areas are co-located and this reduces the need for fertilizer on these fields. For the chicken models in this study, this manure application is assumed to take place on adjacent farms (this is a system expansion approach when more than one product is used in the system, the other product being chicken and subsequently chicken meat). A number of chicken LCAs, including Putman (2017) incorporated the emissions from manure application as well as the avoided emissions from manure replacing fertilizer at farms. In this study, based on the IPCC (2006) guidance, approximately 50% of the managed manure nitrogen and phosphorus is available to replace the equivalent synthetic nitrogen-based and phosphorus-based fertilizers and 75% and 97% of the available nitrogen and phosphorous in the manure replaced the equivalent synthetic fertilizers, to mimic previous approaches in Nguyen et al. (2011). This amount represents the "avoided" fertilizers. The quantity of nitrogen available for application was calculated via the Tier 1 emission factors in IPCC (2006) and the quantity of phosphorus available for application was calculated from Beegle & Durst (2002); avoided emissions specifically were estimated from ecoinvent processes for the crops. Specific emission/activity data for manure application are available in Table 9.

Table 9 – Emission and activity factors for manure application activities

Emission/activity	US (per kg live weight chicken)	Reference
Traction	0.157 MJ	Nguyen et al. (2011)
Direct N_2O from application	0.37 g	FAO – GLEAM (FAO, 2017)
NH_3 (assumed 10% of applied nitrogen volatized as ammonia)	3.86 g	IPCC (2006b)
Nitrates leached (assumed 30% leached to freshwater as nitrate)	11.6 g	IPCC (2006b)
Phosphorous leached (assumed 10% leached to	2.20 g	Chastain et al. (2010); IPCC (2006b)

freshwater as phosphate pentoxide[5])		
Avoided traction	0.011 MJ	Nguyen et al. (2011)
Avoided synthetic N fertilizer	38.6 g	Nguyen et al. (2011)
Avoided synthetic P fertilizer	52.7 g	Nguyen et al. (2011)

1.1.3 CBN – CHICKEN SLAUGHTER AND PROCESSING

Water and energy use for chicken slaughter and processing was based on data from Dettling et al. (2016).

The amount of chicken at the slaughterhouse that produced fresh meat available for nuggets (approximately 0.62 kg per kg of live weight) was provided from the World Food Lifecycle Database Methodological Guidelines (Quantis, 2019). Economic allocation was used to assign the impacts of products and co-products at the slaughterhouse. This is because the slaughterhouse process cannot be divided into separate sub-processes and there are no products that could replace the co-products of slaughtering. The economic allocation approach and data align with previous approaches used in Impossible Foods (2020) and others. The economic allocation assigns 96% of the impact categories to the fresh meat and 4% to the remainder of the products (Quantis, 2019).

No transportation was assumed between the slaughterhouse and the secondary processing because they are often co-located.

1.1.4 CBN – PRIMARY PROCESSING

The bulk processing, seasoning, and forming activities used for the ICN1 and ICN2 are used for the CBN1 and CBN2, respectively. This is because the chicken-based and plant-based chicken nuggets are made using similar processes. . It is assumed, as well, there is a loss of 5% by weight of the CBN from this processing stage. Thus, the process was modelled with 5% of the output going to landfill.

1.1.5 CBN – COOKING AND FINISHING

The breading, frying, baking, freezing, packaging, and transport activities used for the ICN1 and ICN2 are used for the CBN1 and CBN2, respectively. It is assumed, as well, there is a loss of 5% by weight of the CBN from this processing stage.

[5] The calculation was performed using an assumed 69 lbs phosphorous pentoxide/ton manure available in chicken broiler manure (Chastain, Camberato, & Skewes, 2010). 100% of the phosphorous was available for soil over the year and 10% leached to freshwater based on a conservative assumption noting that phosphates tend to leach less relative to nitrates.

1.1.1 CBN – TRANSPORTATION TO DISTRIBUTOR

The CBN1 and CBN2 are distributed to distributors, where the study boundary is drawn, using, a fixed distance of 1,500 km of freezer truck travel to the distributor gate. It is noted that the in-scope life cycle stages stop at the gate of the distributor; they do not include any activity beyond the gate of the distributor as it is expected to be equivalent between the ICN and CBN scenarios.

4 LIFE CYCLE IMPACT ASSESSMENT

4.1 LCIA PROCEDURES AND CALCULATIONS

LCIA was carried out using characterization factors programmed into GaBi®. ReCiPe Midpoint (H) v1.12/World Recipe H (RIVM, 2018) was used to quantify global warming potential (GWP), freshwater eutrophication potential, land occupation, and water consumption.

4.2 LCIA RESULTS

The GaBi® software calculates LCIA results in its balance function and computes the environmental impact results according to pre-defined characterization methods in the selected LCIA methodology.

4.2.1 COMPARATIVE SCENARIOS

The impact category results are provided in Table 10, on a per kg of food delivered to the retailer basis, for ICN1, ICN2, CBN1, and CBN2.

Table 10 – All scenario indicator category results, per functional unit

	Impact categories			
Scenario	Global warming potential (kg CO_2e)	Freshwater eutrophication potential (g P-eq)	Land occupation (annual m^2 crop eq)	Water consumption (m^3)
ICN1 - US	2.19	3.13	2.60	0.15
CBN1 - US	3.43	5.89	5.07	0.27
Difference	-36%	-47%	-49%	-44%
ICN2 - US	2.19	3.15	2.68	0.16
CBN2- US	3.43	5.93	5.17	0.28
Difference	-36%	-47%	-48%	-43%

The impact category results for the ICN scenarios are lower than those of the CBN scenarios for the four selected impact categories. ICN1 and ICN2 are not significantly different across all impacts with little difference between the scenarios; the only differences result from slight changes in breading type and different packaging.

Because the two scenarios for both ICN and CBN (i.e., ICN1 and 2 and CBN1 and 2) were found to have insignificant differences when comparing inter-scenario results, for the contribution analysis, only ICN1 and CBN1 are discussed in Table 11. All other scenarios are expected to have similar results.

Table 11 – ICN1 and CBN1 indicator results, contribution of each life cycle stage to the overall impact categories (Numbers may not add to 100% due to rounding)

Life cycle stage	Impact categories							
	Global warming potential (kg CO_2e)		Freshwater eutrophication potential (g P-eq)		Land occupation (annual m^2 crop eq)		Water consumption (m^3)	
	ICN1	CBN1	ICN1	CBN1	ICN1	CBN1	ICN1	CBN1
Base meat production	37%	60%	82%	91%	99%	100%	86%	92%
Processing	54%	35%	18%	9%	1%	0%	14%	8%
Packaging	0%	0%	0%	0%	0%	0%	0%	0%
Distribution	8%	5%	0%	0%	0%	0%	0%	0%

Raw materials production for the ‘base meat’ and breading, and frying contributes significantly to all selected impact category results for the ICN1 and CBN1, as expected. However, it is noted that processing contributes more than base meat production for the ICN1 for global warming potential because of the relatively smaller contribution from base meat production to global warming potential than for CBN1. Processing has a significant contribution to the global warming potential and freshwater eutrophication potential result primarily because of energy demand in this life cycle stage. For land occupation, raw materials production, as expected, contributes close to 100% of the result. Packaging and distribution have at most a 8% contribution for all selected impact categories, with that coming in global warming potential, as expected. Table 11 is shown graphically in Figure 3.

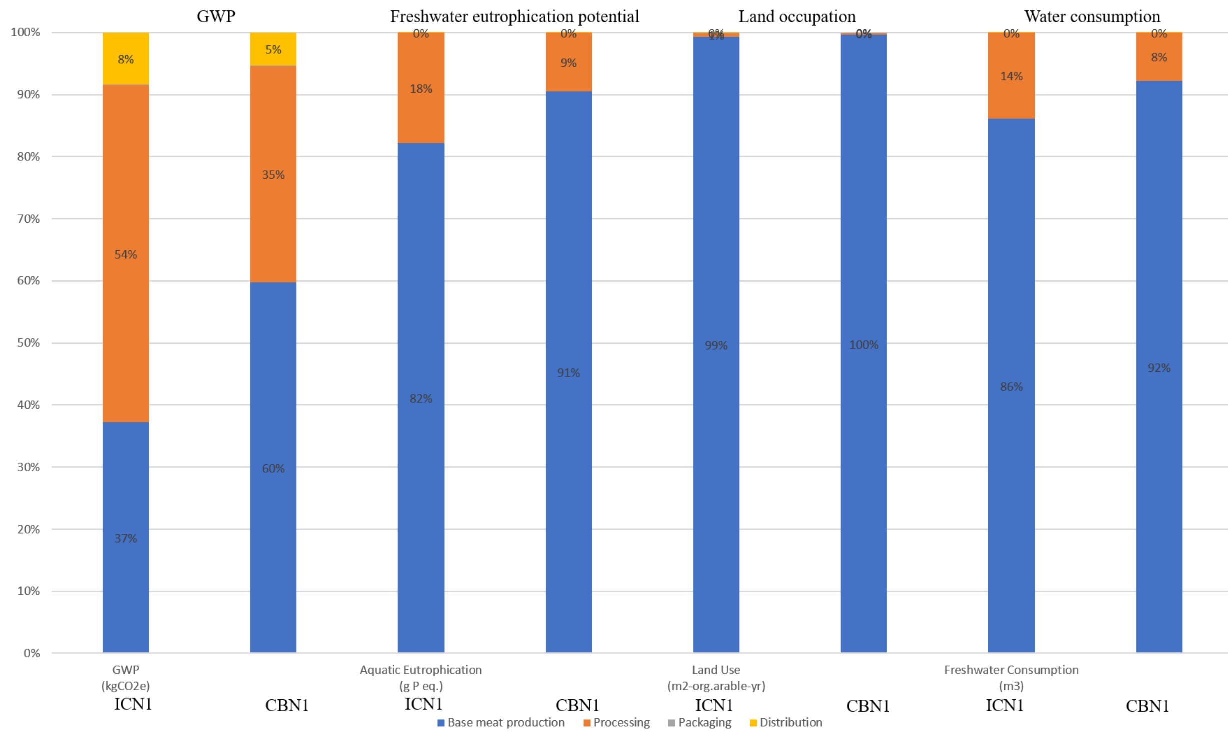

Figure 3 - ICN1 and CBN1 indicator results, contribution of each life cycle stage to the overall impact category

Overall, the global warming potential result for the ICN is 36% lower than that of the CBN because of the additional crop inputs and manure management emissions for the CBN.

The freshwater eutrophication potential result for the ICN is 47% lower than that of the CBN because of the additional crop inputs, manure application, and electricity demand for feed production in the CBN scenarios. The ICN freshwater eutrophication potential impacts are primarily associated with the soybean oil used in frying.

The land occupation result for the ICN is 48% to 49% lower than that of the CBN scenarios; the land use result for all scenarios is primarily due to crop production. The primary contributor for the ICN is soybeans (including oil), sunflower oil, and wheat flour. The difference between the ICN and CBN scenarios is due to the lower cropland requirements for the ICN in general. The corn and wheat crops used for chicken feed production are the primary contributors to land use impacts for the CBN.

The water consumption result for the ICN is 43% to 44% lower than the CBN primarily because of water withdrawal for chicken production and to a more limited extent, crops used in feed production. The use of sunflower oil and wheat in the ICN contributes significantly to its water consumption result.

4.2.2 PROCESS CONTRIBUTION ANALYSIS

For the studied impact categories, those processes that contributed more than 5% to the overall potential impact are provided in Table 12 only for ICN1 (the results do not differ significantly than for ICN2 so only ICN1 is shown). Where no value is given under a specific indicator, the process noted contributed less than 5% to that overall indicator.

Table 12 - List of significant contributing processes (i.e. those than contribute more than 5% to overall total) for the ICN1

Process	Global warming potential (kg CO_2e)	Freshwater eutrophication potential (g P-eq)	Land occupation (annual m^2 crop eq)	Water consumption (m^3)
Textured soy protein concentrate process	11%		24%	5%
Sunflower oil process			16%	18%
Carbon dioxide process	12%			
Wheat production process			26%	29%
Soybean oil process	12%	72%	25%	12%
Electricity process	29%	14%		
Tap water process				11%
Freezer truck distribution process	8%			

For global warming potential, in addition to soy products, electricity, carbon dioxide, and freezer truck distribution to retailers provide significant contributions. For freshwater eutrophication potential, impacts associated with soybean oil and electricity used in processing comprise the vast majority of the value. For land occupation, soy products, wheat used in breading, and sunflower oil, contribute the most significantly to this value. For water consumption, wheat in breading, sunflower oil, and water consumption in processing contribute the most significantly to this value.

It is evident that the breading stages increases the impact categories of concern in this product; however, these impact both types of products similarly as a similar type of breading is used in ICN and CBN.

For the specific impact categories, those processes that contributed more than 5% to the overall potential impact are provided in Table 13 only for CBN1 (results do not differ significantly than for CBN2). Where no value is given, the process contributed less than 5% to the overall indicator.

Table 13 - List of significant contributing processes (i.e. those than contribute more than 5% to overall total) for the CBN1

Process	Global warming potential (kg CO_2e)	Freshwater eutrophication potential (g P-eq)	Land occupation (annual m^2 crop eq)	Water consumption (m^3)
Corn	7%		24%	25%
Soybean	6%		35%	
Wheat	12%		19%	43%

Electricity	29%	12%		
Manure management	15%	36%		
Soybean oil	8%	38%	13%	10%
Carbon dioxide	8%			
Tap water				11%
Freezer truck distribution	5%			

For the CBN, the primary contributors to the impact categories are crop processes, manure management, and then electricity. As the CBN contains a number of similar processes to the ICN (breading, cooking, and all subsequent processes), the primary contributors do not differ significantly, except for the manure management process. Overall, the manure management processes (including application of manure) contributes 15% to the global warming potential and approximately 51% to the freshwater eutrophication potential. For the base meat production stage only, the contribution of manure management processes is approximately 32% to the global warming potential; this is typical for manure management emissions in chicken rearing. The smaller contribution of the manure management to the overall global warming potential, for example, is lower than a non-breaded chicken product because of the breading impacts.

4.3 LCIA RESULTS LIMITATIONS RELATIVE TO DEFINED GOALS

Other impact categories were not quantified in the results of the study because they do not serve to answer the questions defined in the goal and scope of the study for the intended audience stated in Section 1. As such, the application of the results of this study are limited to interpretations based on all potential impact categories included and cannot be generalized or applied to other impact categories.

4.4 DESCRIPTION OF PRACTITIONER VALUE CHOICES

The practitioner value choices have been limited to the selected LCIA. All results are presented on a mid-point basis, using the methods noted in Section 4.1; normalization and weighting are not used. Other impact categories have been excluded from the results because they do not answer the questions defined as the goal and scope for the intended audience in Section 1 of this report.

4.5 STATEMENT OF RELATIVITY

LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins, or risks. No grouping of impact categories has been performed; all impacts are presented at the mid-point level. LCIA impacts presented in this report are based on mid-point characterization factors (e.g., kg CO_2 equivalent for GWP), and this study does not refer to the ultimate damage to human health and the environment. For example, GWP may be a negative or a positive environmental impact depending on the conditions in locations where emissions occur. Since this study does not present end-point results, it does not draw any conclusions about the relative impact (positive or negative) for the categories considered by the study. It is recognized, however, that higher impacts in the above categories may have negative impacts on the health of people and the planet.

5 LIFE CYCLE INTERPRETATION

5.1 IDENTIFICATION OF RELEVANT FINDINGS

Based on the results presented in Section 4, the ICN1 and ICN2 have lower select impact category results over the CBN1 and CBN2, respectively, among the four impact categories of concern.

5.2 DATA QUALITY ASSESSMENT

Data quality for each process in the inventory boundary that contributed 5% or more of the potential environmental impact was evaluated and the efforts to improve data quality are reported in the following sections, where necessary. The data was assessed using the data quality indicators described in Table 4 generally first and is discussed in Table 14.

Table 14 – Data quality evaluation

Data Quality Requirement	Explanation
Technology coverage	For the Impossible Foods ingredients and other products, proxies were used for some additives and flavourings, but these ingredients have relatively minor contributions (and do not meet the indicated cut-off criteria) to the overall mass of the product. Processing inputs, such as electricity, diesel, natural gas and all chicken processes, are consistent with the technologies they are meant to represent. For secondary data, where used, changes over time are captured through updates to the ecoinvent databases. Therefore, technology coverage is considered good to very good for both the ICN and CBN.
Temporal coverage	Activity factors for Impossible Foods reflect data from 2020 and 2021. Estimates for all utility and other data was from utility bills for direct operations and allocated according to Impossible Foods production data. Secondary data, including emission factors for electricity, natural gas combustion, carbon dioxide cover the time period 2010-2021. Generally, activity data quality for ICN is considered very good whereas for emissions data, quality can be considered fair to good. Activity data for the CBN, including on farm activities and chicken performance data represents US modelled data from 2010 (Putman, 2017), was based on actual farm data from that time and would be considered fair. Emissions for manure management are from GLEAM (FAO, 2017) based on 2017 farming activity and are considered very good. Some emission factors for indirect nitrogen emissions are from over 20 years ago and would be considered poor data quality but are also still used widely in most animal meat LCAs where country- and farm-specific data is not available; these also do not represent a significant amount of the overall impacts.

Geographical coverage	The ingredients for ICN are generally sourced from the US and where not, geographically relevant emission factors were used to the extent possible. Impossible Foods manufacturing data comes from manufacturing data in the US and the emission factors for electricity, natural gas, etc. are all US-based. Geographical coverage for the ICN is considered good to very good. For the CBN, the chicken performance data is from three US farming states that have a high concentration of chicken farms and is noted in Putman (2017) to be appropriately representative of US chicken production. The emission factors for electricity, natural gas, etc. are all US-based. Geographical coverage for the CBN is considered fair to good.
Completeness	Data for the ICN, including ingredients and manufacturing processes is considered complete within the cut-off criteria and data quality is very good. Data for the CBN is based on typical emissions sources for chicken processes and was obtained from energy audits in three states and was adjusted to obtain a national average based on the weighted production of chickens in those states. Data quality for completeness could be considered fair to good for the CBN.
Reliability	Because primary data for modeling the ICN are based on primary data from Impossible Foods, the data quality for reliability is considered to be very good. Variability in primary activity data has not been assessed. All background data is from ecoinvent and is well documented for its reliability. With respect to the CBN, as noted above, on-farm data and performance is based on farm-specific data and is considered to be reliable. However, the manure management and application emission factors from GLEAM (FAO, 2017) are a combination of best estimates and non-verified data. Data quality for CBN for reliability is considered good to fair.

5.2.1 DATA QUALITY ASSESSMENT – ICN

The data is discussed here first in the context of ICN1. The processes contributing significantly (greater than 5%) to the ICN1 potential environmental impact categories (namely, in this case, four impact categories: global warming potential, freshwater eutrophication potential, land occupation, and water consumption) are provided in Table 12. Data quality for these processes is more directly discussed in Table 15.

Table 15 - Data quality commentary for the ICN significant processes

Significant process / input	Data sources	Data quality commentary	Efforts made to improve data quality

Textured soy protein concentrate (Base meat production)	**Activity data:** Data provided by Impossible Foods. **Environmental impact data:** Data from ecoinvent v3.6 database (Wernet, et al., 2016).	Soybean yield updated to US yields and as per USDA (2020). See Impossible Foods (2020) for more information. Data quality considered good to very good.	US yields and fertilizer use as per USDA (2020). See Impossible Foods (2020) for more information.
Sunflower oil (Base meat production)	**Activity data:** Data provided by Impossible Foods. **Environmental impact data:** Data from ecoinvent v3.6 database (Wernet, et al., 2016) and Agifootprint database (v1.0) (Blonk Agri-footprint BV, 2014).	Sunflower seed yield updated to US yields as per USDA (2020). See Impossible Foods (2020) for more information. Data quality considered good to very good.	US yields and fertilizer use as per USDA (2020). See Impossible Foods (2020) for more information.
Carbon dioxide (Processing)	**Activity data:** Data provided by Impossible Foods. **Environmental impact data:** Data from ecoinvent v3.6 database (Wernet, et al., 2016).	Data quality considered good to very good.	None required.
Wheat (Processing)	**Activity data:** Data provided by Impossible Foods. **Environmental impact data:** Data from ecoinvent v3.6 database (Wernet, et al., 2016)	Wheat yield updated to US yields and as per USDA (2020). See Appendix C for more information. Data quality considered good to very good.	US yields and fertilizer use as per USDA (2020). See Impossible Foods (2020) for more information.
Soybean oil (Processing)	**Activity data:** Data provided by Impossible Foods. **Environmental impact data:** Data from ecoinvent v3.6 database (Wernet, et al., 2016).	Soybean yield updated to US yields and as per USDA (2020). See Impossible Foods (2020) for more information. Data quality considered good to very good.	US yields and fertilizer use as per USDA (2020). See Impossible Foods (2020) for more information.
Electricity (Processing)	**Activity data**: Amount of electricity used quantified from Impossible Food manufacturers. Data for share of electricity generation overall embedded in electricity processes specific to the region as discussed prior in this work. **Environmental impact data**: Data from ecoinvent v3.6 database (Wernet, et al., 2016).	The specific contributions for each generation source are from data from 2014, but these factors were not expected to change significantly over time. Data quality considered good.	Proportion of electricity generation sources in the grid was updated as per See Impossible Foods (2020) for electricity grid factors.
Tap water (Base meat production, Processing)	**Activity data:** Data provided by Impossible Foods. **Environmental impact data:** Data from ecoinvent v3.6 database (Wernet, et al., 2016).	Tap water for US generally used. Data quality considered good.	None required.
Freezer truck distribution (Distribution)	**Activity data:** Data provided by Impossible Foods. **Environmental impact data:** Data from ecoinvent v3.6 database (Wernet, et al., 2016) but updated for freezer transportation as per Table 43.	Updated for freezer transportation as per Table 43. Data quality considered good.	Updated for freezer transportation as per Table 43. Data quality considered good.

The evaluation of each data quality criterion for significant processes in the ICN scenarios, based on preceding comments, is provided in Table 16. The ranking is based on that provided in Table 5.

Table 16 – Evaluation of data quality criteria for the ICN scenarios

Significant process / input	Data	Tech.	Time	Geo.	Comp.	Rel.
Textured soy protein concentrate	Activity data	1	1	1	1	1
	Environmental impact data	1	2	3	2	2
Sunflower oil	Activity data	1	1	1	1	1
	Environmental impact data	1	2	1	2	2
Carbon dioxide	Activity data	1	1	1	1	1
	Environmental impact data	1	2	2	2	2
Wheat	Activity data	1	1	1	1	1
	Environmental impact data	1	2	1	2	2
Soybean oil	Activity data	1	1	1	1	1
	Environmental impact data	1	2	1	2	2
Electricity	Activity data	1	1	1	1	1
	Environmental impact data	1	3	1	2	2
Tap water	Activity data	1	1	1	1	1
	Environmental impact data	1	3	1	2	2
Freezer truck distribution	Activity data	1	1	1	1	1
	Environmental impact data	1	3	1	2	2

In general, data quality for all data is rated between fair and very good, with the majority of the processes rated good and very good and only four out of the 80 indicators Table 16 rated below good. Activity data is considered fair to very good because of data provided by the manufacturer, with the fair data quality related to assumptions that are made with respect to travel distances. The quality of the environmental impact data was rated from fair to very good, depending on the criteria. A sensitivity analysis was completed with respect to the impact of changing transportation distances in Impossible Foods (2020) and showed no difference in the conclusion and this is expected to continue for this LCA.

5.2.2 DATA QUALITY ASSESSMENT – CBN

As noted above, similar processes are used in the ICN and CBN. The primary marginal contributor to the CBN are the manure management processes. Regardless, the processes contributing significantly (greater than 5%) to the CBN1 potential environmental impact categories (namely, in this case, four impact categories: global warming potential, freshwater eutrophication potential, land occupation, and water consumption) are provided in Table 13.

Data quality for these processes is more directly discussed in Table 17.

Table 17 - Data quality commentary for the CBN significant processes

Significant process / input	Data sources	Data quality commentary	Efforts made to improve data quality
Corn (Base meat production, feed)	**Activity data:** Data provided by Putman (2017). **Environmental impact data:** Data from ecoinvent v3.6 database (Wernet, et al., 2016).	Corn yield updated to US yields and as per USDA (2020). See Impossible Foods (2020) for more information. Data quality considered good to very good.	US yields and fertilizer use as per USDA (2020). See Impossible Foods (2020) for more information.
Soybean (Base meat production, feed)	**Activity data:** Data provided by Putman (2017). **Environmental impact data:** Data from ecoinvent v3.6 database (Wernet, et al., 2016).	Soybean yield updated to US yields and as per USDA (2020). See Impossible Foods (2020) for more information. Data quality considered good to very good.	US yields and fertilizer use as per USDA (2020). See Impossible Foods (2020) for more information.
Wheat (Base meat production, feed; Processing)	**Activity data:** Data provided by Putman (2017). **Environmental impact data:** Data from ecoinvent v3.6 database (Wernet, et al., 2016)	Wheat yield updated to US yields and as per USDA (2020). See Appendix C for more information. Data quality considered good to very good.	US yields and fertilizer use as per USDA (2020). See Impossible Foods (2020) for more information.
Electricity (Processing)	**Activity data**: Data provided by Putman (2017). Data for share of electricity generation overall embedded in electricity processes specific to the region as discussed prior in this work. **Environmental impact data**: Data from ecoinvent v3.6 database (Wernet, et al., 2016).	The specific contributions for each generation source are from data from 2014, but these factors were not expected to change significantly over time. Data quality considered good.	Proportion of electricity generation sources in the grid was updated as per See Impossible Foods (2020) for electricity grid factors.
Manure management (Base meat production)	**Activity data:** For chicken performance data, from Putman (2017). **Environmental impact data**: From GLEAM (FAO, 2017) for direct emissions. IPCC (2006a) for indirect emissions.	Emissions modelling data from GLEAM were used; from 2017 farming data and other related models. Indirect emissions from IPCC (2006a) has much lower relative data quality specifically in terms of time as the models used in Tier 1 emission factors and subsequent calculations are based on data more than 20 years old.	None implemented because the indirect emissions are much smaller than the direct emissions.
Soybean oil (Processing)	**Activity data:** Data provided by Impossible Foods (for frying). **Environmental impact data:** Data	Soybean yield updated to US yields and as per USDA (2020). See Impossible Foods (2020) for more	US yields and fertilizer use as per USDA (2020). See Impossible Foods (2020) for more information.

	from ecoinvent v3.6 database (Wernet, et al., 2016).	information. Data quality considered good to very good.	
Carbon dioxide (Processing)	**Activity data:** Data provided by Impossible Foods (for process that mimicked that of Impossible Foods). **Environmental impact data:** Data from ecoinvent v3.6 database (Wernet, et al., 2016).	Data quality considered good to very good.	None required.
Tap water (Processing)	**Activity data:** Data provided by Putman (2017). **Environmental impact data:** Data from ecoinvent v3.6 database (Wernet, et al., 2016).	Tap water for US generally used. Data quality considered good.	None required.
Freezer truck distribution (Distribution)	**Activity data:** Data provided by Impossible Foods. **Environmental impact data:** Data from ecoinvent v3.6 database (Wernet, et al., 2016) but updated for freezer transportation as per Table 43.	Updated for freezer transportation as per Table 43. Data quality considered good.	Updated for freezer transportation as per Table 43. Data quality considered good.

The evaluation of each data quality criterion for significant processes in the ICN scenarios, based on preceding comments, is provided in Table 18. The ranking is based on that provided in Table 5.

Table 18 – Evaluation of data quality criteria for the ICN scenarios

Significant process / input	Data	Tech.	Time	Geo.	Comp.	Rel.
Corn	Activity data	1	3	1	1	1
	Environmental impact data	1	2	3	2	2
Soybean	Activity data	1	3	1	1	1
	Environmental impact data	1	2	3	2	2
Wheat	Activity data	1	3	1	1	1
	Environmental impact data	1	2	1	2	2
Electricity	Activity data	1	2	1	1	1
	Environmental impact data	1	3	1	2	2
Manure Management	Activity data	1	3	1	1	1

	Environmental impact data	1	3	3	3	3
Soybean oil	Activity data	1	1	1	1	1
	Environmental impact data	1	2	1	2	2
Carbon dioxide	Activity data	1	1	1	1	1
	Environmental impact data	1	2	2	2	2
Tap water	Activity data	1	1	1	1	1
	Environmental impact data	1	3	1	2	2
Freezer truck distribution	Activity data	1	1	1	1	1
	Environmental impact data	1	3	1	2	2

In general, data quality for all data is rated between fair and very good, with the majority of the processes rated good and very good. Activity data is considered fair to very good because of data provided by Putman (2017), which while more than 10 years old, is reasonable considering non-significant changes in farming practices. The quality of the environmental impact data was rated from fair to very good, depending on the criteria. The data quality for manure management environmental impact data was reduced to fair because of the use of Tier 1 emission factors (from IPCC (2006a)) for indirect emissions from manure management. It is noted that the data and approach used to calculate the indirect emissions uses much lower quality data, specifically in terms of temporal data quality and representativeness. However, the indirect emissions are much smaller than the direct emissions, which use more recent and relevant data models to produce the emissions estimates.

5.3 SENSITIVITY ANALYSIS

Inventory uncertainty is assessed on a qualitative and quantitative basis. Three types of uncertainty are addressed: parameter uncertainty, scenario uncertainty and model uncertainty (Table 19) with sensitivity analyses. These are discussed in the next sections.

Table 19 – Uncertainty types

Uncertainty types	Sources	Description
Parameter uncertainty	▪ Activity data ▪ LCIA impact category characterization factors	Uncertainty on the accuracy of values used in the inventory. Parameter uncertainty can be assessed through the evaluation of data quality indicators.
Scenario uncertainty	▪ Methodological choices	Uncertainty related to assumptions or methods used for allocation or to model product use or product end-of-life. Scenario uncertainty is assessed via sensitivity analysis.

Model uncertainty	■ Model limitations	Uncertainty associated with the use of simplified models to represent real life phenomena. Model uncertainty can partly be evaluated with data quality indicators or sensitivity analysis. However, some aspects are very difficult to quantify.

5.3.1 PARAMETER SENSITIVITY

Parameter sensitivity for direct emissions data, activity data and emission factor data were discussed in Tables 15 and 17. In general, data quality was very good or good for main contributing processes, both for activity data and emission factors. However, in this section, analyses were performed examining the share of crops used in the feed for the chicken scenarios, the market weight of the chicken and the feed to meat conversion ratio, as well as the transport distances for the end products to the gate of the retailer/food service provider.

5.3.1.1 CHICKEN FEED COMPONENT SENSITIVITY

A review of studies linking environmental impacts of the poultry chain (Skunca, Tomasevic, Nastasijevic, Tomovic, & Djekic, 2018) found that the largest contributor to the environmental profile of the chicken meat chain is feed production. Primary crop inputs for feed for broilers include corn, soybean, and wheat. Sensitivity of the input values for primary crops was analyzed by adjusting the crops used for feed production based on Skunca et al. (2018) and Dettling et al. (2016), as shown in Table 20.

Table 20 – Different scenarios with respect to chicken feed components

Crop Input	CBN1 (Baseline) (Bengoa, Rossi, & Mouron, 2017)	CBN1 – US - Sensitivity 1 (CBN1-S1) (Skunca, Tomasevic, Nastasijevic, Tomovic, & Djekic, 2018)	CBN1 – US - Sensitivity 2 (CBN1-S1) (Dettling, Tu, Faist, DelDuce, & Mandlebaum, 2016)
Corn (kg corn/ kg feed)	0.69	0.50	0.79
Soybean (kg soybean/ kg feed)	0.28	0.40	0.18
Wheat (kg wheat/ kg feed)	0.03	0.10	0.03

For simplicity, only the results for CBN1 are calculated (and compared against ICN1, which is unchanged). The impact category results for the different feed proportions/components are provided in Table 21.

Table 21 – Impact category results with respect to different chicken feed components

Scenario	Global warming potential (kg CO_2e)	Freshwater eutrophication potential (g P-eq)	Land occupation (annual m^2 crop eq)	Water consumption (m^3)
CBN1 (Baseline)	3.43 (-36% relative to ICN1)	5.89 (-47%)	5.07 (-49%)	0.27 (-44%)
CBN1-S1	3.54 (-38%)	6.03 (-48%)	6.05 (-57%)	0.31 (-51%)
CBN1-S2	3.38 (-35%)	5.88 (-47%)	4.57 (-43%)	0.28 (-45%)
ICN1 (Baseline)	2.19	3.13	2.60	0.15

There are differences in the impact category results for CBN1 when feed proportions are modified, but none that change the conclusions of this study. When additional soybean and wheat are added to the chicken feed, as in CBN1-S1, all impact categories increase because both of those crops, but most especially wheat, have higher potential contributions to those impact categories than for corn. When additional corn is added to the feed in place of soybean, as in CBN1-S2, there are insignificant changes in the impact categories, except with respect to land occupation, which is caused by higher yields for corn with respect to soybean. These results are expected but, as noted above, the variation in feeds within reasonable ranges does not change the conclusions of the study.

5.3.1.2 CHICKEN PERFORMANCE SENSITIVITY

The US National Chicken Council tracks chicken production efficiency in terms of market age, market weight, feed-to-meat gain, and mortality rate (National Chicken Council, 2021). In the last decade, the ratio of feed to meat gain has decreased and the average market weight of broilers has increased, representing an increase in efficiency, as shown in Table 22.

Table 22 - Broiler performance metrics for baseline (CBN1) and additional scenario from National Chicken Council (2021)

Broiler performance metric	CBN1 – Baseline (Putman, 2017)	CBN1-NCC (National Chicken Council, 2021)
Market Weight (kg)	2.59	2.91
Feed to Meat Gain Ratio	1.94	1.79

As a means to examine uncertainty with respect to the performance of the chicken farms used within Putman (2017), the impact categories of CBN1- were calculated using the market weight and feed to meat ratio provided by the National Chicken Council (2021), and the impact categories are shown in Table 23.

Table 23 – Impact category results with different chicken performance data

Scenario	Global warming potential (kg CO_2e)	Freshwater eutrophication potential (g P-eq)	Land occupation (annual m^2 crop eq)	Water consumption (m^3)
CBN1 (Baseline)	3.43 (-36%, relative to ICN1)	5.89 (-47%)	5.07 (-49%)	0.27 (-44%)
CBN1 - NCC	3.35 (-34%, relative to ICN1)	5.55 (-44%)	4.82 (-46%)	0.27 (-42%)
ICN1 (Baseline)	2.19	3.13	2.60	0.15

As expected, the impact categories for CBN1 using the National Chicken Council (2021) performance data are reduced compared to the baseline (using data from Putman (2017)) because chicken farms have become more efficient. Regardless, when new, more efficient chicken farms are used in the model, the conclusions of the study do not change but the advantage of the ICN1 against the CBN1 is reduced between 2 and 3%, depending on the impact category.

5.3.1.3 COMPOUNDED FEED AND CHICKEN PERFORMANCE SENSITIVITY

To test more real-life scenarios, the combined sensitivity of modifying the feed quantity and the chicken performance was examined. For simplicity, only the results for CBN1 are calculated (and compared against ICN1, which is unchanged). The impact category results for the different feed proportions/components as shown in Table 20 and the NCC scenario in Table 22 are provided in Table 24.

Table 24 – Impact category results with respect to different chicken feed components and performance

Scenario	Global warming potential (kg CO_2e)	Freshwater eutrophication potential (g P-eq)	Land occupation (annual m^2 crop eq)	Water consumption (m^3)
CBN1 (Baseline)	3.43 (-36% relative to ICN1)	5.89 (-47%)	5.07 (-49%)	0.27 (-44%)
CBN1-S1-NCC	3.46 (-37%)	5.64 (-45%)	5.72 (-55%)	0.30 (-49%)
CBN1-S2-NCC	3.30 (-34%)	5.50 (-44%)	4.35 (-40%)	0.27 (-43%)
ICN1 (Baseline)	2.19	3.13	2.60	0.15

The impact categories for CBN1 using the National Chicken Council (2021) performance data and the S1 feed, which has more soy and wheat, have slightly lower freshwater eutrophication potential and higher land occupation. This is expected based on the results shown in Table 21 and demonstrates that the feed mix has more contribution overall compared to the feed to meat gain ratio. When S2 feed is used, the differences are fairly consistent except much lower land occupation is seen because of the higher corn proportion in S2 results in lower land occupation (because of corn being higher yield than the other crops). Regardless, when new, more efficient chicken farms are used in the model with different feed quantities, the conclusions of the study do not change but the advantage of the ICN1 against the CBN1 is reduced between 2 and 3%, depending on the impact category.

5.3.1.4 DISTRIBUTION DISTANCE SENSITIVITY

The distance used for distribution of the final products (ICN1/2 and CBN1/2) was 1,500 km based on an estimate of the maximum weighted average distance for distribution of similar products in the US. A sensitivity analysis was performed to examine whether the distance travelled by the final products influenced the conclusions. Table 25 shows the impact category results for when the distance used for distribution for ICN1 and CBN1 is changed to 500 km and 3,000 km. This represents a relatively short distance within the US and a relatively long distance within the US.

Table 25 – Impact category results with different transport distribution distances

Scenario	Global warming potential (kg CO_2e)	Freshwater eutrophication potential (g P-eq)	Land occupation (annual m^2 crop eq)	Water consumption (m^3)
CBN1 (1,500 km)	3.43 (-36%, relative to ICN1 - 1,500 km)	5.89 (-47%)	5.07 (-49%)	0.27 (-44%)
ICN1 (1,500 km)	2.19	3.13	2.60	0.15
CBN1 (500 km)	3.30 (-37%, relative to ICN1 - 500 km)	5.89 (-47%)	5.07 (-49%)	0.27 (-44%)
ICN1 (500 km)	2.07	3.13	2.60	0.15
CBN1 (3,000 km)	3.61 (-34%, relative to ICN1 – 3,000 km)	5.89 (-47%)	5.07 (-49%)	0.27 (-44%)
ICN1 (3,500 km)	2.38	3.13	2.60	0.15

Generally, the longer distribution distance does not change the conclusions that ICN1 performs superior in the selected impact categories. It is noted that only the difference in the global warming potential between the ICN1 and CBN1 changes with a changing distribution distance. As expected, the longer the distribution distance the higher the global warming potential. The difference between the ICN1 and CBN1 is also smallest with the longer distribution distance because of the higher ICN1 value. The remainder of the indicators do not change significantly as the impacts from added distribution are primarily related to the combustion of fossil fuels resulting in higher global warming potential.

5.3.1.5 PHOSPHATES LEACHING SENSITIVITY

The phosphates in the chicken manure was estimated to leach into freshwater at a rate of 10%, based on a conservative estimate where phosphates leach at a lower rate than that of nitrates. To evaluate the sensitivity of the results to this assumption, the impact categories were evaluated using different rates of leaching (5% and 15%) were calculated for CBN1, as shown in Table 26.

Table 26 – Impact category results with different phosphate leaching estimates

Scenario	Global warming potential (kg CO_2e)	Freshwater eutrophication potential (g P-eq)	Land occupation (annual m^2 crop eq)	Water consumption (m^3)
CBN1 (5% leaching)	3.43 (-36% relative to ICN1)	4.82 (-35%)	5.07 (-49%)	0.27 (-44%)
CBN1 (10% - baseline))	3.43 (-36%)	5.89 (-47%)	5.07 (-49%)	0.27 (-44%)
CBN1 (15%)	3.43 (-36%)	6.96 (-55%)	5.07 (-49%)	0.27 (-44%)
ICN1	2.19	3.13	2.60	0.15

Only the freshwater eutrophication potential changes when the leaching rates change. As expected, the lower the leaching rate of phosphates, the lower the freshwater eutrophication potential. Even with a rate of 5%, however, the difference between CBN1 and ICN1 is reduced to 35%. While the leaching of phosphates is shown as a significant contributor to freshwater eutrophication potential (as shown in Table 13), there are other sources. Even a reasonably low leaching rate does not change the conclusions of the study.

5.3.2 SCENARIO SENSITIVITY

Due to the nature of the product and the inventory boundary, typical sources of scenario uncertainty (e.g., use profile, end-of-life profile) are not assessed through sensitivity analysis, as no assumptions were made regarding those aspects. However, two aspects, such as the choice of functional unit and the use of economic allocation to assign the contribution to the impact categories of the chicken slaughterhouse activities, may be of interest.

5.3.2.1 NUTRITIONAL FUNCTIONAL UNITS

As is noted above, the choice of functional unit is based on mass of food, which aligns with previous studies for PBMAs and their animal meat-based equivalents. However, as some people eat food for other means, such as for caloric or protein intake, other functional units may be useful to understand sensitivity to these desires.

This analysis leverages the caloric and protein data provided in Table 1 containing the nutritional information for ICN1 and CBN1. Table 27 shows the impact category results for all scenarios using a functional unit of 100 calories.

Table 27 – Impact category results per 100 calories of food

Scenario	Global warming potential (kg CO_2e)	Freshwater eutrophication potential (g P-eq)	Land occupation (annual m^2 crop eq)	Water consumption (m^3)
ICN1	0.087	0.124	0.103	0.006
CBN1	0.114	0.196	0.169	0.009
Difference	-24%	-37%	-39%	-33%

The CBN has higher caloric content per mass than the ICN and thus, the difference between the impact categories is reduced slightly compared to when just the mass of food is used as the functional unit (as shown in Table 10). Regardless, the results show that when caloric content is used as the functional unit, there is no difference to the conclusion that modeled impact categories are lower for the ICN scenarios than for the CBN scenarios.

Table 28 shows the impact category results for the ICN1 and CBN1 scenarios using a functional unit of 1 g of protein.

Table 28 – Impact category results per 1 g of protein in food

Scenario	Global warming potential (kg CO_2e)	Freshwater eutrophication potential (g P-eq)	Land occupation (annual m^2 crop eq)	Water consumption (m^3)
ICN1	0.016	0.022	0.019	0.001
CBN1	0.022	0.038	0.033	0.002
Difference	-29%	-41%	-43%	-38%

The CBN has slightly higher protein content on a per mass basis than the ICN which means the differences in impact categories between the two are reduced slightly compared to the mass-based functional unit. Regardless, the results show that when protein content is used as the functional unit, there is no difference in the conclusion that all impact category results are lower for the ICN scenarios than for the CBN scenarios.

5.3.2.2 MASS ALLOCATION

Testing the sensitivity of the impact categories to the use of mass allocation in the slaughterhouse inventory may not be appropriate given the disparity in economic value of the fresh meat versus the remainder of the carcass, which is still used but has a much lower economic value than the fresh meat. However, it is done here regardless to show the sensitivity of the conclusions to this change in allocation. There is a significant difference in the allocation of impacts to the chicken meat available for grinding into a nugget: using mass allocation, 62% of the impacts are allocated to the grindable nugget and using economic allocation, 96% of the impacts are allocated to the grindable nugget. Table 29 shows the impact category results when with CBN1 using mass allocation are compared against the baseline ICN1 results (using economic allocation).

Table 29 – Impact category using mass allocation

Scenario	Global warming potential (kg CO_2e)	Freshwater eutrophication potential (g P-eq)	Land occupation (annual m^2 crop eq)	Water consumption (m^3)

ICN1	2.19	3.13	2.60	0.15
CBN1 (mass allocation)	2.85	4.87	3.81	0.22
Difference	-23%	-36%	-32%	-29%

Using mass allocation reduces the difference between the impact category results of the ICN and CBN scenarios, compared to the results shown in Table 10 because the meat in the CBN scenarios is allocated less of the impacts than prior. However, for most of the impact categories, the difference is still significant. The results show that when using mass allocation, there is still no difference in the conclusion that all impact category results are lower for the ICN scenarios than for the CBN scenarios.

It is noted that mass allocation can be applied to other processes within the inventory, including the crop processes where co-products are produced (i.e. soy concentrate production from soybeans in the ICN). While it is recognized that applying mass allocation has the potential for a different absolute value for the ICN1 and ICN2, it is not expected to significantly change that absolute value because of the small overall contribution to the ICN1 impact categories from the ingredients where some sort of allocation was required.

5.3.3 MODEL SENSITIVITY

ReCiPe Midpoint (H) v1.12 was used to quantify the impact categories considered in this study. To examine the differences in impact category results using a different LCIA method, the scenarios were run using the CML 2.0 method for the global warming indicator (the 100-year time horizon GWPs without carbon feedback from AR5 are utilized (IPCC, 2014)), IMPACT 2002+ for aquatic eutrophication potential and land use. No other relevant water consumption indicator was compared. The results for the three impact categories for the ICN1 and CBN1 run using CML 2.0 and IMPACT 2002+ are shown in Table 30.

Table 30 – Relevant impact category results with different models used

Scenario	Global warming potential (kg CO_2e) – CML 2.0	Aquatic eutrophication potential (g $PO4^{3-}$eq P-lim) – IMPACT 2002+	Land occupation ($m^2 \cdot a$) – IMPACT 2002+
ICN1	2.26	6.61	2.73
CBN1	3.55	8.82	5.10
Difference	-36%	-33%	-46%

There are no differences in the conclusions between the impact categories new methods and ReCiPe Midpoint method, indicating that these conclusions are not sensitive to the specific LCIA methods investigated in this work. It is noted that the results are not directly comparable to the baseline results and thus only the individual impact category conclusions are relevant; these do not change. It is noted that no additional water consumption indicator was tested as one that was not relevant to the goals of the study (to determine water consumption of the products) was not found.

5.4 ASSUMPTIONS AND LIMITATIONS

The evidence presented in this report and Impossible Foods (2020) is unique to the assumptions and practices of Impossible Foods and involves assumptions that are used by their production team to collect and record data. The reference scenarios have been specifically developed to be comparable to Impossible Foods production models as much as possible. The results are not intended to be a platform for comparability to other companies and/or other products. Even for similar products, differences in unit of analysis, life cycle stage profiles and data quality may produce incomparable results.

The LCA performed for Impossible Foods compares the life cycle of ICN and CBN produced in the US and distributed to the US. Any conclusion described by this report must be considered only within the context of the study, with considerations of the data, assumptions and limitations used to arrive at those conclusions.

The limitations in this current study should be highlighted to ensure there are mitigating actions made for future studies of Impossible Foods™ products against their animal meat-based equivalents:

- The chicken production feed used in this study is based on specific farming operations in specific regions of the US where data were available from three states examined by Putnam (2017). As well, it is recognized that activity factors for on-farm operations, such as water intensity, energy use, and type and quantity of feed, may not be consistent across all states within the US; however, Putnam (2017) did take efforts to "nationalize" the data to ensure representativeness across the country. Regardless, due to simplicity, this heterogeneity was not attempted to be improved. While those farming operations are intended to be best representatives of chicken farming feed in those regions, they cannot be considered representative of average production for those countries. It is noted that the use of GLEAM emissions data for manure management was meant to be representative of the respective regions. The results in this work are consistent with previous chicken LCA values for the four impact categories of focus.
- Chicken performance data is from 2010 (Putman, 2017) and may not be most representative of current chicken production. However, a sensitivity analysis using more recent chicken performance data (with the recognition that no other farm performance data was available) was conducted and while chicken farming performance has improved (i.e., broiler weights increased and feed to meat ratio has decreased) the conclusions of the study did not change.
- Mass was used as a functional unit in this study although there are other functional units, such as calories or protein content, that could also be relevant; a sensitivity analysis was conducted using calories and protein content as the functional unit and the conclusions of the study did not change, but the difference between the impacts of the ICN and CBN were reduced.
- Only four impact categories were considered here because they were of most interest to Impossible Foods and they were typical indicators for food-based and plant-based meat alternative LCAs; it is recognized that there are other impact categories available to evaluate the overall environmental performance of the studied products.
- Different LCIA methods were used to calculate the impact category results because they were not all available in a single one; a sensitivity analysis was conducted using the same method for all impact categories and the conclusions did not differ.

Finally, LCA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.

5.5 CONCLUSIONS AND RECOMMENDATIONS

This LCA compares the ICN, a PBMA produced in the US, with CBN, a chicken nugget product produced in the US. These products are considered to have functional equivalency because of their ability to satiate hunger, but also to provide similar quantities of nutrients.

The goal of this LCA is to compare the environmental profile made up of four impact categories, namely global warming potential, freshwater eutrophication potential, land occupation, and water consumption, associated with two ICN recipes and two functionally equivalent CBN recipes and understand the extent to which the results for those particular impact categories for the ICN variety is lower than for CBN.

The following are the key findings from this work, generalized for all ICN and CBN results:

- 1 kg of ICN shows a global warming potential result between 36% lower than 1 kg of CBN, with little difference between ICN1 and ICN2 because the recipes differ so little
- 1 kg of ICN shows a freshwater eutrophication potential result 47% less than 1 kg of CBN, as it avoids some crop fertilizer and manure application emissions present in chicken production
- 1 kg of ICN shows a land occupation result between 48% to 49% less than 1 kg of CBN, as it required fewer land-intensive crops.
- 1 kg of ICN shows a water consumption result between 44% to 43% less than 1 kg of CBN due to lower demand for agricultural irrigation for the ICN ingredients than for the CBN ingredients and high-water withdrawal for the chicken production and slaughterhouse stages.

For ICN products, the processing and production of raw ingredients is generally the main contributor to the impact category results. For CBN, the ingredients themselves constitute the main contributor to the impact category results (as well manure management).

In considering the results of this study, it should again be noted that the nutritional content, an important feature of food and objective behind the consumption of food, has been considered and the directionality of the results do not change. The intention here is to portray an environmental comparison for the four impact categories of concern as accurately and clearly as possible, which can be used along with nutritional considerations, and other considerations such as taste, cost and convenience, in helping consumers make food choices.

In summary, the study has found that there are clear benefits, under the four impact categories of concern discussed in this study, to using ICN varieties studied in this work instead of CBN, but note that the LCA only estimates impact potentials.

6 CRITICAL REVIEW

A critical review was performed by a third-party Critical Review Panel. The review process will be directed by the International Reference Centre for the Life Cycle of Products, Processes and Services (CIRAIG). The members of the review panel are listed in Table 31.

Table 31 – Members of the Critical Review Panel

Member	Title and organization	Role	Competencies
Pierre-Olivier Roy, Ph.D.	Lead, Energy, CIRAIG	Head of the review panel	Experience in LCA and carbon footprinting in oil and gas, manufacturing, and industry.
Benjamin Goldstein, Ph.D.	Assistant Professor of Bioresource Engineering at McGill University	Member of the review panel	Academic and professional experience in LCA and carbon footprint (performed several studies in food, energy, municipalities, and recycling sectors).
Horacio Aguirre-Villegas, Ph.D.	Assistant Scientist, Biological Systems Engineering University of Wisconsin-Madison	Member of the review panel	PhD in biological systems engineering and familiar with farm and produce processes in LCA.

The critical review will be performed according to the guidelines in the ISO-14044 standards (ISO, 2006). The steps of the critical review process are described in Table 32.

Table 32 – Critical review process

Step	Description	Outcome
Final report review	Review of the final report by all members of the Critical Review Panel	Review note sent by the CIRAIG and update of the final report by WSP
Preparation of the critical review report	Comments, remarks and questions made by the review panel throughout the process as well as the answers and modifications proposed by WSP	Critical review report sent by the CIRAIG to be attached to the final report

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8 APPENDIX A – ICN

Table 33 – ICN1 – Ingredients

Redacted

Table 34 – ICN2 – Ingredients

Redacted

Table 35 - Soybean protein concentrate; modified process (Impossible Foods, 2020)

Output	GaBi input	Amount	Units	Comments
Soybean protein concentrate	Soybean protein concentrate {US}	540	kg	Allocation = 63.68%
Co-product	Soybean hulls, from crushing (solvent, for protein concentrate), at plant/AR Economic	74	kg	Allocation = 0.98%
Co-product	Soybean molasses, from crushing (solvent, for protein concentrate), at plant/AR Economic	290	kg	Allocation = 28.64%
Co-product	Crude soybean oil, from crushing (solvent, for protein concentrate), at plant/AR Economic	180	kg	Allocation = 6.7%
Emissions to air	Hexane	0.8	kg	
Wastewater	Wastewater, unpolluted, market for {GLO} – U-so	164	m^3	
Ingredient/input	**GaBi input**	**Amount**	**Units**	**Comments**
Ethanol for cleaning	Ethanol, without water, in 99.7% solution state, from fermentation, market for {GLO} – U-so	128	kg	
Diesel for heat	Diesel, burned in building machine, market for {GLO} – U-so	410	MJ	
[redacted]	[redacted]	[redacted]	[redacted]	
Soybean input	Soybean production {US} – agg	1	ton	
Electricity	Electricity, medium voltage, market for [redacted] – U-so	1,080	MJ	
Steam	Steam, in chemical industry, market for {GLO} – U-so	720	kg	

Table 36 – Crude sunflower oil; modified process (Impossible Foods, 2020)

Output	GaBi input	Amount	Units	Comments
Crude sunflower oil	Crude sunflower oil, from crushing (solvent), at plant/AR Economic – Agri-footprint process modified	289	kg	To be used in refined sunflower oil (see Table 37); allocation=80%
Byproduct	Sunflower seed meal, from crushing (solvent), at plant/AR Economic – Agri-footprint process modified	350	kg	Allocation=20%
Ingredient/input	**GaBi input**	**Amount**	**Units**	**Comments**
[redacted]	[redacted]	[redacted]	[redacted]	
Sunflower seed production	Sunflower seed {ROW} – U-so	1	ton	
Transport from sunflower seed to sunflower oil processor	Transport, freight, lorry 16-32 metric ton, EURO3, market for {GLO} – U-so	0.2	t·km	Transport from sunflower seed to sunflower oil processor
Water	Tap water production, conventional treatment {US} - agg	0.248	ton	
Electricity	Electricity, medium voltage, market for [redacted] – U-so	27	MJ	
Steam	Steam, in chemical industry, market for {GLO} – U-so	500	kg	

Table 37 – Refined sunflower oil; modified process (Impossible Foods, 2020)

Output	GaBi input	Amount	Units	Comments
Refined sunflower oil	Refined sunflower oil, from crushing (solvent) – Agri-footprint process modified	1,000	kg	Allocation = 98.75%
Byproduct	Soap stock (sunflower solvent crushing) – Agri-footprint process modified	37.95	kg	Allocation = 1.25%
Ingredient/input	**GaBi input**	**Amount**	**Units**	**Comments**

Crude sunflower oil	Crude sunflower oil, from crushing (solvent), at plant/AR Economic – Agri-footprint process modified	1,046.84	kg	See Table 36
Activated charcoal for removal of impurities	Activated bentonite, market for {GLO} – U-so	8.08	kg	
Diesel for refining	Diesel, burned in building machine {GLO}| market for | Alloc Def, U	342.45	MJ	
Electricity	Electricity, medium voltage, market for {Comed} – U-so	54.8	kWh	
Steam	Steam, in chemical industry, market for {GLO} – U-so	731.5	kg	

Table 38 – ICN1 and 2 – Forming

Redacted

Table 39 – ICN1 and 2 – Cooking

Redacted

Table 40 – Packaging – ICN1 and CBN1

Ingredient/Input	GaBi input	Amount	Units	Comments
Packaging	Packaging for 1 kg of nuggets	1	pc	
Ingredient/Input	**GaBi input**	**Amount**	**Units**	**Comments**
Plastic film	Packaging film, low density polyethylene, market for {GLO} – U-so	0.0004	kg	
Cardboard box	Corrugated board box, market for {GLO} – U-so	0.0031	kg	

Table 41 – Packaging – ICN2 and CBN2

Ingredient/Input	GaBi input	Amount	Units	Comments
Packaging	Packaging for 1 kg of nuggets	1	pc	

Ingredient/Input	GaBi input	Amount	Units	Comments
Plastic film	Packaging film, low density polyethylene, market for {GLO} – U-so	0.000908	kg	
Cardboard box	Corrugated board box, market for {GLO} – U-so	0.00454	kg	

Table 42 – Transportation to US – ICN1 and ICN2

Output	GaBi input	Amount	Units	Comments
Freezer transport	Nuggets delivered to retailer	1	kg	
Ingredient/Input	**GaBi input**	**Amount**	**Units**	**Comments**
Product	1 kg of nuggets (ICN 1 or ICN2)	1	kg	
Freezer Truck, diesel	Adapted process (see Table 43)	1.5	t·km	Transportation of bulk ICN 1 and 2 from the forming and cooking facility to various food retailers throughout the US.

Table 43 – Freezer truck transportation (Impossible Foods, 2020)

Output	GaBi input	Amount	Units	Comments
Freezer transport	Freezer transport	1	t·km	
Removed additional emissions from these because only energy increases 27%	Road wear emissions, lorry, market for {GLO} – U-so	-3.52E-6	kg	Removed additional emissions from these because only energy increases 27%
	Brake wear emissions, lorry, market for {GLO} – U-so	-3.03E-6	kg	
	Tyre wear emissions, lorry, market for {GLO} – U-so	-3.49E-5	kg	
Ingredient/input	**GaBi input**	**Amount**	**Units**	**Comments**

R-134a	Refrigerant R134a, market for {GLO} – U-so	2.22E-6	kg	Based on 5 kg charge and 10% leakage per year calculated on a per km basis
Transportation from processing facility to retailer	Transport, freight, lorry 7.5-16 metric ton, EURO3, market for {GLO} – U-so	1.27	tkm	Freezer transport requires 27% more energy than non-refrigerated, as per Tassou et al. (2009)
Emissions to air	**GaBi input**	**Amount**	**Units**	**Comments**
R-134a	Ethane, 1, 1, 1-2-tetrafluoro-, HFC-134a	2.22E-6	kg	Amount adjusted to reflect 100 year GWPs.

Table 44 – Freezer freighter transportation (Impossible Foods, 2020)

Output	GaBi input	Amount	Units	Comments
Freezer transport	Freezer transport	1	tkm	
Ingredient/input	**GaBi input**	**Amount**	**Units**	**Comments**
R-134a	Refrigerant R134a, market for {GLO} – U-so	2.22E-6	kg	Based on 5 kg charge and 10% leakage per year, calculated on a per km basis
Transportation from processing facility to retailer	Transport, freight, sea, transoceanic ship, market for {GLO} – U-so	1.27	t·km	Freezer transport requires 27% more energy than non-refrigerated, as per Tassou et al. (2009)
Emissions to air	**GaBi input**	**Amount**	**Units**	**Comments**
R-134a	Ethane, 1, 1, 1-2-tetrafluoro-, HFC-134a	2.22E-6	kg	Amount adjusted to reflect 100 year GWPs.

9 APPENDIX B – CBN

Table 45 - Feed production - CBN1 and 2

Output	GaBi input	Amount	Units	Comments
Chicken feed - US	Chicken feed - US	1	kg	
Ingredient/Input	**GaBi input**	**Amount**	**Units**	**Comments**
Corn	Sweet corn production {US} – agg	0.69	kg	
Soybean	Soybean production {US} – agg	0.28	kg	
Wheat	Wheat production {US} – agg	0.03	kg	
Poultry manure (application)	Calculated from IPCC Guidelines for GWP impact and WFLDB Methodological Guidelines for Freshwater Eutrophication Impacts	0.31	kg	Based on Putman (2017)
Truck, diesel	Transport, freight, lorry 7.5-16 metric ton, EURO3, market for {GLO} – U-so	0.20	t·km	
Natural Gas	Natural gas, combusted in industrial equipment {RNA} – U-so	0.13	MJ	
Electricity (US, medium voltage)	Electricity, medium voltage {US} – agg	0.29	kWh	

Table 46 – Chicken production – CBN1 and 2

Stage	Ingredient/Input	GaBi input	Amount	Units	Comments
Chicken Production	Live chicken	Live chicken ready for slaughter	1	kg	
Chicken Production	Manure	Manure for application	0.60	kg	Based on Putman (2017)
Chicken Production	Emissions to air from manure management	See Table 8			
Chicken Production	Emissions to air from manure enteric fermentation	See Table 8			
Stage	**Ingredient/Input**	**GaBi input**	**Amount**	**Units**	**Comments**
Chicken Feed	Chicken Feed	Chicken feed - US	1.94	kg	
Chicken Production	Tap Water	Tap water production, conventional treatment {US} - agg	3.88	kg	
Chicken Production	Diesel	Diesel, burned in building machine, market for {GLO} – U-so	0.07	MJ	
Chicken Production	Electricity (US, medium voltage)	Electricity, medium voltage {US} – agg	0.09	kWh	
Chicken Production	Propane	Propane, burned in building machine {ROW} – U-so	0.30	MJ	
Chicken Production	Wood Shavings (market)	Shavings, softwood, measured as dry mass, market for – agg	0.08	Kg	

Table 47 – Manure application

Output	GaBi input	Amount	Units	Comments
Poultry manure (litter)	Manure for application	1	pc	On a per kg live weight basis
Emissions to air	See Table 9			
Ingredient/input	**GaBi input**	**Amount**	**Units**	**Comments**
Energy	See Table 9			

Table 48 – Chicken Slaughterhouse

Output	GaBi input	Amount	Units	Comments
Chicken meat, fresh	Chicken meat, fresh, at slaughterhouse	0.62	kg	From Quantis (2019)
Co-product	Chicken co-product, other, at slaughterhouse	0.38	kg	From Quantis (2019)
Ingredient/input	**GaBi input**	**Amount**	**Units**	**Comments**
Truck, diesel	Transport, freight, lorry 7.5-16 metric ton, EURO3, market for {GLO} – U-so	0.74	t·km	
Water	Tap water production, conventional treatment {US} - agg	2.19	kg	
Electricity (US, high voltage)	Electricity, high voltage {US} – agg, ecoinvent 3.6	0.13	kWh	
Natural Gas	Natural gas, combusted in industrial equipment {RNA} – U-so	0.0034	MJ	

Table 49 – CBN1 and 2 – Forming

Redacted

Table 50 – CBN1 and 2 – Cooking

Redacted

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Centre international de référence sur le
cycle de vie des produits, procédés et services

International Reference Centre for the
Life Cycle of Products, Processes and Services

CRITICAL REVIEW REPORT

CRITICAL REVIEW OF COMPARTIVE CHICKEN NUGGET LIFE CYCLE ASSESSMENT (LCA) COMPLIANT WITH ISO 14040-44 STANDARDS

SEPTEMBER 2021

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POLYTECHNIQUE MONTRÉAL

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The review was based on the provided report, in MS Word format.

It is important to note that the goal of the critical review is not to redo the life cycle assessment study so as to verify the obtained results, but to put in place a review process to add to the credibility of the study. This review does not however extend to the validity of the objectives of the study or to how its results will be used.

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1 Goal of the critical review

This report is provided by CIRAIG to WSP Canada INC (henceforth WSP) as part of the process of critical review of a comparative life cycle assessment study of Impossible™ Chicken Nugget and Meat-based Chicken Nugget.

The critical review has been performed by:

- Dr. Pierre-Olivier Roy (POR), Lead Energy at CIRAIG, president of the review committee for the Final report;
- Dr. Horacio Aguirre-Villegas (HAV), Assistant scientist at the University of Wisconsin-Madison, technical expert of the review committee for the Final report;
- Dr. Benjamin Goldstein (BG), Assistant professor at McGill University, technical expert of the review committee for the Final report.

The review was based only on the provided reports, in MS Word format.

It is important to note that the goal of the critical review is not to redo the carbon footprint study so as to verify the obtained results, but to put in place a review process to add to the credibility of the study. This review does not however extend to the validity of the objectives of the study or to how its results will be used.

2 Procedure of the critical review

The critical review was conducted iteratively between CIRAIG and WSP, the consulting company mandated by Impossible Foods Inc. to perform the life cycle assessment study. The critical review proceeded as follows:

1. The first draft of the final report was sent to the review committee by WSP on July 22, 2021;
2. The review of the draft Final report was performed by the review committee and the review report (the ISO check-list was completed by Pierre-Olivier) was sent to WSP on September 01, 2021.

3 Content of the critical review

The critical review report contains 3 sections:

1. The critical review committee's final judgment on the quality of the study;
2. The check list used to ensure compliance with the requirements of the ISO 14040-44 standards, and all comments, remarks and questions from the reviewer for the Goal and scope report and corresponding answers from the authors;
3. The check list used to ensure compliance with the requirements of the ISO 14040-44 standards, and all comments, remarks and questions from the review committee for the Final report and corresponding answers from the authors.

4 Critical review committee final judgment on the quality of the study

Following the goals of a critical review presented in ISO 14044, it is the opinion of the review committee, after having read the amended Final report and the authors responses to the review comments, that in general:

- the methods used to carry out the life cycle assessment study are consistent with the ISO 14040-44 standards;
- the methods used to carry out the life cycle assessment study are scientifically and technically valid;
- the data used are appropriate and reasonable in relation to the goal of the study;
- the interpretations reflect the limitations identified and the goal of the study;
- the study report is sufficiently transparent and consistent.

It is important to note that the review committee only had access to the Final report; no modeling or calculation files or SimaPro/Gabi/OpenLCA project was provided.

5 Review of the Final report

5.1 Check-list on the compliance to the ISO standards

This critical review checklist has been prepared to enable the results of a critical review to conform precisely to the guidelines of the ISO Standards.

This checklist consists of 3 sections.

Section 1 of the checklist corresponds to section 5.1 of ISO 14044, and addresses general reporting requirements, applicable to all LCA studies.

Section 2 pertains to additional reporting requirements that apply in cases where the results of the LCA are to be communicated to any “third party” – that is, to any interested person or organization other than the commissioner or the practitioner of the study.

Section 3 contains the special requirements that come into play when the third-party communication makes what the ISO standards refer to as a “comparative assertion”, which is intended to be disclosed to the public. A comparative assertion is defined (see 3.5 of ISO 14044) as an “environmental claim regarding the superiority or equivalence of one product versus a competing product that performs the same function.”

SECTION 1: General Reporting Requirements and Considerations

The column (or the box) at the left is checked to indicate "yes" and left un-checked to indicate that the requirement does not appear to have been met.

Requirements		Reviewer's comments	Practitioners' responses	Issue resolved? (Y/N)
	Are the results and conclusions of the LCA completely and accurately reported without bias to the intended audience?	Yes		
	Are the results, data, methods, assumptions, and limitations transparent and presented in sufficient detail to allow the reader to comprehend the complexities and trade-offs inherent in the LCA?	Yes		
	Does the report allow the results and interpretation to be used in a manner consistent with the goals of the study?	Using only a partial set of environmental indicators prevents overall environmental preference to be claimed. This was however stated clearly as a limitation of the study		

SECTION 2: Requirements when results will be communicated to third parties (parties other than the commissioners and the practitioners of the LCA)

Requirements		Reviewer's comments	Practitioners' responses	Issue resolved? (Y/N)
	a) General aspects: ☒LCA commissioner, practitioner of LCA (internal or external); ☒date of report; ☒statement that the study has been conducted according to the requirements of 14044.			
	b) Goal of the study: ☒reasons for carrying out the study; ☒intended applications; ☒target audiences;			

	☒statement whether the study intends to support comparative assertions intended to be disclosed to the public.			
	c) Scope of the study: 1) function: ☒statement of performance characteristics; ☒any omission of additional functions in comparisons; 2) functional unit: ☒consistency with goal and scope; ☒definition; ☒result of performance measurement; 3) system boundaries: ☒omissions of life cycle stages, processes or data needs; ☒quantification of energy and material inputs and outputs; ☐assumptions about electricity production; 4) cut-off criteria for initial inclusion of inputs and outputs: ☐description of cut-off criteria and assumptions; ☐effect of selection on results; ☐inclusion of mass, energy and environmental cut-off criteria.	The details of relevant grid mixes are not provided. Cut-off criteria have been used but not explicitly defined for all systems.		
	d) Life cycle inventory analysis: ☒data collection procedures; ☒qualitative and quantitative description of unit processes; ☒sources of published literature; ☒calculation procedures; validation of data: ☒data quality assessment; ☒treatment of missing data; ☐sensitivity analysis for refining the system boundary; allocation principles and procedures:	The details of the foreground processes inventory calculations were provided by Impossible Foods without verification.		

	☒documentation and justification of allocation procedures; ☐uniform application of allocation procedures.			
	e) Life cycle impact assessment: ☒LCIA procedures, calculations and results of the study; ☒limitations of the LCIA results relative to the defined goal and scope of the LCA; ☒relationship of LCIA results to the defined goal and scope, see clause 4.2 of 14044; ☒relationship of the LCIA results to the LCI results, see clause 4.4 of 14044; ☐impact categories and category indicators considered, including a rationale for their selection and a reference to their source; ☐description of or reference to all characterization models, characterization factors and methods used, including all assumptions and limitations; ☐description of or reference to all value-choices used in relation to impact categories, characterization models & factors, normalization, grouping, weighting and, elsewhere in the LCIA, a justification for their use and their influence on the results, conclusions and recommendations; ☒statement that the LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks; Are any new impact categories, category indicators, or characterization models used as part of the LCIA? ☒NO (Proceed to part f) Life Cycle Interpretation) ☐YES (IF YES, complete the checklist items below) ☐description and justification of the definition and description of any new impact categories, category indicators or characterization models used for the LCIA; ☐statement and justification of any grouping of the impact categories;	Limited justification for the choice of environmental indicators was provided.		

	☐any further procedures that transform the indicator results and a justification of the selected references, weighting factors, etc.; ☐any analysis of the indicator results, for example sensitivity and uncertainty analysis or the use of environmental data, including any implication for the results; ☐data and indicator results reached prior to any normalization, grouping or weighting shall be made available together with the normalized, grouped or weighted results.			
	f) Life cycle interpretation: ☒results; ☒assumptions and limitations associated with the interpretation of results, both methodology and data related; ☒data quality assessment; ☒full transparency in terms of value-choices, rationales and expert judgments;			
	g) Critical review: ☒name and affiliation of reviewers; ☒critical review report; ☒responses to comments/recommendations.	This document. Provided as an additional file.		

SECTION 3: Requirements for Comparative Assertions intended to be disclosed to the public

Requirements		Reviewer's comments	Practitioners' responses	Issue resolved? (Y/N)
X	Analysis of material and energy flows to justify their inclusion or exclusion			
X	Assessment of the precision, completeness and representativeness of data used			
X	Description of the equivalence of the systems being compared in accordance with 4.2.3.7 of 14044;	The studied product systems can be compared and be considered equivalent regarding the applied LCA methodology.		

X	Description of the critical review process			
	Evaluation of the completeness of the LCIA	Only a partial set of environmental indicators has been analyzed.		
	Statement as to whether or not international acceptance exists for the selected category indicators and a justification for their use	Four environmental indicators were taken from a published LCIA method.		
	Explanation for the scientific and technical validity and environmental relevance of the category indicators used in the study	Limited justification for the choice of environmental indicators was provided.		
X	Results of the uncertainty and sensitivity analyses			
	Evaluation of the significance of the differences found	Significance of the differences was not specifically addressed.		
	Is Grouping included in the LCA? ☒NO (Checklist is complete) ☐YES (IF YES, complete the checklist items below) ☐procedure and results used for grouping; ☐statement that conclusions and recommendations derived from grouping are based on value choices; ☐justification of the cut-off criteria used for normalization and grouping (these can be personal, organizational or national value-choices); ☐statement that "ISO 14044 does not specify any specific methodology or support the underlying value-choices used to group the impact categories"; ☐statement that "The value-choices and judgments within the grouping procedures are the sole responsibilities of the commissioner of the study (e.g. government, community, organization, etc.)".			

5.2 Reviewer's comments and authors' answers

See Excel file "WSP_Impossible Foods_Critical_review_comments_final.xlsx"

Comment No.	Reviewer initials	Section and paragraph (§), Figure, Table	Type of comment (gen., tech., ed.)	Reviewer comment	Reviewer suggested action(s)	Authors response	author resolved?	Issue resolved (Y/N)	Reviewer Comment2	Authors response2	Issue resolved (Y/N)2	Authors response3	Issue resolved (Y/N)3	Issue resolved (Y/N)4
1	HAV		General	As a general comment, it would be beneficial to include line numbers in the document to facilitate identifying the exact location for each comment		Added line numbers	Y	Y	Issue resolved					
2	POR	Executive Summary, first paragraph	General	"that aims to mimic the flavour and texture of a chicken-based nugget (CBN)"	Put a disclaimer that such an assertion cannot be assessed with an LCA. Comment also applies when ever the assertion is made in the document	We don't expect a reasonable person would read this LCA as a means to compare "flavour" and "texture". In fact, we think adding a disclaimer saying this LCA doesn't evaluate that would confuse the reader. We will choose not to address this comment as it editorial.	Y	N	I understand that a disclaimer might be cumbersome but please add a mention of this point in the Assumptions and Limitation section.	Completed	Yes			
3	POR	Executive Summary, first paragraph	Editorial	global warming, freshwater eutrophication, land occupation and wate	*global warming, freshwater eutrophication, land oc*	This is an oxford comment suggestion. We have reviewed the document for consistency.	Y	N	Consistency in the document was not achieved; e.g. line 232 where no coma was found in the enumeration.	Completed	No - consistency has still not been achieved (e.g. Assessment summary). But at this point it is a minor comment and doesn't hinder the review			
4	POR	Executive Summary, first paragraph	Editorial	produced, manufactured and distributed within the US	produced, manufactured, (missing comma) and distrib	See comment 3	Y	Y	Issue resolved					
5	HAV	Executive Summary, first paragraph	Editorial	The word "products" is missing here.	Add the word to read " ... meat, fish, and dairy products from plants."	Addressed	Y	Y	Issue resolved					
6	HAV	Executive Summary, first paragraph	General	It would seem that the system boundaries also include distribution in the US and in the NL. However, after looking at the system	Please specify and clarify that the distribution process is not included, and where the distributor is located	Apologies. Adjusted Figures 1 and 2 to reflect distribution that removed any	Y	Y	Issue resolved					
7	HAV	Executive Summary, Results, First bullet	General	First bullet point: After reading the results section, the higher difference is presented in US scenarios (ICN1-US vs CBN1-US and	Review wording.	Addressed and revised as NL scenario was removed.	Y	Y	Issue resolved					
8	HAV	Executive Summary, Results, First	Editorial	All environmental impacts for ICN are lower than CBN. The word "generally" is not needed.	Remove the word "generally"	Addressed	Y	Y	Issue resolved					
9	HAV	Executive Summary, Results, Second	Editorial	"Is" should be "are" in: Furthermore, the resutls caculated for the ICN1 and ICN2 is...	Correct typo	Addressed	Y	Y	Issue resolved					
10	BG	Assessment Summary	ed.	My understanding from the Executive Summary was that the difference between ICN1 and ICN2 was the distribution in the US and NL. Now it sounds like the difference is between the intended retailer	Clarify the text in the Executive Summary and Assessment Summary so they align.	Language updated to reflect clarity required over scenarios. Rotterdam scenario removed.	Y	Y	Issue resolved					
11	POR	Executive summary, critical review	Editorial	Interuniversity Research Centre for the Life Cycle of Products, Proces	It should read: the International reference center for the life cycle of products, processes, and services	Addressed	Y	Y	Issue resolved					
12	POR	Assessment summary, functional unit	Technical	A functional unit should always quantify the function, the location,	kilogram (kg) of food product at the retailer (located e	Language adjusted to be more clear	Y	Y	Issue resolved					
13	HAV	Assessment summary, page 6	General	The database validity range from ecoinvent is presented from 2009-2019. Were the databases updated?	Review validity of databases or justify why newer databases were not used.	The database (ecoinvent 3.6) is only one behind the most up to date (3.7), but	Y	Y	Issue resolved					
14	HAV	1. Goal of the Study, second	General	According to the ReCiPe definitions, these (climate change, freshwater eutrophication) are impact categories rather than environmental	Please clarify these terms and be consistent throughout.	Language adjusted for clarity throughout.	Y	N	There are still places where impact categories and indicators are used interchangeably (e.g., line 200)	Completed	Y	Issue resolved		
15	BG	1 §1	gen.	You don't explain or define what a chicken nugget is. Reader doesn't know if it is breaded, seasoned in a particular way, etc.	Add one-sentence description of chicken nugget.	Addressed but also described later in the system description	Y	Y	Issue resolved					
16	BG	Table 1	tech.	Calorie and fat content are markedly lower in the ICN. This would affect the primary functionality of the ICN.	Consider using a composite metric that accounts for macronutrient content. For instance, see Nutrient Rich Food index:	The primary function (as detailed throughout) is consumption of food for perceived satiation by mass. This is	Y	Y	Issue resolved					
17	POR	Section 1.2	Editorial	with ICN ingredients, production, and in distribution	with ICN ingredients, production, and distribution	Addressed	Y	Y	Issue resolved					
18	POR	Section 2.2	Technical	See previous comment (Assessment summary, page 6) on the functional unit definition		Addressed	Y	Y	Issue resolved					
19	POR	Assessment summary/section 2.2	Editorial	Ensure consistency between functional units between the assessment summary and section 2.2; one aims a product the othe		See Comment #18	Y	N	Please ensure FU constistency between section 2.2 and the Assessment summary:"The functional unit is one kilogram (kg) of product manufactured in the US in 2021 and delivered to at the retailer (ICN1) and/or food service provider (ICN2) in the US.." vs "one kilogram (kg) of product manufactured in the US in 2021 and delivered to the retailer in the US for ICN1, CBN1 and to the food service provider in the US for ICN2, CBN2"	Completed	Yes	Issue resolved		
20	POR	Section 2.2	Technical	"multiple reasons people eat food (i.e., for nutrition, to reduce or miti	Add text stating that these possible secondary functio	Addressed	Y	Y	Issue resolved					
21	BG	2.2 §1	gen.	What about aesthetics? Does the ICN look like a conventional nugget?	Provide a picture of the ICN (and a regular nugget) or	Addressed	Y	Y						
22	POR	Section 2.3.1; ICN 1 and ICN 2 bullet points description	General	From the description in the bullet-points I understood that, ICN1 and ICN2 were the same product in every way and that b		Lines 205-208 include this text already. We have clarified above more things related to the differences, but in 2.3.1 after the bullets it made clear the icn1 and icn2 differences are the recipe and packaging.	Y	Y	Issue resolved					
23	HAV	2.3.1 Impossible chicken made from plants, fourth paragraph.	General	the phrase "different packaging requirements" is too ambiguous. This could mean different processing steps, materials, material quantities, etc.	Be more specific on what packaging requirements are.	Packaging requirements are provided later in the text. This would not be the space to go into too much detail.	Y	Y	Issue resolved					
24	POR	2.3.1	General	"Retail, use and end-of-life stages are excluded from the study as these do not differ significantly between the ICN and the		ICN1 and ICN2 are not meant to be functional equivalents, but ICN1-US and CBN1-US are. Added clarity to identify which are to be compared.	Y	Y	Issue resolved					
25	HAV	2.3.1 Impossible chicken made from plants, sixth paragraph.	General	When describing the system boundaries, the wholesale distributor is located either in the US or NL. This would be a good place to clarify this.	Clarify that distributor is located in different countries based on analyzed products.	Added more language and removed reference to NL because scenario removed.	Y	Y	Issue resolved					
26	POR	2.3.1	General	"they are not significant contributors of impacts in agricultural systems and are thus not included". Do you have data to back this assertion? If so, does it hold true for all investigated indicators?		Adjusted language to say they would just not be included. This is a typical exclusion in this type of LCA and in previous Impossible Foods LCAs.	Y	Y	Issue resolved					
27	HAV	2.3.1 Impossible chicken made from plants, Figure 1	General	"Raw material production and processing" for the Base Meat and the Ingredient Production do not add too much information. The level of detail of the base-meat production is much greater in CBN than in ICN. Is this because data is only available at an aggregated level? If not, it would be helpful to include further detail in Figure 1.	if possible, include some examples under "raw material production and processing" for the Base Meat and the Ingredient Production in order to differentiate and identify them.	This is a summary figure meant to summarize the process. We do not believe it is necessary to detail every input/process into each ingredient in this space and it is not customary to do so.	Y	N	There are many general steps that you could show here as you did in Figure 2. The level of detail between these two figures is not consistent. For the ICN, is there crop production? (for the plant based ingredients), transport of crops? Processing at a plant? You don't have to be so specific but it would be useful to have at least the same level of detail as in Figure 2 to be consistent.	Figure 1 includes "raw material production and processing, transport of ignredients to bulk formation facility". Then they are described in more detail in Table 2. Not sure what else you would like us to do and we don't think it's that confusing.	Y	Issue resolved		
28	POR	2.3.1; Table 2	General	It was previously stated that ICN1 and ICN2 packaging differed but not mention to these differentiation are stated in the table. The same can be said about the ingredients that differs from ICN1 and ICN2.		Language added	Y	Y	Issue resolved					
29	POR	2.3.1 Table 2	General	It is stated that that the U.S. is one of the targeted location and Rotterdam the other. Considering that one is very wide and the other very targeted, how have you considred the transport distances in the		We considered 1,500 km to be an average distance for the US (given transport from WI area and maximum distance within the	Y	Y	Issue resolved					
30	BG	Table 2	ed.	What do you mean by typical locations? Locations that produce and export large volumes of specific primary ingredients?	Clarify text.	Language added, but not meant to show exact places due to commercial reasons	Y	Y	Issue resolved					
31	BG	Table 2	tech.	How is the bulk product delivered to Wisconson?	Add details on distribution.	Added	Y	Y	Issue resolved					
32	BG	Table 2	ed.	The explanation of the scenarios is prone to confusion (see my comment above).	Add a small table with details of all of the products (ICN1 ICN2, etc.) and scenarios (US vs EU). This will avoid confusing the reader. Could also give the scenarios names (e.g. ICN1-US vs. ICN1-EU) to reduce	Yes added this above in Section 2.2	Y	Y	Confusion unlikely now that Rotterdam scenarios are removed.					
33	BG	2.3.1 §2	gen.	Why shipping to the Rotterdam? The US is a big place. Where are the nuggets ending up?	Justify choice of Rotterdam and provide brief explanation of how you handled distribution in the US.	Rotterdam was removed as a scenario. No specific spot in the US was chosen as it is multiple, that's why average 1,500 km is chosen. See Comment #56	Y	Y	Issue resolved					
34	BG	2.3.1 §2	tech.	Executive summary states that scope is from "cradle-to-gate of retailer." If Rotterdam is the end destination in the EU, it seems like this scenario only follows the nuggets to port of import and not to retailer and is not aligned with the US scenario. This will reduce	Account for distribution to retailers in EU.	R was removed as a scenario and clarity provided on what is actually meant to be functionally equivalent in the LCA.	Y	Y	Issue resolved					
35	BG		tech.	EU is enacting regulations on food waste from retailers. See: https://ec.europa.eu/food/safety/food-waste/eu-actions-against-food-waste_en. Wastage rates from EU retailers might be lower than US	Consider incorporating retail phase. Alternatively, justify that this will have meagre impact on results and include clarifying text.	We don't expect waste rates to be different between the ICN and the CBN products and have included language already in	Y	Y	Understood. This would still have affected the absolute values.					
36	BG	2.3.1 §4	tech.	You define scope as "cradle to the gate of the wholesale distributor." This does not align with the Executive Summary.	Correct wording in Executive Summary.	Language modified in ES and 2.3.1 §4	Y	Y	Issue resolved					
37	BG	2.3.1 §4	tech.	"not significant contributors" is vague. Could also include a citation to support this claim.	Quantify and provide a citation.	See comment #26	Y	Y	Issue resolved					
38	BG	2.3.1 §4	ed.	Use and end-of-life are not included. But is retail? Does not align with earlier text, which states that retail is excluded.	Align text	Checked text and did not see mis-alignment. Reviewed throughout. Retail is excluded.	Y	Y	I see. There are multiple instances where you wrote "delivered to the retailer" which suggests some aspect of retail was included, but it is only to the gate of the retailer.					
39	HAV	2.3.2 Chicken nugget boundary description, Table 3, cultivation and harvesting of crops	General	Results might be different if organically produced chicken nuggets were evaluated. Lime application usually results in carbon dioxide emissions, but lime is mentioned under the nitrogen emission sentence. Also, you	It should be stated that the evaluated chicken nuggets in this study are produced in conventional poultry systems. Review this sentence.	Language adjusted	Y	N	Suggestion: include that the production of chicken is for conventional farms in the definition of chicken nugget production in the 2.3.2 section (e.g., line 295). Also, it is not clear in Tabe 3 if you are considering carbon dioxide (CO2) emissions from lime application as you are grouping lime in the "nitrogen emission" text. CO2 emissions (non-	Completed	Y	Issue resolved		
40	HAV	2.3.2 Chicken nugget boundary	General	The sentece "This is also borne out in practice where meat-based and plant-based nuggets are prepared and made using the same processes	This justification should be highlighted earlier in the document	Added language in 2.3 opening § and in Table 2	Y	Y	Issue resolved					
41	BG	Table 3	ed.	Missing comma between "fertilizers" and "lime"	Add comma.	Changed language otherwise based on previous comment.	Y	Y	Issue resolved					
42	BG	Table 3	ed.	The description of the sub-stages note where emissions occur and potential environmental impacts. This was not done in Table 2 for the ICN. Gives the impression that CBN are a priori more	Use similar descriptions in Table 2 to describe where emissions and impacts arise in the ICN system.	Added language to Table 2	Y	Y	Issue resolved					
43	BG	Fig 1, Table 1, Fig 2, Table 2	ed.	Names of sub-stages in tables and figures do not always match.	Align names of sub-stages across figures and tables. Even if you don't want to do this for all of the sub-	Figures updated	Y	Y	Issue resolved					
44	BG	Table 3	tech.	No mention of where feed and broilers are typically produced in the US. Beef and pork production are concentrated in a few states. Similar	Add geographic specificity for sub-stages as needed.	Languaged added in Table	Y	Y	Issue resolved					
45	POR	Section 2.4	General	Is the 0.5% cut-off applied to foreground or background processes. Please specify. If to the foreground, and ecoinvent 3.6 cut-off database, was used, explain the possible coherency issue when		Language added	Y	Y	Issue resolved					
46	BG	2.6	ed.	Seems to switch between past and present tense.	Check tenses.	Language added	Y	Y	Issue resolved					
47	BG	2	gen.	Might be a matter of style, but it seems to me that according to ISO 14044, the Goal and Scope is missing the following:	Add the requested elements to the Goal and Scope	Some of the requested language is provided for G in Section 1, but the authors do not believe the audience needs	Y	Y	Understood. But given that consumers are one of the intended audiences of this report, it seems incongruous to not provide a cursory (i.e. one-sentence) description of your impact categories, particularly					
48	POR	Section 2	General	Which ecoinvent 3.6 database was used (cutoff, point of substitution)? Please clarify everywhere in the report.		Added throughout	Y	Y	Issue resolved					
49	POR	Section 3.1	General	"ecoinvent 3.6 database default allocation"; did you mean cut-off?		See Comment #48	Y	Y	Issue resolved					
50	POR	Section 3.1	General	"global increments are used". Global and/or RoW? Please clarify		Either were used when available with a preference for Global if available. Language	Y	Y	Please define RoW but otherwise this comment is resolved	N	Row has still not been defined	Issue resolved		
51	HAV	3.1.1 ICN Raw materials	General	There is little background information on how the plant ingredients were produced. It is mentioned that data from ecoinvent was used.	Expand the information about crops/plants and assumptions for those crops.	Paragraph added. There are not many differing assumptions for these crops.	Y	Y	Issue resolved					
52	POR	Section 3.1.1, table 4	General	How is the list of ingredients different between ICN1 and ICN2?		The list of ingredients do not change it is the amounts of the specific ingredients, most specifically the breading quantities.	Y	Y	Issue resolved					
53	POR	Section 3.1.1, table 4	General	Which version of the Agri-footprint database was used? Please specify		Language added	Y	Y	Issue resolved					
54	BG	Table 4	tech.	US is fairly self sufficient for most agricultural commodities. I question the use of global market values for certain inputs and suggest	Replace them with more geographically representative datasets, if needed	This was a mistake between the tables in the appendices and in the document	Y	Y	Issue resolved					
55	BG	Table 4	tech.	Please clarify. Is the global water processes for irrigation, washing equipment, or for incorporation into the product? In either case, energy and carbon intensity of water delivery can vary highly depending on method of conveyance and energy source	Consider a more geographically representative water process that properly accounts for the system of conveyance or explain elsewhere that this choice will have little effect on the results.	This is for direct incorporation into the product. There are no state-specific / city-specific water conveyance methods modeled in	Y	N	Be that as it may, the authors could still augment the ecoinvent process to better align with the conveyance method and energy grid of the crop production regions.	We do not envision this to be material for this LCA.	N	Evidence suggests that emissions from irrigation can be substantial and are not insignificant. See: https://link.springer.com/article/10.1007/s11367-018-1506-0	Adjusted language	Y
56	BG	3.1.1 §3	tech.	1500 miles is arbitrary. Certainly possible to account for geographic distribution of production across the US. For instance, corn in the	Account for where commodities are actually produced in the US or include a sensitivity analysis around this	We don't think a sensitivity around this assumption is necessary. We assumed a	Y	Y	Understood. Perhaps add a clarifying note to the text.					
57	BG	3.1.1 §3	tech.	How did you decide which ports received imported goods?	Clarify in text.	Language added	Y	N	Suggest changing "typical port cities" to "main port cities" or "dominant port cities."	Completed	Yes	Issue resolved		
58	POR	Section 3.1.1	General	"A fixed distance of 1,500 km by diesel truck was used for each US-based product transported to the Chicago-based ICN		See comment #56	Y	Y	Issue resolved					
59	BG	3.1.2 §2	tech.	Although Metro Chicago is in the RFCW region, it is actually supplied by the PJM/Commonwealth Edison sub-region which is specific to the metropolitan area.	Please check to make sure that this would not have a significant impact on the results. Grid mix and carbon intensity data is available through the U.S. Energy	Adjusted - no real difference but to be more precise.	Y	Y	Issue resolved					
60	BG	3.1.3 §2	tech.	MRO is very carbon intensive and might not accurately represent the mix of fuels used by the utility provider to Fort Atkinson (WE Energy).	Replace eGrid fuel mix with fuel mix disclosed by WE Energy. See p. 9: https://www.weenergygroup.com/csr/climate-report2021.pdf	Replaced. No significant difference.	Y	Y	Issue resolved					
61	POR	Section 3.1.6	General	"The amount of plastic film and corrugated cardboard used for the packaging in ICN1 is 10.2 g and 98.0 g, respectively,		Adjusted Language	Y	Y	Issue resolved					
62	HAV	3.1.5 ICN Transportation to distributor	General	Including this information in the executive summary and in Figure 1 would help the reader understand the different products/scenarios from the start. You are modelling 4 scenarios based on processing and transportation.	Suggestion: consider including this level of detail (ICN1-US, ICN2-US, ICN1-R, ICN2-R) in the executive summary and system boundaries graph.	We added additional language throughout. Thank you	Y	Y	Issue resolved					
63	POR	Section 3.1.5	General	What motivated the distance assumptions and should a sensitivity analysis be attempted to assess the contribution of these assumptions to the overall impacts indicators?		See Comment #56	Y	Y	Issue resolved					
64	BG	3.1.5	tech.	My guess is that ICN will be shipped to the EU from the eastern seaboard and not Chicago. Trains are typically more efficient than inland shipping, especially in winter months.	Confirm mode of transport and change model as needed.	Moot as Rotterdam scenario removed.	Y	Y	Issue resolved					
65	BG	3.1.5	tech.	Distances are arbitrary. Distribution could be anywhere in the US or EU. Likely in or near major population centres or logistics hubs.	Given inherent uncertainty in location of distribution perform sensitivity analysis on transport distances.	Sensitivity analysis performed.	Y			This was blank in "Issue resolved". Assume resolved.	Yes	Issue resolved		
66	BG	3.2 §1	ed.	The last sentence is confusing.	Please clarify. An example would also help.	Language adjusted	Y	Y	Issue resolved					
67	BG	3.2 §2	ed.	Data are plural, datum is singular	Change "was" to "were"	Language adjusted	Y	Y	Issue resolved					
68	BG	3.2 §2	tech.	I appreciate the transparency regarding the limitations of using the older IPCC model. There are alternative, widely-accepted models with regional and even sub-national capabilities, such as GLEAM by the	Consider using newer model or at least discuss how IPCC specificity is flawed and how this may or may not impact your results.	The GLEAM outputs for the US are actually quite similar to the results we obtained from the IPCC. We switched to using	Y	Y	Issue resolved					
69	BG	3.2 §3	ed.	Did you mean 2020 and not 2010?	Check text.	See Comment #68	Y	Y	Issue resolved					
70	HAV	3.2.1 CBN Chicken production, second paragraph	General	How was the average annual temperature of 15 C defined? According to NOAA, the average annual temperature in the U.S. is around 12 C, which affects methane emissions from manure	Provide context around the temperature definition.	See Comment #68	Y	Y	Issue resolved					
71	HAV	3.2.1 CBN Chicken production, Table	Technical	I believe IPCC provides manure management methane Tier 1 emission factors on a per head, per year basis. Is this also per year? What data	Expand the methods used to estimate live weight broiler and clarify if emission factors are per year	See Comment #68	Y	Y	Issue resolved					
72	BG	3.2.1 §1	ed.	Awkward sentence "...only the crop ingredients are modelled for feed com..."	Consider rephrasing	Language adjusted	Y	Y	Passive sentence structure still reads oddly, but will leave it to author's discretion.					
73	BG	3.2.1 §2	tech.	Authors could do more to highlight why it is important to have regional data for ag LCIs in the US. For instance, difference in	Add additional explanatory text.	Language adjusted	Y	Y	Issue resolved					
74	BG	3.2.1	gen.	I really question if the EU is importing chicken nuggets from the US. My guess is that nuggets imported from the US represent a sliver of	Use a life cycle inventory for nugget production in the EU or remove the EU comparison.	Rotterdam was removed as a scenario.	Y	y	Issue resolved					
75	BG	Table 5 footnote	tech.	Table only includes 3 ingredients. You should be able to mention exactly which ingredients required proxies due to lack of ecoinvent	Clearly mention which feed constituents were modelled with proxies.	In the text, "include fish meal, amino acids, fats and vitamins" are included and	Y	Y	Issue resolved					
76	HAV	3.2.2 CBN Manure application, first	General	Add	Clarify that this approach is called system expansion and used when more than one product is produced.	Language added	Y	Y	Issue resolved					
77	HAV	3.2.2 CBN Manure application, first	General	What co-products are produced?	Be more specific on the co-products produced.	Language added	Y	Y	Issue resolved					
78	BG	3.2.3 §2	tech.	Economic allocation is fine and makes sense in this context. Still might be useful to know what the allocation would look like if done based on calories or protein.	List alternative allocation keys and values.	This is done in Section 5.3.2	Y	Y	Issue resolved					
79	POR	Section 3	General	On numerous occasions, it is mentioned: "WSP has not audited this data and relies on Impossible Foods and their suppliers to ensure accuracy of provided data". I completely understand the need for such a disclaimer. However, I do feel like it is the responsibility of the		This language is added as a disclaimer. WSP works with our clients to ensure that the data provided is representative of their processes, but as noted in the disclaimer	Y	Y	Issue resolved					
80	BG	3.3	gen.	Again, my understanding of the ISO is that the allocation procedure should be placed earlier on in the report. At its current location, the explanation of the allocation procedure comes after allocation is	Move to earlier in the report.	Moved to earlier in the report.	Y	Y	Issue resolved					
81	POR	Section 3.6	General	"an economic allocation procedure was used because chicken products have such widely different values on the market". Would other allocation procedure such as mass	Perform sensitivity analysis on allocation procedure	This is done in Section 5.3.2	Y	Y	Issue resolved					
82	POR	Section 4.1	Technical	I understand that one needs to focus on some indicators in the results interpretation but the ISO standard requires that all impact categories of an impact assessment method be reported at the midpoint level. All indicators should be reported to keep from misleading indication that are favorable to one's product.	Report all indicator results from ReCiPe method at least once; interpret those results even if the focus is to remain on the four selected indicators.	Based on previous CIRAIG-reviewed IF LCAs, and other relevant food-related LCAs, we have provided justification for disclosing only on select indicators. These are the most relevant to food products, based on previous LCAs and other IF LCAs.	Y	N	As you have done in previous IF LCA reviewed by the CIRAIG, indicator results from other impact categories should at least be presented in the Appendix and rapidly discussed	The previous IF LCA reviewed by the CIRAIG (https://impossiblefoods.com/sustainable-food/sausage-life-cycle-assessment-2020) did not contain all impact categories. We have provided this as a limitation.	Y	Issue resolved		
83	BG	4.1	gen.	ISO states that the LCIA methods and impact categories should be	Move this section to the Goal and Scope. Also	Adjusted	Y	Y	Issue resolved					
84	HAV	4.2.1 Comparative	General	This is another example where climate change, global warming, and	Please use this same terminology throughout the	Adjusted	Y	N	There are still mismatches in terminology (e.g., eutrophication vs	Completed	Y	Issue resolved		
85	POR	4.2.1 Table 6	General	Units for land occupation in ReCiPe are annual m2 crop eq. - the m2	add m2 to the land occupation unit	Adjusted	Y	Y	Issue resolved					
86	HAV	4.2.1 Comparative	Technical	The only difference between the comparison between ICN1-US vs	Review sources of difference besides transportation	Removed Rotterdam scenarios	Y	Y	Issue resolved					
87	POR	4.2.1 below Table	General	Most of the explanations for the discrepancies are related to a	Try merging section 4.2.1 and 4.2.2. so the reader	Merged	Y	Y	Issue resolved					
88	BG	Table 6	gen.	The EU and US scenarios are pretty much identical. Not surprising	Again, I suggest including a chicken nugget produced in the	Removed Rotterdam scenario	Y	Y	Issue resolved					
89	BG	4.2.2 §1	gen.	This entire paragraph just supports my above comments.		Removed Rotterdam scenario	Y	Y	Issue resolved					

90	BG	Table 9	tech.	Funny that distribution does not contribute to eutrophication for	Check	It is because of the crops overwhelming	Y	Y	Issue resolved					
91	BG	Table 9	gen.	Would be nice to see this (and Table 8) as a figure. This will enhance	Add figures to results.	Added	Y	Y	Issue resolved					
92	BG	4.2.3	gen.	This section can be fleshed out more. A table with a list of	Add more details about	Added a Table of ingredients/processes	Y	Y	Issue resolved					
93	POR	Section 4.2.3	General	", this may significantly change texture and marketability". Since no	Either remove part of the sentence or provide factors	Language adjusted	Y	Y	Issue resolved					
94	POR	Section 4.3	General	I'll repeat my previous comment: I understand that one needs to focus on some indicators in the results interpretation but the ISO standard requires that all impact categories of an impact assessment method be reported at the midpoint level. All indicators should be reported to keep from nitpicking indicators that are favorable to one's product	Report all indicator results from ReCiPe method at least once; interpret those results even if the focus is to remain on the four selected indicators.	See Comment #82	Y	N	See comment #82	See Comment #82	Y	Issue resolved		
95	HAV	5.1 Identification of relevant	General	First, it is stated that there are significant benefits, but the second sentence states that the values are only slightly lower.	Review wording.	Language adjusted	Y	Y	Issue resolved					
96	BG	Table 11	ed.	Some minor grammatical errors in the Technology Coverage section:	Revise wording.	Language adjusted	Y	Y	Formatting off for the GLEAM citation in the 3rd row of the table.					
97	BG	Table 11	ed.	Last sentence of Temporal Coverage section has an error.	Check	Language adjusted	Y	Y	Issue resolved					
98	BG	Table 11	gen.	Difficult to get a good overview of the data quality using this table in	Suggest making a more detailed table that lists sub-	Added a more fulsome review of data	Y	Y	Issue resolved					
99	HAV	5.3.1 Parameter	General	Given the uncertainty around manure (IPCC Tier emission 1 factors are	Consider discussing the effects of manure	Language adjusted to add GLEAM.	Y	Y	Issue resolved					
100	HAV	5.3.1 Parameter uncertainty	General	You presented sensitivity around 2 parameters separatedly (feed component and performance). It would be interesting to see the	Consider presenting the combined effect of the analyzed parameters in the sensitivity analysis.	The authors do not think this is a relevant scenario as it's impossible to tell if those	Y	N	These two factors can happen by 1st, changing the diet composition and 2nd, improving feed effciciency (feed:meat). It is not impossible as both	Completed	Y	Issue resolved		
101	POR	5.3.1	General	You are carrying a sensitivity analysis - not an uncertainty analysis with a Monte Carlo approach. Wording should reflect was is being		Language adjusted	Y	Y	Issue resolved					
102	BG	Table 14	ed.	Cannot see how much changing feed changed CBN performance	Add percentages (CBNx/ICN1 * 100) beside the	Added	Y	Y	Issue resolved					
103	BG	5.3.1.1	tech.	Equally important to changing feed ratios will be changing feed production locations. For instance, what does soy from Brazil do to	Sensitivity analysis should include feed from different countries.	We don't expect this to significantly change the results directionally. Note that	Y	Y	Issue resolved					
104	BG	Table 15	tech.	Significant figures not consistent throughout tables.	Use 3 sig figs for all values.	Adjusted	Y	Y	Issue resolved					
105	BG	Table 16	ed.	Cannot see how much changing feed changed CBN performance relative to ICN.	Add percentages (CBNx/ICN1 * 100) beside the absolute values.	Added	Y	Y	Issue resolved					
106	BG	5.3.2.2	gen.	Shouldn't you also test mass allocation for the soy ingredients to the ICN and chicken feed?	Justify choice to not do mass allocation for these processes or include an additional sensitivity	Language adjusted	Y	Y	Issue resolved					
107	BG	5.3.3 §1	gen.	Why wasn't another water indicator compared? Hard to know given how little space was dedicated to explaining the different midpoint	Suggest adding uncertainty analysis that includes a different water use LCIA method, namely, one based	We did not want to use a "water stress" indicator because the relevant category for	Y	Y	Issue resolved					
108	BG	5.4	gen.	Major limitation is that the CBN distributed in the EU is not produced in the EU.	Use a life cycle inventory for nugget production in the EU or remove the EU comparison.	Rotterdam scenario removed.	Y	Y	Issue resolved					
109	BG	5.5 §5	tech.	Directionality might not change, but relative impacts become smaller and approach the uncertainty bands for the assessed indicators.	Suggest replacing "conclusions do not change." to "the directionality of the results do not change."	Language adjusted	Y	Y	Issue resolved					
110	POR	5.3.3	General	"IMPACT 2002+ uses 500-year GWPs for climate change indicator	State which version of IMPACT 2002+ has been used.	Language adjusted	Y	Y	Issue resolved					
111	POR	5.3.3	General	For the readers conveniance, please state which IPCC factors are in the CML 2.0 method.		Language adjusted	Y	N	From which IPCC report? AR-3, AR-4, or AR-5? Simply restate the information from section 2.6	Completed	Y	Issue resolved		
112	POR	5.3.3	General	"these conclusions are not sensitive to the specific LCIA method used". As you haven't tested all impact assessment method, this	these conclusions are not sensitive to the investigated LCIA method	The language says "specific LCIA methods used" not all LCIA methods, but we will	Y	Y	Issue resolved					
113	HAV	5.5 Conclusions and	General	Again, the higher difference (35%) is presented in US scenarios (ICN1-US vs CBN1-US and ICN2-US vs CBN2-US)	Review wording.	Language adjusted	Y	Y	Issue resolved					
114	HAV	5.5 Conclusions and	General	This sentence reinforces the need to explore the contribution of manure management to GWP	Consider discussing the effects of manure management on overall results.	Done in Section 3.	Y	Y	Issue resolved					
115	BG	5.5 §5	tech.	Directionality might not change, but relative impacts become smaller and approach the uncertainty bands for the assessed indicators.	Suggest replacing "conclusions do not change." to "the directionality of the results do not change."	See Comment #109	Y	Y	Appears to be a duplicate comment.					
116	BG	Table 21	ed.	Information about Benjamin Goldstein is outdated.	Update title and organization to "Assistant Professor of Bioresource Engineering at McGill University."	Language adjusted	Y	Y	Issue resolved					
117	POR	Section 6	Editorial	Please update reviewers' information		Added	Y	Y	Issue resolved					
118	BG	Table 23	tech.	Why do you use Quebec tap water for the ICN meat production? Does not seem geographically representative, especially for the background energy grid. Same comment for ICN2	Justify or update proces to better represent Chicago.	Added	Y	Y	Issue resolved					
119	BG	Table 23	tech.	Does wastewater proxy include proper treatment? This can be extremely energy intensive and should be accounted to some degree.	Clarify	The wastewater treatment process includes typical processing for typical wastewater.	Y	Y	Issue resolved					
120	BG	Table 25	ed.	"comed" in electricity process. I assume this is ConEdison.	Change to ConEd	Adjusted	Y	Y	Issue resolved					
121	BG	7	ed.	There are three IPCC 2006 references, but you only use IPCC 2006 and IPCC 2006b in the text.	Update reference list and text to use IPCC 2006a, IPCC 2006b, and IPCC 2006c.	Adjusted	Y	Y	Issue resolved					

Comment No.	Reviewer initials	Section and paragraph (§), Figure, Table	Type of comment (gen., tech., ed.)	Reviewer comment	Reviewer suggested action(s)	Authors response	author resolved?	Issue resolved (Y/N)	Reviewer Comment2	Authors response2	Issue resolved (Y/N)2	Authors response3	Issue resolved (Y/N)3
122	HAV	First page	ed.	ISO - conformant LCA resport is presented twice	Review and adjust	Completed		Y	Issue resolved				
123	POR	List of tables	ed.	Review list of tables; numbering goes from 1-13, then goes back to 11, then to 16, then there are three different table 17. Also check Table in text prior to introducing tables. For example, see section 4.2.1 where Table 8 is introduced but table 10 is presented		Completed		Y	Issue resolved				
124	BG	Executive Summary, L109	gen.	Some would argue that IF doesn't make meat, fish, and dairy products, but rather, meat, fish, and diary analogs. I know that they have used this term in their own writing before.	Consider replacing "product" with "analogs"	Completed		Y	As an aside. Seems like British English is the dominant form in the report. Should change analog to analogue.	Adjusted	Y		
125	BG	Executive Summary, L113	gen.	Can also mention that these impact categories are particularly salient to animal agriculture. Would provide a better scientific basis for your choice of indicators.	Add text	Completed		Y					
126	POR	Executive summary, line 136	ed.	"in conformance with ISO 14044 (ISO, 2006), Section 6. "	see section 6?	Completed		N	add space between see and Section	Adjusted	Y		
127	HAV	ES, line 140	ed	Remove the word "between" as you are presenting a single number. Also, period in line 148 is missing.	Adjust	Completed		Y	Issue resolved				
128	POR	Assessment summary	gen.	The temporatl boundary of the ecoinvent database is up to 2020 while the function unit is for 2021. Please add a disclaimer or a footnote stating that the difference in temporal horizon isn't significant		Completed		N	Where is the footnote/explanation or change to the functional unit or the temporal boundary?	Changed temporal boundary because data is still relevant inclusive of 2021.	Y		
129	POR	line 190	ed.	add (and ensure consistency within the report) for the climate change potential as well as the eutrophication potential	potential is missing to the eutrophication impact category	Completed		Y	Issue resolved				
130	BG	2.1, L233	gen.	The primary function is to provide food to eat	Suggest adding the word "primary" to function sentence.	Completed		Y					
131	HAV	2.3, Line 259	ed	"." missing in " ... and cooking This is also borne..."	Adjust	Completed		Y	Issue resolved				
132	HAV	Table 2, line 292	ed	typo: "fata", change to "data"	Adjust	Completed		Y	Issue resolved				
133	BG	Table 2	ed.	I believe you meant "fats" and not "fata."	Check spelling	Meant to be fats. Completed		Y					
134	BG	Fig 1	ed.	If "retail" is excluded, then it should also be shaded in the figure similarly to consumption and eol.	Update figure.	Completed		Y					
135	HAV	2.3.2, line 303	General	Adjust "packaging requirements" to reflect that these are actually the packaging quantities	Adjust	Completed		Y	Issue resolved				
136	HAV	2.6, line 335-338	ed.	Repetitive sentences "Data has been selected...."	Adjust	Completed		Y	Issue resolved				
137	HAV	2.6, line 342	General	It would be useful to include the characterization factors for CH4 and N2O To facilitate the reader understanding which factors were used	Include chracterization factors for CH4 and N2O used in the study	AR5; this is noted a number of times.		N	It is mentioned that AR5 factors are used but it would be useful to explicitly state the numbers (e.g., 28 for methane and 265 for N2O)	Adjusted	Yes		
138	BG	Table 4	ed.	Table is very thin. Makes for awkward appearance and reading.	Make wider.	These are "fit to window". No action taken.		Y	Might have been compatibility issue.	Adjusted	Y		
139	BG	Table 6	ed.	You wrote "ataset"	Change to "dataset"	Completed		Y					
140	BG	3.2 § 1	ed.	Data are plural, datum is singular.	Change "was" to "were" in "production data from Putnam..."	Completed		Y					
141	HAV	3.2.1 - Line:511	General	The sentence of Subscript 3 is incomplete	Adjust	Not meant to have a third ***		Y	Issue resolved				
142	HAV	3.2.1 - Line:515	ed.	Table 6 in the text should be table 8.	Review table numbering in all the document.	Completed		Y	Issue resolved				
143	HAV	3.2.2, Table 9	General	The assumption for phosphate leached should be referenced as it directly affects eutrophication potential or explain how this number was determined.	Reference the amount of phosphorus that is assumed to be leached	Language updated and expanded as well as sensitivity analysis.		Y	Issue resolved				
144	POR	4.2.1 line 584	General	"Packaging and distribution have an insignificant contribution "	Please specifiy under which percentage is a contribution judged insignificant	Completed		Y	Issue resolved				
145	POR	4.2.1 line 584	ed	"Table 10is shown"	add space between table 10 and is	Completed		Y	Issue resolved				
146	HAV	4.2.2, Tables 12 and 13	General	There is a mix of processes and inputs presented in the "processes" column of tables 12 and 13	Adjust the title or the wording in each "process" to reflect processes rather than inputs.	Completed		N	Table 13 is still presenting inputs	Adjusted	Yes		
147	HAV	4.2.2 628 - 631	ed	These two sentences are hard to understand.	Please review wording.	Completed		Y	Issue resolved				
148	POR	5.1	ed	"have significant benefits "	Please define what is considered significant	Completed		Y	Issue resolved				
149	BG	5.2.1 § 3	ed.	Should read "Table 17" not "Table 16"	Adjust text.	Completed		Y					
150	BG	Tables 16 & 17	tech.	Tables say that tap water for US used, but Table 6 lists global tap water process. Does this refer to the LCI tables in the Appendix?	Align text with table 6 or clarify.	Adjusted throughought		Y					
151	HAV	Table 17	General	GLEAM model was used for direct emissions from manure, but IPCC emission factors were used for indirect N2O emissions (from ammonia volatilization). Also, there is no mention to data quality of manure management.	Include information sources for indirect emissions and include data quality commentary	Completed		Y	Issue resolved				
152	POR	Section 5.2.1 line 676	General	In the first round of comment I recommended doing a sensitivity analysis on the tranport distances. With this sentence: "of changing transportation distances in Impossible Foods (2020) and showed no difference in the conclusion and this is expected to continue for this LCA", a sensitivity analysis should be carried out to make sure that this sentence is true	carry out the sensivity analysis on transport distances	Completed		Y	Issue resolved				
153	HAV	Table 18	ed	The font type and size of CBN1 is different	Adjust number size and font type in row CBN1	Completed		Y	Issue resolved				
154	POR	5.3 line 695	ed	In the first round of comments, I recommended to change the term uncertainty to sensitivity. This was changed in the text of appropriate section but not in the more generalized one nor in the title of section 5.3.1.		Completed		Y	Issue resolved				
155	POR	line 730	ed	"more efficient chicken farms are used in the model, the conclusions of the study do not change"	Finish off the observation by stating that the advantage of the ICN1 is decreased by 2-3% depending on the impact category	Completed		Y	Issue resolved				
156	POR	5.3.1	general	I do not understand why you would have a section in the sensitivity analysis telling that you will not perform said sensitivity analysis. As mentionned previously, the study should have a sensitivity analysis about the transport distances. After all, the most populous state in the US (California) is at least 3000 km from Chicago; twice the considered distance	Perform said sensitivity analysis	Completed		Y	Issue resolved				
157	HAV	5.3.3 line 783	ed	typo: remove ", and" in line 783	Remove typo	Completed		Y	Issue resolved				
158	BG	Table 21	ed.	Change "Dr. Benjamin Goldstein" to "Benjamin Goldstein, PhD" for consistency.		Completed		Y					
159	HAV	Table 23, Appendix	ed	The process Tap Water production is still from CA-QC	Adjust to reflect U.S., here and in following tables	Completed		Y	Issue resolved				
160	BG	Table 31	ed.	So ICN2 is a patty and ICN1 is a nugget? This is not clear in the above text.	Clarify in the system descriptions the differences between ICN1 and ICN2 if there are any or use consistent language (patty or nugget) throughout.	Nugget. Holdover from process from previous LCA. Adjusted		Y					
161	BG	Table 35	tech.	Tassou reference is for road transport. Nothing available for shipping? Moreover, there are newer references worth considering: https://www.sciencedirect.com/science/article/pii/S1361920917303735 or https://www.sciencedirect.com/science/article/abs/pii/S0048969720365049	Check references to see if more suitable values available for road and water transport.	Reviewed references and less direct available information. We are comfortable with the approach taken and have justified it within Impossible Foods (2020). WE thank the reviewer for the additional references.		Y					
162	BG	Footnote 4	ed.	Incomplete sentence at the end of the paragraph.	Adjust text.	Removed text. Completed		Y					

Comment No.	Reviewer initials	Section and paragraph (§), Figure, Table	Type of comment (gen., tech., ed.)	Reviewer comment	Reviewer suggested action(s)	Authors response	author resolved?	Issue resolved (Y/N)	Reviewer Comment2	Authors response2	Issue resolved (Y/N)2	Authors response3	Issue resolved (Y/N)3
163	BG	Executive Summary, L111	ed.	IF doesn't necessarily reduce the impact of climate change. That would be climate change adaptation. IF aims to mitigate climate change by avoiding emissions in the first place.	Suggest changing "reduce" to "mitigate." Leave this to authors' discretion.	Adjusted		Y					
164	BG	Assessment summary	ed.	You write "food service" here, but "foodservice" at other points in the report (e.g. L123).	Align in text, tables, and figures.	Adjusted		Y					
165	BG	Table 1	ed	Consider showing the percent difference between the two products. Moreover, since ICN1 and ICN2 have slightly different recipes, does this table hold try for both version of the product?		Added language recognizing while the recipes di		Y					
166	BG	Table 3	ed.	Unsupported claim: "Hatcheries have a relatively minor contribution to the impacts associated with poultry production."	Please add a reference	Removed.		Y					
167	BG	3.2.3 and 3.2.4	tech.	No mention of wastage rates for chicken processing in the same manner as the iCN. Did you assume no losses? A percentage wasted? Something else?	Clarify in text.	Assumed same 5%. Language added to sections.		Y					
168	BG	Table 11	tech.	GWP does not add to 100% for ICN1. Probably a rounding error.	Check numbers.	Added qualification.		Y					
169	BG	Section 4.5	ed.	I would add to this disclaimer that there is general scientific consensus that higher impacts in these categories have negative consequences on the health of people and planet.		Adjusted		Y					
170	BG	Tables 16 & 18	ed.	No explanation of what the numbers mean. Is 1 better or 3?	Add clarifying text.	Language added to direct to Table 5		Y					
171	BG	5.4, L842	ed.	"...shipped to two destinations." Is this a holdover from the earlier version which included the EU scenario or do you mean ICN1/CBN1 goes to a retailer and ICN2/CBN2 goes to a wholesaler?	Clarify	Yes - revmoed.		Y					
172	BG	5.4, L862	ed.	The conclusions of the study did not change when using different functional units, but the difference between ICN and CBN was reduced.	Modify text to note this.	Adjusted		Y	Change "were" to "was."				
173	BG	5.5, L898	ed.	There appear to be clear benefits, but we don't know this because an LCA only estimates impact potentials.	Modify text to note this.	Adjusted		Y					