Impossible Foods Inc.

Final Report

Impossible™ Sausage Made from Plants

Life Cycle Assessment

October 10, 2020

Building a better working world

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List of acronyms

CIRAIG: Interuniversity Research Centre for the Life Cycle of Products, Processes and Services
CN: China
EY: Ernst & Young LLP
FAO: Food and Agriculture Organization
GHG: Greenhouse gas
GWP: Global warming potential
IPCC: Intergovernmental Panel on Climate Change
ISO: International Standards Organization
IS1: Impossible Sausage 1
IS2: Impossible Sausage 2
LCA: Life cycle assessment
LCIA: Life cycle impact assessment
MRO: Midwest Reliability Organization
PBMA: Plant-based meat alternative
PS1: Pork Sausage 1
PS2: Pork Sausage 2
RFC: Reliability First Corporation
US: United States
USDA: United States Department of Agriculture

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Executive summary

Impossible Foods Inc. (Impossible Foods) has developed a new plant-based meat alternative (PBMA), named the Impossible Sausage Made from Plants (IS), that aims to mimic the flavour and texture of a pork-based sausage (PS) patty. The company has undertaken work to calculate four specific life cycle environmental indicators of the product: global warming potential, aquatic eutrophication, land occupation and water depletion. In this report, four life cycle environmental indicators of two IS (indicated by IS1 and IS2) products, both manufactured in the United States (US), with one scenario delivered to the US (IS1 – US and IS2 – US) and one scenario delivered to China (IS1 – CN and IS2 – CN), are compared against functionally equivalent PS patties produced (indicated by PS1 and PS2) in the US (PS1 – US and PS2 – US) and China (PS1 – CN and PS2 – CN), and delivered to their respective domestic markets. As of the date of this report, IS was not sold in China. Rather, China was included because it is the largest producer and consumer of PS in Asia and thus a benchmark for IS.

Boundaries and scope

The type of inventory is cradle-to-gate of retailer (defined as the initial purchaser of finished product, whether a distributor, foodservice operator, or traditional retailer), prior to purchase by an end-consumer; the 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 IS has similar cooking time, specific heating capacity, shelf-life and distribution systems to the PS patty). Two types of IS were compared: one is not pre-cooked (IS1) and the other is pre-cooked (IS2). Both have the same ingredients but with slightly different proportions to accommodate the cooking process. The four environmental indicators for all scenarios are considered on a per kilogram (kg) of delivered final product basis. While a mass-based functional unit is the baseline consideration in this work, a sensitivity analysis with respect to a caloric- and protein-based functional unit was conducted to determine any change in the study's conclusions.

IMPACT 2002+ v2.12 was used to quantify global warming potential, aquatic eutrophication and land occupation; ReCiPe Midpoint (H) v1.12/World Recipe H was used to quantify water depletion. These four environmental indicators 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 environmental indicators were quantified because these are the key environmental areas of concern for Impossible Foods; this specific reporting of environmental indicators 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.

Results

In general, the four environmental indicators of the IS varieties are lower than the PS patty equivalents, as shown in Figure 1.

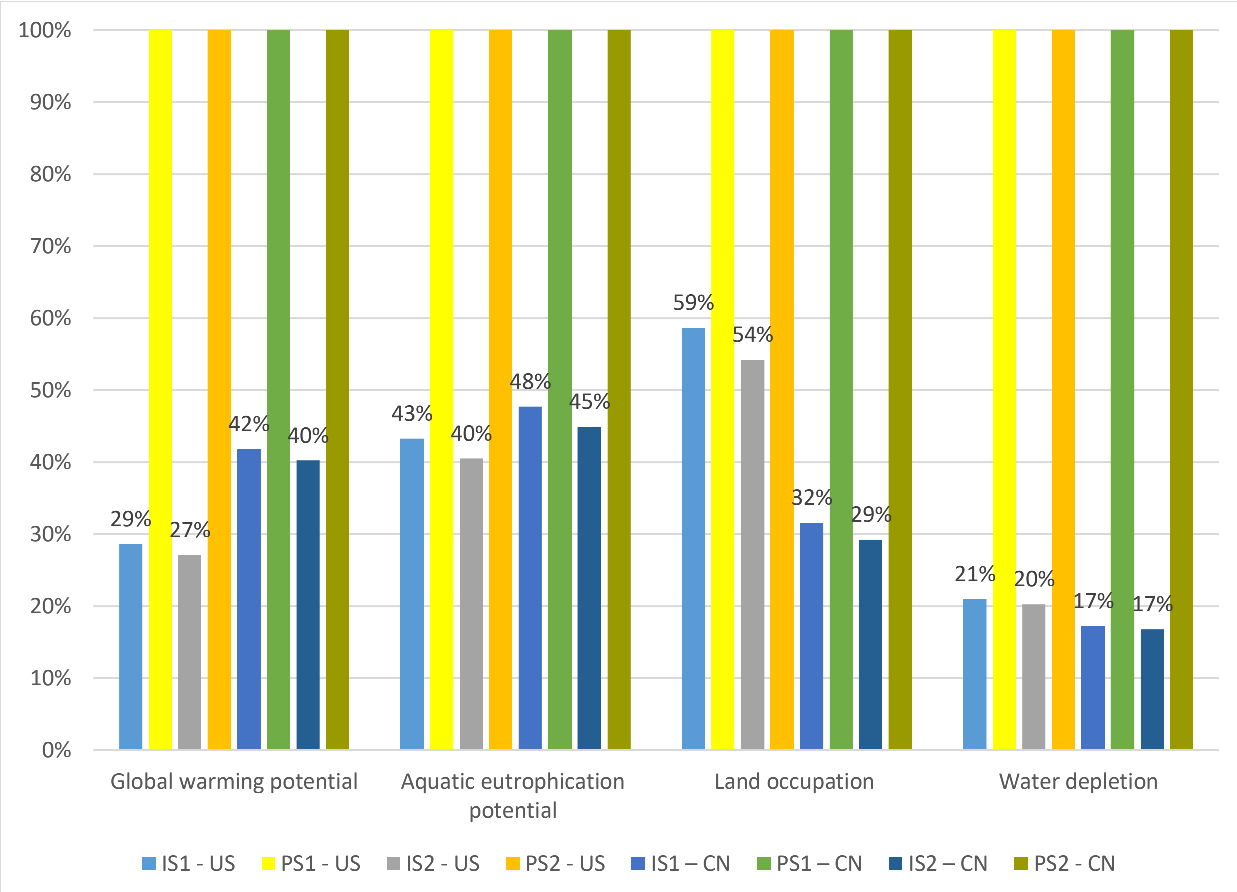

Figure 1 – Environmental indicators of the IS scenarios against the PS patty scenarios. Note the maximum of the two pairs (i.e., IS1 – US and PS1 – US; IS2 – US and PS2 – US) is indicated at 100%.

A brief summary of the range of results, noting that IS1 and IS2 are not comparable because they have slightly different life cycle stages due to cooking and thus have different functional units:

- 1 kg of IS shows a global warming result between 4.2 kg CO_2e and 5.3 kg CO_2e (58% and 73%) lower than 1 kg of PS patty, with the higher result for the IS when it is distributed in China.
- 1 kg of IS shows an aquatic eutrophication result between 0.77 g PO_4^{3-}eq and 0.88 g PO_4^{3-}eq (52% and 60%) less than 1 kg of PS patty, as it avoids some crop fertilizer and manure application emissions present in pig production.
- 1 kg of IS shows a land occupation result between 2.45 m^2·org. arable·year and 7.79 m^2·org. arable·year (41% to 71%) less than 1 kg of PS patty. The largest contribution for the IS is the production of sunflower oil, which has a much lower yield than other crops in the ingredients.
- 1 kg of IS shows a water depletion result between 0.44 m^3 and 0.56 m^3 (79% to 83%) less than 1 kg of PS patty. This is due to the much lower demand for agricultural irrigation for the IS ingredients than for the pig feed ingredients and high water withdrawal (and low water returned) for the pig production and slaughterhouse stages.

More detailed results, including the direct comparison between those foods with the same functional units, is provided in the report.

For the IS and PS products, the production of raw inputs (i.e., ingredients) generally contributes the largest amount to the environmental indicators of concern. For IS, the ingredients contribute close to half of the global warming potential, but distribution contributes significantly (approximately 47%) to the IS1 – CN and IS2 – CN scenarios because of the long distribution distance from the US to China. The ingredients (and their associated background processes) contribute more than 90% to the other three environmental indicators of concern. There is little difference between the IS1 (uncooked) and IS2 (cooked) environmental indicators.

In summary, the study has found that there are clear potential environmental benefits in the environmental indicators of concern discussed in this study, to using IS varieties examined in this work compared to their PS patty product equivalents.

Critical review

A critical review was performed by a third-party panel directed by the Interuniversity Research 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.

The procedures EY performed do not constitute an audit, examination or a review in accordance with generally accepted auditing standards or attestation standards. We have not audited or otherwise verified the information supplied to us in connection with this engagement.

Future events are inherently unpredictable. It is not possible to predict future events or anticipate all potential circumstances. As such, actual results achieved for the periods covered in this document may vary.

1. General information

1.1 Context

In January 2020, Impossible Foods released a new plant-based meat alternative (PBMA), called Impossible Sausage Made from Plants (IS), that aimed to mimic the flavour and texture of a ground pork sausage patty. This is the second PBMA released by Impossible Foods, the first being a plant-based ground beef burger alternative, called the Impossible Burger.

The IS is made primarily from plant-based proteins, fats, oils and binders and includes the use of a proprietary ingredient called heme. Heme is leghemoglobin protein that provides the IS with a meat-like flavour and texture, as well as a visual "bleeding", meant to mimic that of a meat-based sausage product. There are also two varieties of the IS, with slightly different quantities of ingredients and different preparations, which are specifically designed to cater to different end-users.

For this report, four environmental indicators of two varieties of IS are compared against the same four environmental indicators for the IS's ground pork sausage patty functional equivalent. Using the IMPACT 2002+ (V2.12) life cycle impact assessment (LCIA) method, which is further described in Humbert et al. (2012), three environmental indicators were quantified: global warming, aquatic eutrophication and land occupation. Using the ReCiPe Midpoint (H) Method (World H), which is further described in Goedkoop et al. (2009), 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 IS is currently being produced in the United States (US).

The life cycle assessment (LCA) is performed by Ernst & Young LLP (EY) for Impossible Foods. Contact information for all parties is provided in Table 1.

Table 1 – Contact information for all parties

<table>
<tr><th>Organization</th><th>Contact information</th></tr>
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</table>

1.2 Goal and intended audience

The goal of this study is to conduct a comparative LCA of two IS products produced in the US over four potential environmental impact indicators (global warming, aquatic eutrophication, land occupation and water depletion) against their ground pork sausage patty functional equivalent produced in the US and China. While other environmental impact indicators are available under the IMPACT 2002+ and ReCiPe methodologies, the above four environmental impact indicators are most often reported by other PBMA LCAs (Dettling, Tu, Faist, DelDuce, & Mandlebaum, 2016; Khan, Loyola, Dettling, & Hester, 2019; Heller & Keoleian, 2018) and are of particular relevance to Impossible Foods and the PBMA sector as a whole.

This project report is intended to support Impossible Foods in quantifying those four particular environmental indicators associated with IS ingredients and production, and in supporting the comparative assertions of those four particular environmental indicators associated with the IS products studied here against the functionally equivalent PS patty, intended to be disclosed to the public. Specific audiences may include the company's employees, business partners, customers, and the general public. This LCA is intended to be compliant with the requirements of ISO-14044 (ISO, 2006), which governs the requirements for public product-to-product comparisons for LCAs.

1.3 Background on plant-based meat alternatives

PBMAs have an estimated current market value of US$684 million in the US and approximately US$883 million in China (MSBNC, 2020), with year-over-year growth over 15% in China. The investment firm UBS has noted that the plant-based protein and lab-based meat market could be worth up to US$85 billion globally by 2030 (UBS, 2019).

The PBMA market, however, is still much smaller than the global meat market, estimated to be worth US$1.8 trillion (CB Insights, 2019). Pig production in the US has an estimated market value of US$23.4 billion for 2.2 million metric tons of pig and pig products, with 26% of that exported to other countries in 2019 (Queck-Matzie, 2019). China, by contrast, has set a target of 57.6 million metric tons for national pig output in 2020 (USDA, 2017). China is, however, turning towards imports to feed its population, with imports rising dramatically since 2010, with the main suppliers being the US (approximately 125,000 metric tons in 2018 (USDA, 2019)) and Germany (USDA, 2017). The size of the market comes with a proportional environmental impact. The global livestock market is responsible for 14.5% of global greenhouse gas (GHG) emissions (Gerber, P.J., et al., 2013) and between 20% (Opio, Gerber, & Steinfeld, 2011) and 27% (Mekonnen & Hoekstra, 2012; Hoekstra & Mekonnen, 2012) of global water consumption. As such, customers are beginning to look for food alternatives with lower environmental impact, such as PBMAs, and companies such as Impossible Foods are introducing products intended to meet the increasing demand for more sustainable meat and dairy products across the globe (Alexandratos & Bruinsma, 2012).

With few LCA studies conducted for plant-based pork alternatives, a literature review was completed (in the previously completed Goal & Scope document) for both PBMAs and the ground pork equivalent. The stage with the highest environmental indicator results for both products prior to cooking is raw material production (i.e., ingredient production for the PBMA and feed production for pig). The typical highest contributors for four of the most relevant environmental indicators are provided in Table 2. It is noted that most LCAs do not consider cooking processes in their scope, especially for pork LCAs, so while it is not expected to be significant, the relative impact of these hotspots may change slightly based on the scope considered.

Table 2 – Hotspots for four environmental indicators for PBMAs and ground pork

Product	Global warming	Aquatic eutrophication	Land occupation	Water depletion
PBMA	Raw material production: fossil fuel and fertilizer used to grow crops for ingredients	Raw material production: use of fertilizer for crop production	Raw material production: land used for crop production	Raw material production: irrigation in crop production
Ground pork sausage patty	Feed production: fossil fuel and fertilizer used to grow crops for ingredients	Feed production: use of fertilizer for feed production and manure application	Feed production: land used for crop production and, to a lesser extent, the land used for animal production	Feed production: irrigation in crop production and, to a lesser extent, water withdrawal during pig production and in the slaughterhouse

For pork production, there are other significant contributions from manure handling, enteric fermentation and feed production (Röös, Sundberg, Tidaker, Strid, & Hansson, 2013). It was also noted in the literature review that the type of crops used for raw materials production in the PBMA and feed production in pig production has a significant influence on the environmental indicators for those stages and overall (McAuliffe, Chapman, & Sage, 2016). As a result, the quantity of feed for the pig production in this study is subject to a sensitivity analysis.

2. Scope

This LCA focuses on the comparison of two varieties of the IS against their functionally equivalent ground pork sausage patty products using four specific environmental indicators. This section includes a description of the relevant product scenarios, in-scope life cycle stages and cut-off approach, the functional unit, and other relevant scenario and scope information.

2.1 Description of the products studied

2.1.1 Impossible Sausage

There are two varieties of the IS under study in this LCA:

- IS1: a PBMA that includes sausage flavouring and is delivered uncooked and frozen to a retailer; and
- IS2: a PBMA that includes sausage flavouring but has a different moisture content from IS1 and is delivered cooked and frozen to a retailer.

The IS is intended to be included in recipes and meals as a direct and equivalent substitute for ground pork. It consists of ingredients sourced globally, including plant-based proteins, fats, oils, binders, as well as a proprietary product heme, which gives the IS its characteristic meat-like flavour, colour and behaviour. It is noted that the environmental indicators of the IS1 and IS2 are not meant to be compared in this study and are not considered to be functionally equivalent; they are to be compared to their PS functional equivalents only.

Heme is manufactured through a fermentation and isolation process wherein a genetically modified yeast strain is produced in culture and expresses leghemoglobin protein, which is then isolated downstream (Khan, Loyola, Dettling, & Hester, 2019). It is shipped from its manufacturing facilities to the Chicago, Illinois-based Impossible Foods bulk product processing facilities. There, it is mixed and processed with other plant-based proteins and fats. The bulk sausage product is then delivered to secondary facilities for seasoning, patty forming, cooking (for IS2) and then freezing; the patty is then packaged for sale also at the same location. The packaged product is then distributed to wholesale distributors, grocery stores and restaurants for end-consumers.

The boundary of the system studied includes all activities necessary to produce the IS in a patty form from "cradle to the gate of the retail/wholesale distributor's truck." Retail, use and end-of-life stages are excluded from the study as these do not differ significantly between the IS and the reference PS patty 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 significant contributors of impacts in agricultural systems and are thus not included. While it is recognized that some new or retrofitted infrastructure may be required for some processes in this study, it is not possible to allocate all of the impacts to the new activities nor is it possible to quantify that allocation due to the prospect of other uses during and after the study period. Thus, the infrastructure processes were excluded from the inventory calculation using the embedded SimaPro functionality.

Figure 2 further details the system under study, including raw materials production, the IS 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 from the pork sausage patty equivalent.

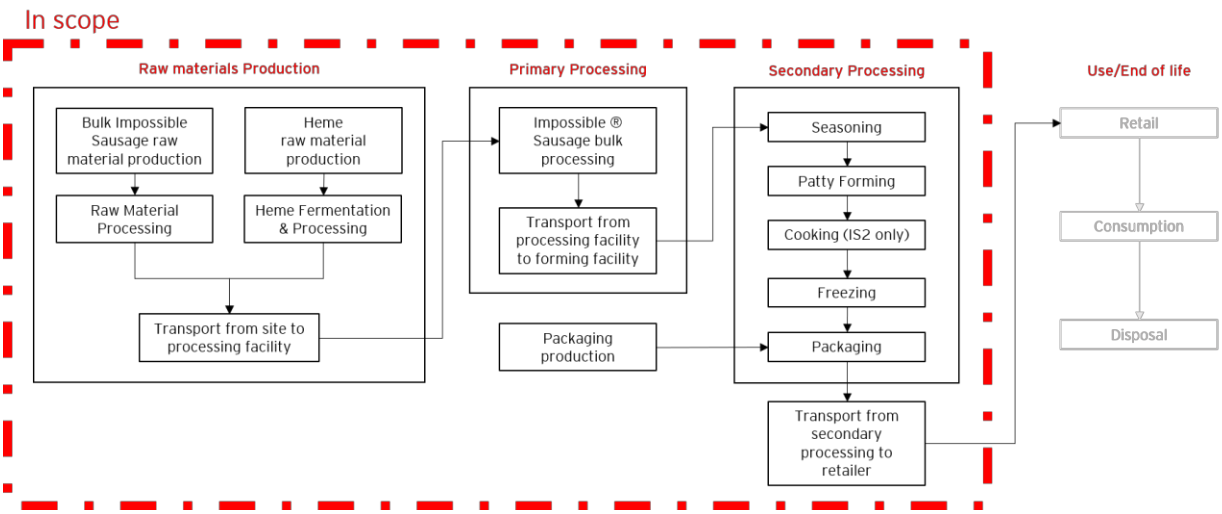

Figure 2 - Inventory boundary for the IS (IS1 and IS2) scenarios (EY analysis)

The in-scope life cycle stages of the IS, with the specific sub stages that are relevant to the potential environmental impact calculations, are described briefly in Table 3.

Table 3 – In-scope life cycle stages of IS

Stages	Sub stages	Description
Raw materials production	Bulk IS raw material production	The ingredients in the IS include organic and inorganic compounds, 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. The agricultural processes require fossil fuel inputs, including fertilizers and/or manure, as well as water, to grow the plants.
	Heme raw material production and fermentation	The ingredients used to produce heme in fermentation include yeast substrates (organic and inorganic chemicals and carbohydrates) and the yeast itself. The organic and inorganic chemical production may require electricity, natural gas and other fossil fuel inputs, as well as other primary chemical inputs. The agricultural processes to produce the carbohydrate substrate requires fossil fuel inputs, including fertilizers and/or manure, as well as water, to grow the plants. Heme is produced through fermentation, in which a genetically modified yeast strain expresses the naturally occurring leghemoglobin protein. Following fermentation, the leghemoglobin protein is isolated and concentrated from the fermentation media (Khan, Loyola, Dettling, & Hester, 2019).
	Transport from site to processing facility	The raw materials and crops, including heme, for the IS are delivered via truck to the Impossible Foods production plant in the Chicago, IL, area from their typical locations.
Primary processing	IS bulk processing	The production process for the IS involves first the development of a bulk product. There is electricity and water withdrawal in all processing steps, carbon dioxide for cooling, as well as small amounts of ammonia consumption from refrigeration.

Stages	Sub stages	Description
	Transport from processing facility to forming facility	The bulk IS products are then delivered to a forming facility. IS1 and IS2 are both formed in the greater Chicago, IL, area but at different sites.
Secondary processing	Seasoning and patty forming	After delivery of the bulk IS product to the forming facility, the product is seasoned and formed into patties for sale. For IS1, the product is then frozen and packaged (packaging occurs at the same site as the seasoning and patty forming). For IS2, the product is cooked, frozen and packaged at a nearbysite.
	Cooking (for IS2 only)	The cooking, for IS2 only, is conducted using an in-line oven that uses natural gas.
Packaging	Packaging production	The IS packaging consists of plastic film that will wrap around the patties. These patties are then packed in corrugated cardboard. Packaging and patty production are co-located, obviating transportation emissions between these steps (Khan, Loyola, Dettling, & Hester, 2019). Electricity, natural gas, and water withdrawal are fully considered in the production process. The packaging is done at the same site as the forming plant.
Distribution to retailer	Transport from secondary processing to retailer	The packaged IS (IS1 and IS2) are then delivered, via truck, to retailers, primarily grocery stores and/or restaurants. For the China scenario, trucks deliver the products to the Los Angeles port and ships deliver them to Shanghai as a regional proxy, where additional truck travel is used to deliver the products to distributors and then retailers. Impossible Foods is currently not available in mainland China.

2.1.2 Pork sausage patty product boundary description

For the PS patty scenarios, pigs are produced in the US and China and processed to ground pork for local consumption. The products are meant to be functionally-equivalent to the IS, to be sold frozen and in the form of a pork sausage patty (divided into individual servings that can be cooked from frozen). To achieve the functional equivalence of the IS varieties, two ground pork products are under study in this LCA:

- Pork Sausage 1 (PS1): a ground pork sausage that is delivered uncooked and frozen to a wholesale distributor, retailer and/or restaurant; and
- Pork Sausage 2 (PS2): a ground pork sausage that is delivered cooked and frozen to a wholesale distributor, retailer and/or restaurant.

Figure 3 further details the system under study, including feed production, pig production (i.e., the pig rearing process and slaughter), pork product processing, and then distribution to wholesale distributor, retailer and/or restaurant. As noted prior, the use and end-of-life stages of the finished goods are not included here because they are not considered to differ from the IS equivalent.

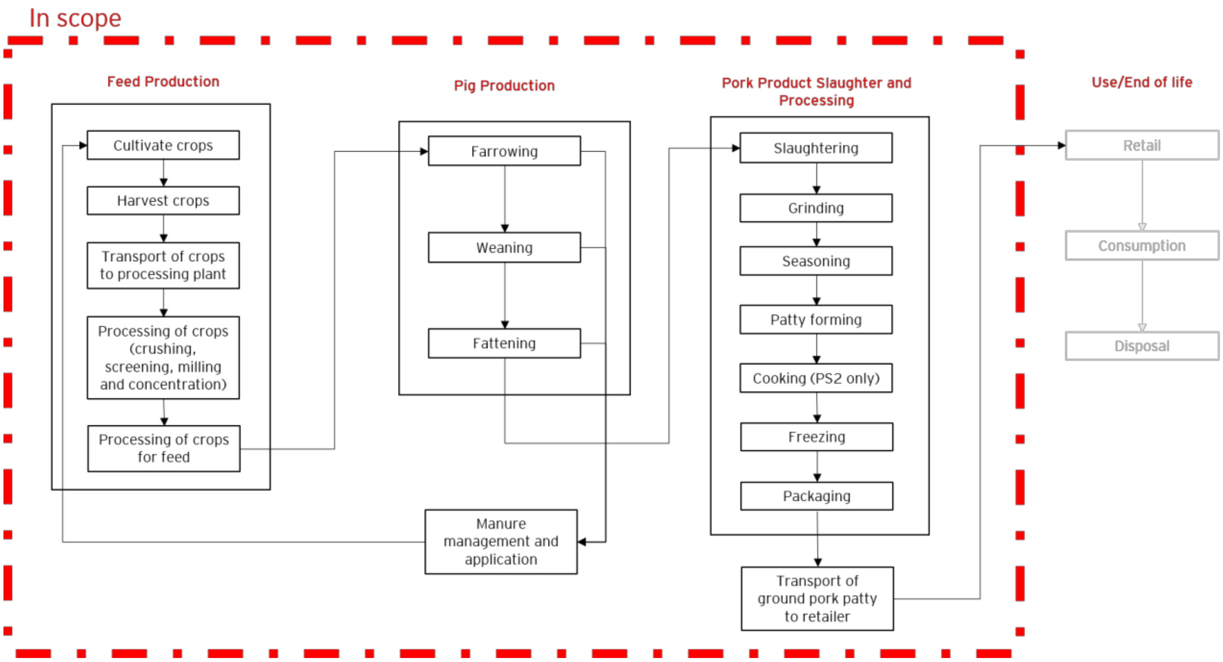

Figure 3 – Inventory boundary for pork scenarios (PS1 and PS2) (EY analysis)

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 using the SimaPro function for doing so.

Based on EY analysis, the in-scope life cycle stages of the pork scenarios, with the specific sub stages that are relevant to environmental impact calculations, are described briefly in Table 4.

Table 4 – Boundary descriptions for pork scenarios

Stages	Sub stages	Description
Feed production	Cultivation and harvesting of crops	Before beginning the cultivation of the crops of feed production, the appropriate crop must first be selected, depending on what will be used as feed during pig production (Reckmann, Blank, Traulsen, & Krieter, 2016). Next, the soil needs to be prepared for the growing season, which includes applying fertilizer or manure to add nutrients, tillage and plowing to remove any unwanted weeds or grass. Once the soil is prepared, the seeds are sowed, followed by irrigation and application of fertilizers and/or manure. Once the crops reach maturity, they are harvested using a combine and then 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 lime, manure and synthetic nitrogen resulting in leaching causing potential eutrophication, water withdrawal and return for irrigation and land occupation for the cropland itself (Dalgaard, Halberg, & Hermansen, 2007).
	Transport of crops to processing plant	Once ready for shipment, the harvested crops are transported to the feed processing plant. 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 pigs. Because of fossil fuel and electricity use during the processing stage, GHG emissions are the primary source of environmental impacts from this substage (Dalgaard, Halberg, & Hermansen, 2007).

Stages	Sub stages	Description
	Transport of crops to pig farm	Once ready for shipment, the processed feed is transported to the pig farm 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).
Pig production and slaughter	Farrowing, weaning and fattening	Farrowing, nursery and growing/finishing are the three primary stages of pig production, which relate to the maturity of the pig. Farrowing is the first stage of the pig's life, which is the act of giving birth to piglets; this stage, from birth to weaning, takes about 21 days. Nursery refers to the stage where the piglet become dependent upon consuming feed, rather than the mother's milk, and lasts about 42 to 56 days. Growing/finishing refers to the stage at which the pigs are being prepared for their conversion to edible meat and lasts about 115 to 120 days (National Pork Board, 2016). This timing may differ slightly amongst regions, countries and breeds, but not significantly. The primary differences between the stages are the amount and the composition of feed given, as the nutritional requirements may differ (Rougoor, Elferink, Lap, & Balkema, 2015). The primary impacts from growing pigs are GHG emissions from manure handling, energy use for operating the equipment and pig housing, and enteric fermentation from the pigs themselves (Dalgaard, Halberg, & Hermansen, 2007; Röös, Sundberg, Tidaker, Strid, & Hansson, 2013).
	Manure management and application	During the farrowing, weaning and fattening substage, manure and pig excrements are stored for later use as a source of nutrients during the crop cultivation stage (in place of fertilizer). There are three types of manure management systems including solid, slurry or liquid (lagoon), depending on the method of collection, storage, transportation and the distribution of the manure onto the fields. The resulting GHG emissions vary as a result. The significant impacts in this stage are GHG emissions in the form of methane from anaerobic decomposition and N_2O formed during storage, eutrophication from the nutrients leaching into water and leaching during storage prior to the cultivation stage (Dalgaard, Halberg, & Hermansen, 2007; Reckmann, Blank, Traulsen, & Krieter, 2016; Nguyen, Hermansen, & Mogensen, 2011). This leaching impacts the crop production stage as well. The manure is later applied to crops at the same site or nearby and replaces fertilizer.
	Slaughtering	Slaughtering refers to the stage at which the fattened pigs are converted into pork. The emissions contributions from this stage are primarily GHG emissions from the transportation of the pigs to the slaughterhouse and from the use of electricity and fossil fuels during operations (Rougoor, Elferink, Lap, & Balkema, 2015; Röös, Sundberg, Tidaker, Strid, & Hansson, 2013). At this stage, fresh meat is separated from food grade, feed grade and other co-products from the pig and sent to secondary processing, which is modelled as being co-located with primary processing in this study (i.e., there is no transportation required).
Secondary processing	Grinding, seasoning, forming, cooking (for PS2 only) and freezing	At the secondary processor, the fresh pork meat is ground into ground pork, seasoned where necessary, formed into similar patties to that of the IS, cooked on a line oven (but only for PS2), then frozen and packaged.
	Packaging	Ground pork is packaged for sale using similar packaging to that of the IS: plastic film and corrugated cardboard.
Transportation to retailer	Transport of ground pork sausage patty to retailer	Once ready for shipment, the ground pork patties are delivered by truck to a retailer for sale and consumption.

2.2 Scenario descriptions

There are two groups of scenarios that are relevant to this LCA: one that compares the two IS varieties (IS1 and IS2) manufactured in the US with their pork analogs produced in the US (PS1 and PS2) and one that compares the two IS varieties (manufactured in the US and distributed to China) with their pork analogs produced in China. It is noted again that the environmental indicators of the IS1 and IS2 are not meant to be compared in this study and are not considered to be functionally equivalent.

As a result, the corresponding reference scenarios for each of the above vary slightly. Each specific scenario is detailed in Table 5.

Table 5 – Product scenarios for this LCA

Scenario name	Impossible Foods scenario	Functionally equivalent scenario name	Functionally equivalent scenario
IS1 – US	IS1 that is produced in the US in 2020 and distributed uncooked, frozen to a typical US wholesale distributor, retailer and/or restaurant.	PS1 - US	Typical ground pork patty that is produced in the US in 2020 and distributed uncooked, frozen to a typical US wholesale distributor, retailer and/or restaurant..
IS1 - China	IS1 that is produced in the US in 2020 and distributed uncooked, frozen to a typical Chinese wholesale distributor, retailer and/or restaurant..	PS1 - China	Typical ground pork patty that is produced in China in 2020 and distributed uncooked, frozen to a typical Chinese wholesale distributor, retailer and/or restaurant..
IS2 – US	IS2 that is produced in the US in 2020 and distributed pre-cooked and frozen to a typical US wholesale distributor, retailer and/or restaurant..	PS2 – US	Typical ground pork patty that is produced in the US in 2020 and distributed pre-cooked and frozen to a typical US wholesale distributor, retailer and/or restaurant..
IS2 – China	IS2 that is produced in the US in 2020 and pre-cooked and frozen in the US and delivered to a typical Chinese wholesale distributor, retailer and/or restaurant..	PS2 - China	Typical ground pork patty that is produced in China in 2020 and delivered pre-cooked and frozen to a typical Chinese wholesale distributor, retailer and/or restaurant..

2.3 Unit of analysis

The unit of analysis is defined through the identification of the **function**, the **functional unit** and the **reference flow**. This will facilitate the comparison of the IS varieties against their respective pork scenarios. The units of analysis are shown in Table 6 for the products.

Table 6 – Unit of analysis for IS varieties and ground pork equivalents

Function	To provide food for consumers to eat
Functional unit	1 kg of food at a retailer (For IS1 and PS1, this is 1 kg of uncooked food; for IS2 and PS2, this is 1 kg of cooked food)
Reference flow	1 kg of food

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.), the IS was designed to be nutritionally similar to ground pork sausage patty, as noted in Table 7.

Table 7 – Nutritional data for IS and PS; cooked and raw

Nutrient	Units	IS1 – 100 g (Impossible Foods, 2020)	PS1 – 100 g (USDA, 2019)*	IS2 – 100 g (Impossible Foods, 2020)	PS2 – 100 g (USDA, 2019)**
Calories	kcal	237	288	231	392
Total fat	g	16.68	24.80	15.41	37.25
Saturated fat	g	7.19	7.57	5.95	12.13
Trans fat	g	0	0.101	0	0.184
Cholesterol	mg	0	70	0	74
Sodium	mg	588.17	739.00	692	810
Total carbohydrate	g	9.07	0.93	9.79	0.69
Dietary fiber	g	1.16	0	1.53	0
Total sugars	g	1.30	0.93	0.7	0.53
Added sugars	g	1.28	no data	0.7	no data
Protein	g	12.58	15.39	13.29	13.46

*Nutritional information provided for pork sausage, link/patty, unprepared
**Nutritional information provided for pork sausage, link/patty, fully cooked, unheated

The products are compared here on a per-mass basis to correspond with similar studies of PBMAs against their meat-based analogs (Dettling, Tu, Faist, DelDuce, & Mandlebaum, 2016; Khan, Loyola, Dettling, & Hester, 2019; Heller & Keoleian, 2018) and that of pig/pork-based LCAs (Dalgaard, Halberg, & Hermansen, 2007; Reckmann, Blank, Traulsen, & Krieter, 2016; Djekic, Radovic, Lukic, Stanisic, & Lilic, 2015; Dettling, Tu, Faist, DelDuce, & Mandlebaum, 2016; Rougoor, Elferink, Lap, & Balkema, 2015; Pelletier, Lammers, Stender, & Pirog, 2010; Zhou, Dong, Xin, Zhu, & Huang, 2018) to ensure comparability. It is noted, though, that human bodies digest animal proteins differently than vegetables; this effect was not examined in this specific study. Furthermore, an additional limitation to using the per-weight basis to examine the environmental indicators would be the fact that some people eat to satiate specific dietary needs, for example, protein intake. A sensitivity analysis is completed to examine the environmental indicators on a caloric and protein basis as well later in this study.

2.4 Cut-off approach

It is noted that for all scenarios, a mass-based cut-off criterion is used, where those cumulative inputs that comprise less than 1% of the total mass of the final products are not included in the quantification of the environmental indicators. This is consistent with other studies of plant-based meat alternatives (Dettling, Tu, Faist, DelDuce, & Mandlebaum, 2016; Khan, Loyola, Dettling, & Hester, 2019). For processes that are above that threshold where no modelled processes were available, proxies are used. Inputs where proxies were used are identified in Table 8.

2.5 Inventory date and version

This is the first version of the inventory comparing the IS scenarios against the reference scenarios. The Impossible Foods production data is based on the most recent design and production data provided by Impossible Foods. For the pork scenarios, 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 IS and pig/pork product production in the US for the US-based scenarios and then representative of pig/pork production in China for the Chinese pork scenarios, during the year that the study is conducted (2020). 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 13. The vast majority of sources of information for this report are all relevant and considered to represent the best available data and conditions in the industry. Certain processes may generate emissions over a longer period than the current year, but all data has been selected to represent current conditions, where practical.

For the global warming indicator, the 100-year time horizon global warming potentials (GWPs) without carbon feedback from AR5 are utilized (IPCC, 2014). The biogenic methane GWP was used.

2.7 Land-use change impacts

The literature review noted that GHG emissions from direct land-use changes from the use of crop lands to produce PBMA ingredients and crops for pig feed production may be significant (Reckmann, Blank, Traulsen, & Krieter, 2016). The quantification of GHG emissions for specific ingredients is sourced from the ecoinvent v3.1 (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.

3. Data collection and quality

The assessment of a life cycle inventory typically requires three types of data:

- Direct emissions data, which is determined through continuous monitoring, stochiometric equation balancing, mass balance approaches or other similar methods;
- Activity data, which captures the physical inputs, outputs and other metrics for processes (energy consumption, material consumption, distance travelled, etc.); and
- Emission or characterization factors, which are used to calculate GHG emissions from activity data (e.g., kg CO_2 for 1 kWh of energy or 1 kg of material).

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.

The process-specific stages for Impossible Foods scenarios use primary production data obtained through nameplate data for electricity use and natural gas use as well as water meters for water withdrawal. For the reference pork scenarios, secondary data from literature, government or industry sources is used.

When modeling the two product systems under study, the ecoinvent v3.1 default allocation (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, but the background processes were replaced with ecoinvent v3.1 processes; whenever possible, appropriate country inventories were selected. When neither country-specific nor region-specific inventories were available, global inventories are used; for example, the global inventory in ecoinvent v3.1 was used for citric acid as there was no US-specific inventory. For agricultural processes, local and recent crop yields were used to update inventories and make them more reflective of local conditions (see Appendix C for modified crop yields). 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).

The following sections provide details on the data used for the IS and reference PS patty scenarios, respectively.

3.1 Data sources for IS

Primary data for the stages controlled by Impossible Foods, such as the production of the bulk sausage, heme, and the patty forming, seasoning and cooking, were provided by Impossible Foods and their suppliers/manufacturers. EY 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, feed production and distribution, secondary data was used from commercial databases and literature. Appendix A contains the processes used to model IS1 and IS2.

3.1.1 IS – Raw materials production

The raw materials that constitute the ISs are divided into two primary parts: the bulk IS mix and the ingredients to produce heme, the ingredient in the IS that provides a meat-like flavour and texture meant to mimic that of a meat-based patty.

A list of the ingredients modelled in the IS is provided in Table 8. 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 IS in the SimaPro LCA software (https://www.pre-sustainability.com). All ingredients cumulatively contributing less than 1% to the total mass of the product are excluded from the analysis and not included in Table 8.

For specific products, proxies may have been used; these are identified in Table 8. It is especially noted that a process that does contain animal products (fodder yeast) was used as a proxy for the non-animal yeast ingredient in the modelling (yeast extract); this was used because there were no non-animal yeast processes in ecoinvent v3.1. The IS does not contain animal products. Appendix A contains the processes used to model IS1 and IS2.

Table 8 – List of IS ingredients

IS ingredient list*	Modelled dataset***	Database
Water	Tap water {ROW}, market for	ecoinvent v3.1
Soy protein concentrate	Used Agri-footprint dataset for foreground process but replaced all background processes with ecoinvent v3.1 processes	ecoinvent v3.1 See Appendix B – Table 41 for process See Appendix C for updated crop yields
Coconut oil	Coconut oil, crude {PH} production	ecoinvent v3.1 See Appendix C for updated crop yields
Sunflower oil	Used Agri-footprint dataset for foreground process but replaced all background processes with ecoinvent v3.1 processes	ecoinvent v3.1 See Appendix B – Table 39 and Table 40 for processes See Appendix C for updated crop yields
Methylcellulose**	Carboxymethyl cellulose, powder {GLO}, market for; used as proxy	ecoinvent v3.1
Cultured dextrose**	Sugar, from sugarcane {GLO}, production for; used as proxy	ecoinvent v3.1
Food starch modified**	Potato starch {GLO}, market for; used as proxy	ecoinvent v3.1
Sodium hydroxide	Sodium hydroxide, without water, in 50% salutation state {GLO}, market for	ecoinvent v3.1
Sodium ascorbate (Vitamin C)	Citric acid {GLO} production	ecoinvent v3.1
Yeast extract (non-animal product)**	Fodder yeast {GLO}, market for; this is a animal product that is used as a proxy for the non-animal product yeast used in the IS****	ecoinvent v3.1
Soy leghemoglobin ("heme")	Proprietary product; see Appendix A for process	ecoinvent v3.1

*This list only contains ingredients that were modelled and does not include products that comprise less than 1% of the total product mass, as per the defined cut-off rules.
**These products were modelled using best available proxies in the ecoinvent v3.1 database.
***All processes were default allocation.
****The yeasts and yeast extracts in the IS are completely animal-product free. An animal-product yeast proxy was used here because it was the only available yeast process in ecoinvent 3.1. There are no animal products in the IS and it is noted that the use of an animal-based product as proxy would most likely increase the environmental indicators, compared to the use of a non-animal yeast, making the proxy a conservative estimate.
Note: there are two IS varieties but only the proportion of ingredients varies between the two, not the list of ingredients.

The environmental indicators of the production of the ingredients of heme as well as the manufacturing of heme are also included in this stage because they constitute an ingredient of the IS. The data for electricity use, including refrigeration, refrigerant use (in this case, ammonia), water withdrawal and waste was collected from the heme manufacturer. The heme production process also produced two waste streams: one stream that was modelled as household wastewater and another solid waste stream that was modelled as municipal solid waste sent to landfill, as the solid waste stream was sent to a local landfill. The data was based on the nameplate data for equipment used, such as agitators, mixers, chillers and pumps inside the facility, as well as load factors and run-time cycles for when heme for Impossible Foods was produced; as such, the contribution to the environmental indicators from the heme production within the facility was fully allocated to the heme for Impossible Foods. For heme production, the ecoinvent v3.1 electricity process was modified to use the 2018 (best available) mix of electricity generation sources (IEA, 2020). The modelled process for heme is provided in Appendix A.

The transportation processes required to deliver the heme ingredients to the heme manufacturing facilities, freezer transportation of the heme to Chicago for the manufacturing of the IS bulk mix, and then transportation of the IS ingredients to the Chicago area for the IS bulk mix are also included in this stage. A fixed distance of 1,500 km by truck was used for each North America-based product transported, which represents approximately one-third of the width of the continental US (this is a conservative approach used by Dettling, Tu, Faist, DelDuce, & Mandlebaum (2016)). Transportation of the heme product to the Chicago area for incorporation into the IS bulk mix was modelled using truck transport and the actual road distance between the two cities.

To model frozen distribution without a freezer-travel specific process in ecoinvent v3.1, it was assumed that, based on Tassou et al. (2009), freezer truck travel requires 27% more energy to fuel the transport than ambient truck travel; the same value was used for freezer freighter travel as no other data was available. Furthermore, a refrigerant charge of 5.0 kg (R-134a) was assumed, with an annual leakage rate of 10%, for both freezer truck and freighter travel. The freezer truck and freezer freighter processes are provided in Appendix A.

Any products that originated outside North America were modeled using a combination of truck and ocean transport using actual road and sea distances, respectively.

It is noted that the Critical Review panel had access to the specific ingredient listing and quantities, the heme production data (electricity use, refrigeration, water withdrawal and waste), the location of heme production, and the modelled processes for each ingredient and process for the purposes of their review. However, to protect proprietary information, these are redacted from the public report.

3.1.2 IS – Primary and secondary processing

The IS mix undergoes primary and secondary processing stages, both in the Chicago, IL, area. Once the bulk IS mix is produced, it is delivered to one of two facilities (depending on IS1 or IS2) within the Chicago area to complete the seasoning, forming, cooking (for IS2 only) and packaging. Both facilities use pumps, liquefiers, motors, refrigerators and other equipment to prepare the patties for distribution. Transport between the primary and secondary processing facilities is modelled using truck travel of 100 km.

The data for electricity, natural gas, water withdrawal, waste and carbon dioxide use for the primary and secondary processing facilities was collected by the manufacturer. The data was based on the nameplate data for equipment used, as well as load factors and run-time cycles for when the product is produced; as such, the environmental indicator contribution from production within the facility is fully allocated to the IS. The electricity grid for Chicago was modelled using the existing ecoinvent v3.1 Reliability First Corporation (RFC) electricity process, but modified to reflect the PJM/Comed grid as of 2018 (Comed, 2019). See Appendix E for electricity grid share for Illinois used in this study.

It is assumed, as well, there is a loss of 5% by weight of the IS from each of the primary and secondary processing stages. Thus, both processes were 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 replicated here.

3.1.3 IS – Packaging

The IS is packed using a flexible plastic pouch, suitable for use for frozen food applications, and this packaging is distributed to retail locations using corrugated cardboard secondary packaging. The patties are distributed in portions of 2.5 lb (1.1 kg), packed in corrugated cardboard boxes containing 20 lb

(4.53 kg) of product (i.e., one corrugated cardboard package contains 20 lb of IS). One 20 lb box of patties uses 0.44 kg of corrugated cardboard and contains 8 plastic pouches with sausage patties, each using 20.5 g of plastic film. Thus, the amount of plastic film and corrugated cardboard used for the packaging is 18.1 g and 48.6 g, respectively, per kg of IS. The same packaging is assumed to be used for the reference PS patty packaging. See Table 44 for the packaging process used.

3.1.4 IS – Transportation to retailer

The distribution to retailer for the IS products differs between the US and China scenarios. For IS1 and IS2 going to US retailers, a fixed distance of 1,500 km of freezer truck travel was used to model the distribution to typical US retailers from the Chicago area. For IS1 and IS2 going to Chinese retailers, a fixed distance of 3,242 km of freezer truck travel between Chicago and Los Angeles, 10,751 km of freezer freighter travel from Los Angeles to Shanghai, and a fixed distance of 1,500 km freezer truck travel within China was used to model the distribution to Chinese retailers from Chicago.

It is noted that the in-scope life cycle stages stop at the gate of the distributor; they do not include any activity at the retailer as it expected to be equivalent between the IS and PS patty scenarios.

3.2 Data sources for PS patties

For the PS1 and PS2 US and Chinese scenarios, data related to pig feed and population was obtained from literature sources, and emission factors for manure management and enteric fermentation were calculated using a combination of Tier 1 emission factor methodologies from IPCC (2006), using guidance from IPCC (2006), Nguyen et al. (2011), Pelletier et al. (2010) and Zhou et al. (2018).

The PS1 and PS2 – US scenarios were modelled using feed and pig population data from Pelletier et al. (2010), a pig production system in Iowa, US (and intended to be representative for pig production in the US in general), with a pig inventory of 2,400 breeder pigs and 40,000 – 50,000 market pigs annually, in 2006. While Pelletier et al. (2010) studied a specific manure management system, the typical representation provided in IPCC (2006) of North American manure management systems is used to calculate Tier 1 emission factors using a population-weighted average of the inventory of breeder and market pigs, using the typical weights for each provided in IPCC (2006).

The PS1 and PS2 Chinese scenarios were modelled using feed and pig population and some on-farm operation data from Zhou et al. (2018), a pig production system in Hubei province, China (and intended to be representative of pig production in China), with a pig inventory of 7,200 sows and 59,160 weaned pigs, in 2015. While Zhou et al. (2018) studied a specific manure management system, the typical representation provided in IPCC (2006) of Asian manure management systems is used to calculate Tier 1 emission factors.

It is noted here that the above models may not be representative of the full spectrum of pig production processes in each country. This is certainly a limitation of the work; however, it is considered the best available approach given that Iowa and Hubei province are the primary producers of pigs in their respective countries. It is recognized that there may be variation in resource intensity for the inputs from the countries (i.e., the amount of water or fertilizer used for feed production in certain regions of each country), which is not considered here.

3.2.1 Pork product – Feed production

In pig rearing for food, the pigs are fed different feed over the course of their lives, depending on the age of the pig. Specific feed compositions for the US and Chinese scenarios are provided in Pelletier et al. (2010) and Zhou et al. (2018), respectively. In the US scenarios, the feed is primarily composed of corn and soybean meal, as well as other fatteners, proteins and vitamins. In the Chinese scenarios, the feed is similar to the US feed, but also includes barley. The average feed composition used in this study to model the feed delivered to pigs throughout their different stages of development for US and Chinese scenarios is provided in Table 9.

Table 9 – Compound feed composition*, by country

Feed type	US scenarios feed: Pelletier et al. (2010)	China scenarios feed: Zhou et al. (2018)
Corn	75%	65%
Soybean (meal)	25%	20%
Barley	0%	15%

*Other constituents in the feed include fish meal, amino acids, fats and vitamins; due to a lack of comparable processes in the ecoinvent v3.1 database to model these compounds, the share of the feed related to these constituents is modelled as the feed itself.

US feed constituents were modelled using US-based processes in the ecoinvent v3.1 database, but modified to reflect 2017 US census-based yield (USDA, 2020), the average fertilizer use between 2014 and 2018 (FAO, 2019), and the 2019 Iowa grid (EIA, 2020); see Appendix C for updated yield, Appendix D for fertilizer amounts and Appendix E for Iowa grid electricity share used in this study. Chinese feed constituents were modelled using global processes in the ecoinvent v3.1 database, but all were modified to reflect yields and fertilizer use as per Zhou et al. (2018), as well as an updated Chinese electricity grid mix from 2018 (IEA, 2020); see Appendix C for updated yield, Appendix D for fertilizer amounts and Appendix E electricity grid share for China used in this study. The limitations of using country-wide yields for crops in specific crops are recognized here, but due to a lack of region-specific data, country-wide, and sometimes global, data for crops was used.

Energy for on-farm operations and drying and mixing the feed, as well as 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 for the US scenario, a simplification of the distances used in Pelletier et al. (2010). For the Chinese scenarios, the distances in Zhou et al. (2018) were used: 325 km for the movement of corn, 493 km for the movement of soybean and 30 km for the movement of barley.

3.2.2 Pork product – Pig production

As noted above, pig performance data for the US and Chinese scenarios was modelled using pig performance data by Pelletier et al. (2010) and Zhou et al. (2018), respectively. The reader is directed to those resources for more specific data on pig performance. The primary sources of environmental impact in this stage are manure management, enteric fermentation and on-farm operations.

For the Chinese scenarios, methane emissions from manure management were calculated using Tier 1 emission factors (IPCC, 2006) for Asia for an average annual temperature of 15°C; there is no differentiation between market and breeding swine emission factors for this region in IPCC (2006). For the US scenarios, methane emissions from manure management were calculated using Tier 1 emission factors (IPCC, 2006) with a weighted average of the market and breeding swine population from Pelletier et al. (2010) using the share of manure management systems indicated in IPCC (2006) for North America; emission factors were chosen for an average annual temperature of 15°C. Default values, based on the IPCC (2006) worksheets for nitrogen excretion, were used to calculate direct and indirect nitrous oxide, ammonia and nitric oxide emissions from manure management.

For on-farm operations, the contributions to the environmental indicators are associated with energy use for climate control, cleaning and other uses, as well as water withdrawal. For the US scenarios, data was not provided by Pelletier et al. (2010); on-farm operations contributions to the environmental indicators were assumed to be consistent with those used by Nguyen et al. (2011) and water withdrawal was provided by Blonk Agri-footprint BV (2014). Activity data for the Chinese scenarios was provided by Zhou et al. (2018) and water withdrawal was provided by Blonk Agri-footprint BV (2014). It is noted that the water activity factor assumed spatial homogeneity of water intensity associated with pork production for both US and Chinese scenarios; this is a limitation noted later in the conclusions as well.

For both US and Chinese scenarios, methane emissions from enteric fermentation were calculated using Tier 1 emission factors (IPCC, 2006) for developing and developed countries, respectively.

Emissions and activity factors for the pig production stage for both the US and China scenarios are provided in Table 10.

Table 10 – Emission and activity factors for enteric fermentation and manure management

US and China scenarios, on a per kg live weight basis

Emission/activity	US (per kg live weight pig)	Reference/guideline	China (per kg live weight pig)	Reference/guideline
CH_4, manure management	97.75 g	IPCC (2006); Nguyen et al. (2011) – Tier 1 emission factor	35.23 g	IPCC (2006); Nguyen et al. (2011) – Tier 1
Direct nitrous oxide (N_2O), manure management	0.022 g	IPCC (2006); Nguyen et al. (2011); Pelletier et al. (2010) – Tier 1	0.0068 g	IPCC (2006); Nguyen et al. (2011); Zhou et al. (2018) – Tier 1
Ammonia (NH_3-N), manure management	1.41 g	IPCC (2006); Nguyen et al. (2011); Pelletier et al. (2010) – Tier 1	0.86 g	IPCC (2006); Nguyen et al. (2011); Zhou et al. (2018) – Tier 1
NO_2, manure management	0.35 g	IPCC (2006); Nguyen et al. (2011); Pelletier et al. (2010) – Tier 1	0.21 g	IPCC (2006); Nguyen et al. (2011) – Tier 1
N_2O, manure management (indirect)	0.028 g	IPCC (2006); Nguyen et al. (2011) – Tier 1	0.017 g	IPCC (2006); Nguyen et al. (2011) – Tier 1
Electricity	0.148 kWh	Nguyen et al. (2011)	0.616 kWh	Zhou et al. (2018)
Heat/diesel	0.541 MJ	Nguyen et al. (2011)	0.001146 kg diesel	Zhou et al. (2018)
Water	12.75 L	Blonk Agri-footprint BV (2014)	12.75 L	Blonk Agri-footprint BV (2014)
Methane (CH_4), enteric fermentation	11.61 g	IPCC (2006) – Tier 1 (Developed)	11.74 g	IPCC (2006) – Tier 1 (Developing)

3.2.3 Pork product – Manure application

The manure collected during the rearing phases is spread on adjacent fields for crop production; the farm and pig rearing areas are co-located and this reduces the need for fertilizer on these fields. For the pig models in this paper, this manure application is assumed to take place on adjacent farms. A number of pig/pork LCAs, such as Nguyen et al. (2011), included the emissions from manure application as well as the avoided emissions from manure replacing fertilizer at farms. The calculation methodology to estimate the emissions from manure application used by Nguyen et al. (2011) was related to the Danish regulation requiring up to 75% of nitrogen fertilizer to come from manure. In this study, a slightly more conservative approach was taken where 75% of the nitrogen available (after direct and indirect emissions) in the manure replaced the equivalent synthetic nitrogen-based fertilizer and 97% of the available phosphorous in the manure replaced the equivalent synthetic phosphate-based fertilizer. This amount represents the "avoided" fertilizer and is calculated based on the amount of nitrogen remaining after direct and indirect emissions.

Emission and activity factors for the manure application stage for both the US and China scenarios are provided in Table 11.

Table 11 – Emission and activity factors for manure application US and China scenarios, on a per kg live weight basis

Emission/activity	US (per kg live weight pig)	China (per kg live weight pig)
Traction	0.157 MJ	0.157 MJ
Direct N_2O from application	0.053 g	0.032 g
NH_3	0.99 g	0.60 g
NO_2	0.0053 g	0.0032 g
Nitrates leached	0.45 g	0.62 g
Phosphates leached	0.0076 g	0.0046 g
Avoided traction	0.011 MJ	0.011 MJ
Avoided synthetic N fertilizer	3.97 g	2.41 g
Avoided synthetic P fertilizer	0.25 g	0.15 g
Avoided N_2O	0.040 g	0.024 g
Avoided NO_2	0.028 g	0.017 g
Avoided NH_3	0.26 g	0.16 g

3.2.4 Pork product – Pig slaughter

For pork production, the foreground process in the Agri-food database called "Pig meat, fresh, at slaughterhouse/NL Economic" (Blonk Agri-footprint BV, 2014) was modified to incorporate the above pig production processes and other region-specific inputs; to maintain consistency, all background processes were changed to those in ecoinvent v3.1. The amount of pig at the slaughterhouse that produced fresh meat (approximately 57%) was provided within the Agri-food process and was not modified due to little variation in this value throughout the literature.

As per Dettling, Tu, Faist, DelDuce, & Mandlebaum (2016) and Thoma et al. (2011), economic allocation was used to allocate the environmental indicators within this stage. Thoma et al. (2011) leveraged the US economic census data (US Census Bureau, 2020) for value of primary product shipments for NAICS codes related to meat processed from carcasses and rendering and meat by-product processing; this approach is replicated here. Data is provided in Table 12.

Table 12 – Economic census data for meat slaughtering activities in the US (US Census Bureau, 2020)

NAICS code	Sales, value of shipments (US$1,000)	Percentage of total
311612 – Meat processed from carcasses	52,154,653	92%
311613 – Rendering and meat by-product processing	4,303,469	8%

In 2017, the economic allocation assigns 92% of the environmental indicators to the meat processing and 8% to the rendering processes. While these activities include meats other than pork, in the absence of more specific US data, this is the best initial estimate. Due to a lack of available data for China, this economic allocation was applied for the Chinese scenarios as well; however, it is recognized that there may be regional and national variations of this allocation and this may affect, slightly, the results for the Chinese scenarios. No transportation was assumed between the slaughterhouse and the secondary processing.

3.2.5 Pork product – Pork product processing

At a secondary processing facility, the fresh meat is ground and processed into pork patties using the same data from the secondary processing stage for the IS. For this stage in the pork product life cycle, the data for energy, water, refrigerant and waste to season, form, cook, freeze and package the IS was used due to a lack of available data. This same approach was used by Dettling, Tu, Faist, DelDuce, & Mandlebaum (2016). It is assumed, as well, there is a loss of 5% by weight of the fresh meat from this stage. It is assumed here that the specific heating capacities of the IS and PS are equivalent.

It is noted that the pork scenarios PS1 and PS2 will mimic the processing for IS1 and IS2 (i.e., for IS1 and PS1, the product will not be cooked, and for IS2 and PS2, the product will be cooked).

3.2.6 Pork product – Packaging

The packaging that is used for the IS is used for the reference pork product packaging. See Table 44 for the packaging processes used.

3.2.7 Pork product – Transportation to retailer

For PS1 and PS2 going to US retailers, a fixed distance of 1,500 km of frozen truck travel was used to model the distribution to typical US retailers. For PS1 and PS2 going to Chinese retailers, a fixed distance of 1,500 km of frozen truck travel was also used.

It is noted that the in-scope life cycle stages stop at the gate of the distributor; they do not include any activity at the retailer as it is expected to be equivalent between the IS and PS patty scenarios.

3.3 Data quality

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 13 (Weidema, et al., 2013).

Table 13 – 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 14 (Weidema, et al., 2013).

Table 14 – Pedigree scoring quality criteria

Score	Technology	Time	Geography	Completeness	Reliability
1 - Very good	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
2 - Good	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
3 - Fair	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
4 - Poor	Data from processes and materials under	Data with less than 15 years of difference	Data from area with slightly	Data from only one site relevant for the market or some sites but from shorter periods	Qualified estimate

Score	Technology	Time	Geography	Completeness	Reliability
	study but from different enterprises		similar production conditions		
5 - Very poor	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

3.3.1 Impossible Foods scenarios

The processes contributing significantly (greater than 5%) to the IS1 and IS2 potential environmental impact (namely, in this case, four environmental indicators: global warming potential, aquatic eutrophication potential, land occupation and water depletion), as well as the stage in which they produce impact, are provided in Table 15.

Table 15 – Significant processes for the IS scenarios under the four key indicators

Indicator	Significant processes (contributing greater than 5% to the indicator)	Stage
Global warming	Truck transportation	Distribution of heme and freezer distribution to retailer
	Electricity use	Heme production
Aquatic eutrophication	Sunflower seed production	Ingredient production
	Electricity use	Primary and secondary processing
Land occupation	Sunflower seed production	Ingredient production
	Soybean production	Ingredient production
	Coconut production	Ingredient production
Water depletion	Coconut production	Ingredient production

The significantly contributing processes do not differ between the IS1 and IS2 scenarios, nor the US and China scenarios. Data quality for those processes is provided in Table 16.

Table 16 – Data quality commentary for the Impossible Foods significant processes

Significant process	Data sources	Data quality commentary	Efforts made to improve data quality
Transportation (truck) – transportation of the heme to the IS manufacturing facility and the patties between manufacturing and forming facilities as well as to retailers/grocery stores	**Activity data:** Road distances between relevant locations estimated by authors. **Environmental impact data:** Data from ecoinvent v3.1 database (Wernet, et al., 2016).	Data taken from European sources, which are not directly suitable to the US or China. Data is from between 2007 and 2013.	None required.
Electricity (heme)	**Activity data**: Amount of electricity used quantified from Impossible Foods manufacturers. Data for share of electricity generation overall embedded in electricity processes from ecoinvent v3.1 database (Wernet, et al., 2016). **Environmental impact data:** Data from ecoinvent v3.1 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.	Proportion of electricity generation sources in the grid was updated as per Appendix E for electricity grid factors.
Sunflower seed production – used to produce ingredients in the bulk IS	**Activity data:** Data provided by Impossible Foods manufacturer. **Environmental impact data:** Data from ecoinvent v3.1 database (Wernet, et al., 2016).	Sunflower seed yield updated to US yields as per USDA (2020). See Appendix C for more information.	US yields and fertilizer use as per USDA (2020). See Appendix C for more information.
Soybean production – used to produce ingredients in the bulk IS	**Activity data:** Data provided by Impossible Foods manufacturer. **Environmental impact data:** Data from ecoinvent v3.1 database (Wernet, et al., 2016).	Soybean yield updated to US yields and as per USDA (2020). See Appendix C for more information.	US yields and fertilizer use as per USDA (2020). See Appendix C for more information.
Coconut production – used as an ingredient in the production of the bulk IS	**Activity data:** Data provided by Impossible Foods manufacturer. **Environmental impact data:** Data from ecoinvent v3.1 database (Wernet, et al., 2016).	Coconut yield updated to 2015-2018 averaged data. Data for contributions is from 1995. See Appendix C for more information.	Coconut yield updated to 2015-2018 averaged data. See Appendix C for more information.

The evaluation of each data quality criterion for significant processes in the Impossible Foods scenarios, based on preceding comments, is provided in Table 17.

Table 17 – Evaluation of data quality criteria for the Impossible Foods scenarios

Process	Data	Tech.	Time	Geo.	Comp.	Rel.
Transportation (truck)	Activity data	1	1	3	3	3
	Environmental impact data	1	3	3	2	2
Electricity (heme)	Activity data	1	1	1	1	1
	Environmental impact data	1	3	1	2	2
Sunflower seed production	Activity data	1	1	1	1	1
	Environmental impact data	1	2	3	2	2
Soybean production	Activity data	1	1	1	1	1
	Environmental impact data	1	2	1	2	2
Coconut production	Activity data	1	1	1	1	1
	Environmental impact data	1	4	1	2	2

In general, data quality for all data is rated between poor and very good, with the majority of the processes rated good and very good and only eight out of the 50 indicators in Table 17 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 poor to very good, depending on the criteria, with the poor quality score related to the age of the data used in the Coconut {PH} production process in ecoinvent v3.1. The geographical correlations for the transportation process were rated fair for both activity and environmental impact data because they were based on an average transportation distance and data from Europe, not the US. A sensitivity analysis was completed with respect to the impact of changing transportation distances and showed no difference in the conclusion.

3.3.2 Pork scenarios

The processes contributing significantly (greater than 5%) to the PS1 and PS2 potential environmental impact (namely, in this case, four impact indicators: global warming, aquatic eutrophication, land occupation and water depletion) are provided in Table 18.

Table 18 – Significant processes for the pork scenarios under the four environmental indicators

Indicator	Significant processes (contributing greater than 5% to the indicator)	Stage
Global warming	Manure management	Pig production
	Corn production	Feed production
	Electricity (MRO)	Feed production
	Enteric fermentation	Pig production
Aquatic eutrophication	Corn production	Feed production
	Soybean production	Feed production
	Electricity (MRO)	Feed production
	Barley production (China scenario only)	Feed production
Land occupation	Corn production	Feed production
	Barley production (China scenario only)	Feed production
	Soybean production	Feed production
Water depletion	Corn production	Feed production
	Soybean production	Feed production
	Barley production (China scenario only)	Feed production

The significantly contributing processes do not differ between the PS1 and PS2 scenarios, nor the US and China sub-scenarios. Data quality for those processes (listed in order of contribution) is provided in Table 19.

Table 19 – Data quality commentary for the pork significant processes

Significant process	Data sources	Data quality commentary	Efforts made to improve data quality
Manure management	**Activity data:** For US data, Pelletier et al. (2010), and for Chinese data, Zhou et al. (2018). **Environmental impact data**: Both scenarios calculated using IPCC (2006) Tier 1 methodologies.	Tier 1 emission factors for methane manure management were used. Emission factors are greater than 10 years old and represent averaged and assumed data for large regions.	None required. Uncertainty is included in estimates and will be measured in uncertainty analysis.
Corn production – Used as part of the pig-rearing feed	**Activity data:** Proportion of corn in pig feed: for US data, Pelletier et al. (2010), and for Chinese data, Zhou et al. (2018). **Environmental impact data**: Data from ecoinvent v.3.1 database (Wernet, et al., 2016).	Data for corn production process was updated to reflect US and Chinese yields and fertilizer use as per USDA (2020) (2019) and Zhou et al. (2018), respectively. See Appendix C for more information.	Yields and fertilizer use updated; subject to sensitivity analysis later in this work.
Electricity (MRO or China)	**Activity data**: Amount of electricity used provided by Zhou et al. (2018) based on data from 2008-2010 for China or Nguyen et al. (2011) for US. Modifications made to electricity grid mix for China (IEA, 2020) to reflect 2017 generation data (see Appendix E) and MRO to reflect 2018 data. **Environmental impact data**: Data from ecoinvent v.3.1 database (Wernet, et al., 2016).	**Activity data:** Data is more than 10 years old for amount of electricity, but grid mix has been updated to best available data. Environmental impact data: Based on European data.	Proportion of electricity generation sources in the grid was updated using data from US EPA (2020) and IEA (2020). See Appendix E for electricity grid factors.
Enteric fermentation	**Activity data:** Both scenarios calculated using IPCC (2006) Tier 1 methodologies. **Environmental impact data:** Both scenarios calculated using IPCC (2006) Tier 1 methodologies.	Tier 1 emission factors for enteric fermentation used. Emission factors are greater than 10 years old and represent averaged and assumed data for large regions.	None required. Uncertainty is included in estimates and will be measured in uncertainty analysis.
Soybean production – Used as part of the pig-rearing feed	**Activity data:** Proportion of soy in pig feed: for US data, Pelletier et al. (2010), and for Chinese data, Zhou et al. (2018). **Environmental impact data:** Data from ecoinvent v3.1 database (Wernet, et al., 2016).	Data for soybean production process was updated to reflect US and Chinese yields and fertilizer use as per USDA (2020) and Zhou et al. (2018), respectively. See Appendix C and Appendix D for more information.	Yields and fertilizer use updated; subject to sensitivity analysis later in this work.
Barley production – Used as part of the pig-rearing feed in China only	**Activity data:** Proportion of barley in pig feed: for Chinese data, Zhou et al. (2018). **Environmental impact data:** Data from ecoinvent v3.1 database (Wernet, et al., 2016).	Data for barley production process was updated to reflect Chinese yields and fertilizer use as per Zhou et al. (2018). See Appendix C for more information.	Yields and fertilizer use updated; subject to sensitivity analysis later in this work.

The evaluation of each data quality criterion for significant processes in the pork scenarios, based on preceding comments, is provided in Table 20.

Table 20 – Evaluation of data quality criteria for the pork scenarios

Process	Data	Tech.	Time	Geo.	Comp.	Rel.
Manure management	Activity data	1	4	2	3	3
	Environmental impact data	1	3	2	3	3
Corn production	Activity data	1	1	1	1	1
	Environmental impact data	1	2	1	2	2
Electricity	Activity data	1	1	1	3	2
	Environmental impact data	1	3	1	2	2
Enteric fermentation	Activity data	1	4	2	3	3
	Environmental impact data	1	3	2	3	3
Soybean production	Activity data	1	1	1	1	1
	Environmental impact data	1	2	1	2	2
Barley production (China only)	Activity data	1	1	1	1	1
	Environmental impact data	1	2	1	2	2

Overall, data quality ranges from poor to very good, with the majority of the processes rated good and very good and 14 out of 60 indicators rated below good. Data quality for the activity data ranges from poor to very good, with the lower scores produced by the use of Tier 1 emission factors for manure management and enteric fermentation and the use of activity data that was used as a proxy from the literature. For manure management and enteric fermentation, the data quality for some of the criteria is poor because Tier 1 emission factors from IPCC (2006) were used. The uncertainty associated with the use of these emission factors from IPCC (2006) was used in the Monte Carlo simulation shown later in this paper and produced no difference in the conclusions. The completeness indicator for some of the pig production processes was rated as fair because of the use of activity data from specific sites, not a larger number of sites inclusive of the entire region under study, but limited data is available that permits this type of analysis. For environmental impact data, data quality ranged from fair to very good, with the fair scores related to either the Tier 1 emission factors from IPCC (2006) or data associated with background processes in ecoinvent v3.1 (electricity) that are dated and based on geographies that were wider than the specific areas under study.

In general, for both the IS and PS models, the data quality is comparable and consistent and on average between 1 and 2, which is sufficient for carrying out the LCA.

4. 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 v3.1 processes, no modifications to the allocations embedded were performed. For processes that were modified, existing allocations were maintained. For oils, such as sunflower seeds and coconuts, allocation was conducted on an economic basis:

- For sunflower oil, the contribution of the production of the oil is allocated to the environmental indicators on an economic basis: 80% to oil to 20% to sunflower seed meal; this data was taken from the Agri-footprint sunflower seed process (Blonk Agri-footprint BV, 2014) and entered into a new process that used all ecoinvent v3.1-based processes;
- For coconut oil, the contribution of the production of the oil is allocated to the environmental indicators on an economic basis: 92% to oil and 8% to copra meal; this data was taken from the Agri-footprint coconut oil process (Blonk Agri-footprint BV, 2014) and entered into a new process that used all ecoinvent v3.1-based processes.

At a pig farm, prior to slaughter, live pigs 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 pig or the manure and therefore system expansion must be used. The manure production replaces fertilizer on the market, which means that there is an avoided production of fertilizer and thereby a negative contribution to the potential environmental impact from the life cycle of the pig. In this study, manure that was produced in the pig production process was applied to the crop production processes, as the agricultural processes in ecoinvent v3.1 do not typically contain manure application. The reduced fertilizer requirements as a result were modelled using the manure application process as detailed in this work.

For the pig products in this study during slaughter, an economic allocation procedure was used because pork products have such widely different values in the market. In this study, the pig parts that are available for human consumption (i.e., those available for sausage-making) are allocated 92% of the impacts, whereas those available for other pig feed and other products are allocated 8%. Specific details related to this allocation calculation are provided in the relevant pig/pork production section.

5. Results

This section presents the study results, including the comparison of the environmental indicator results (with a focus on the four environmental indicators of concern) of the Impossible Foods scenarios and the pork equivalent scenarios. The contribution of the major stages of the life cycle of all scenarios to the environmental indicator results is also provided.

Life cycle inventory and impact assessment results are calculated using the SimaPro software (version 8.0.5).

It is noted that when discussing the comparison of two or more products, a significance threshold is often used when deciding which product is superior (or not) in terms of the indicator results, but is not well-defined or codified in the literature. It is used to evaluate the impact of uncertainties in the indicator results. Beltran et al. (2018) note that there are multiple ways to test comparative assertions, including the point-value results (like the results provided here) and overlap testing (evaluating the probability distributions of multiple simulations and evaluating the degree of overlap). While they provide a preferred method for quantifying whether a comparative assertion is valid using statistical analysis, the thresholds for evaluating that "environmental preferability" is still subjective. A precise threshold is not provided here because of the subjectivity; instead, the authors rely on the robust sensitivity analyses completed as a means to test sensitivity to the conclusions.

5.1 Comparative scenarios

The environmental indicator results associated with the production of the IS varieties are lower than those of the traditional pork equivalent for the four selected environmental indicators. For IS1 and PS1 in the US, the results are provided in Table 21, on a per kg of food delivered to the retailer basis (cf. functional unit).

Table 21 – All scenario indicator results, per kg of food (raw weight for IS1/PS1 and cooked weight for IS2/PS2)

Environmental indicators				
Scenario	Global warming (kg CO_2e)*	Aquatic eutrophication (g PO_4^{3-}eq P-lim)*	Land occupation (m^2 org. arable-y)*	Water depletion (m^3)**
IS1 – US	2.09	0.64	3.47	0.115
PS1 – US	7.31	1.48	5.92	0.549
Difference	71%	57%	41%	79%
IS2 – US	1.98	0.599	3.21	0.111
PS2 – US	7.32	1.48	5.92	0.549
Difference	73%	60%	46%	80%
IS1 – China	2.98	0.701	3.47	0.116
PS1 – China	7.13	1.47	11	0.675
Difference	58%	52%	68%	83%
IS2 – China	2.87	0.66	3.21	0.113
PS2 – China	7.14	1.47	11	0.675
Difference	60%	55%	71%	83%

*Global warming, aquatic eutrophication, and land occupation indicators were quantified using the IMPACT 2002+ method.
**Water depletion indicator was quantified using the ReCiPe Midpoint (H) method.

The global warming result for the IS is 58% to 73% lower than that of the pork scenarios because of the contributions from manure management and additional crop usage for the pork scenarios. The IS distributed to China has a higher global warming result than the IS sold in the US because of the transportation emissions required to deliver the patty to China. One effort to mitigate this difference would be to move production for the IS Chinese market to China; however, this may have implications for other indicators. It is noted that the IS2 has a slightly lower global warming result than IS1 even though IS2 is cooked; this is because of the slight difference in ingredients: IS1 has more methylcellulose and soy-based ingredients, which contributes more to the global warming result than the cooking stage.

The aquatic eutrophication result for the IS is 52% to 60% lower than that of the pork scenarios because of the contribution of the crop farming and manure application to the US and Chinese pork scenarios. The IS aquatic eutrophication result is primarily due to sunflower seed production for sunflower oil.

The land occupation result for the IS is 41% to 71% lower than that of the pork scenarios; the land occupation result for all scenarios is primarily due to crop production. The primary contributor for the IS is the use of sunflower oil, which has a lower crop yield relative to corn and soybeans. The difference between the IS and pork scenarios is due to the lower cropland requirements for the IS. The Chinese pork scenarios have higher land occupation results than the US pork scenarios because of the difference in the pig feed, primarily due to lower yields for both corn and soybeans in China (as shown in Appendix C). Thus, the Chinese scenarios require more land to produce the feed.

The water depletion result for the IS is 79% to 83% lower than the pork scenarios, primarily because of water withdrawal from feed and pig production. The use of coconut oil and sunflower oil in the IS contributes significantly to its water depletion result.

The comparative results are shown graphically in Figure 4. The highest values for each compared pair (i.e., for IS1 – US and PS1 – US) for each environmental indicator are set at 100%. Note that this does not permit the comparison of IS1 – US and IS2 – CN as a result.

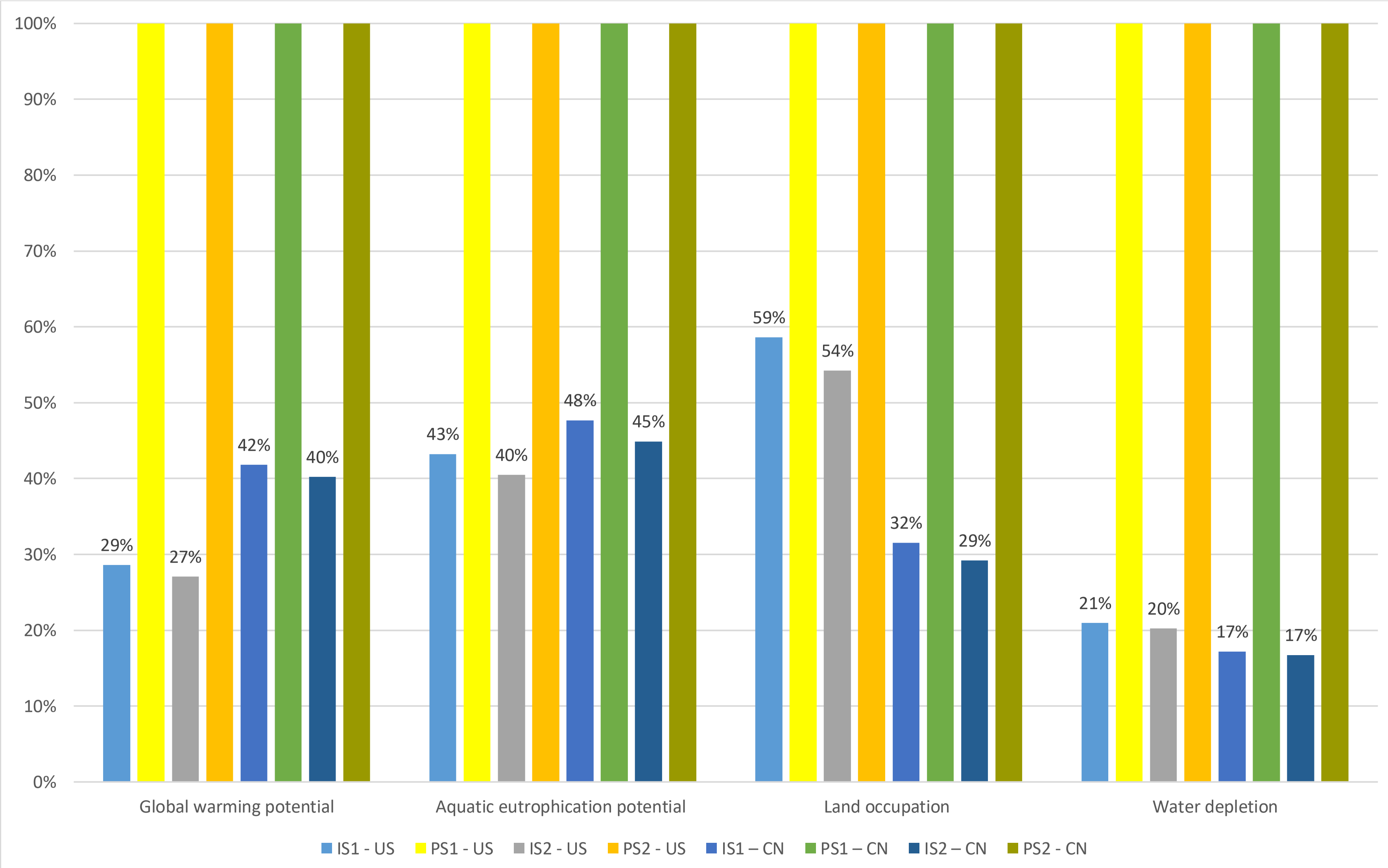

Figure 4 – Results of all IS and PS scenarios under the four environmental indicators of concern

5.1.1 Contribution analysis

Ingredient production contributes significantly to all selected environmental indicator results for the IS scenarios. Distribution to retailer, for the Chinese scenarios only, has a significant contribution to the global warming result primarily because of the need to distribute the US-manufactured product to China. For land occupation, ingredient production contributes to close to 100% of the result. Packaging has a negligible contribution for all selected environmental indicators. The contribution of each life cycle stage for each of the indicators for all four IS scenarios is presented below in Figure 5.

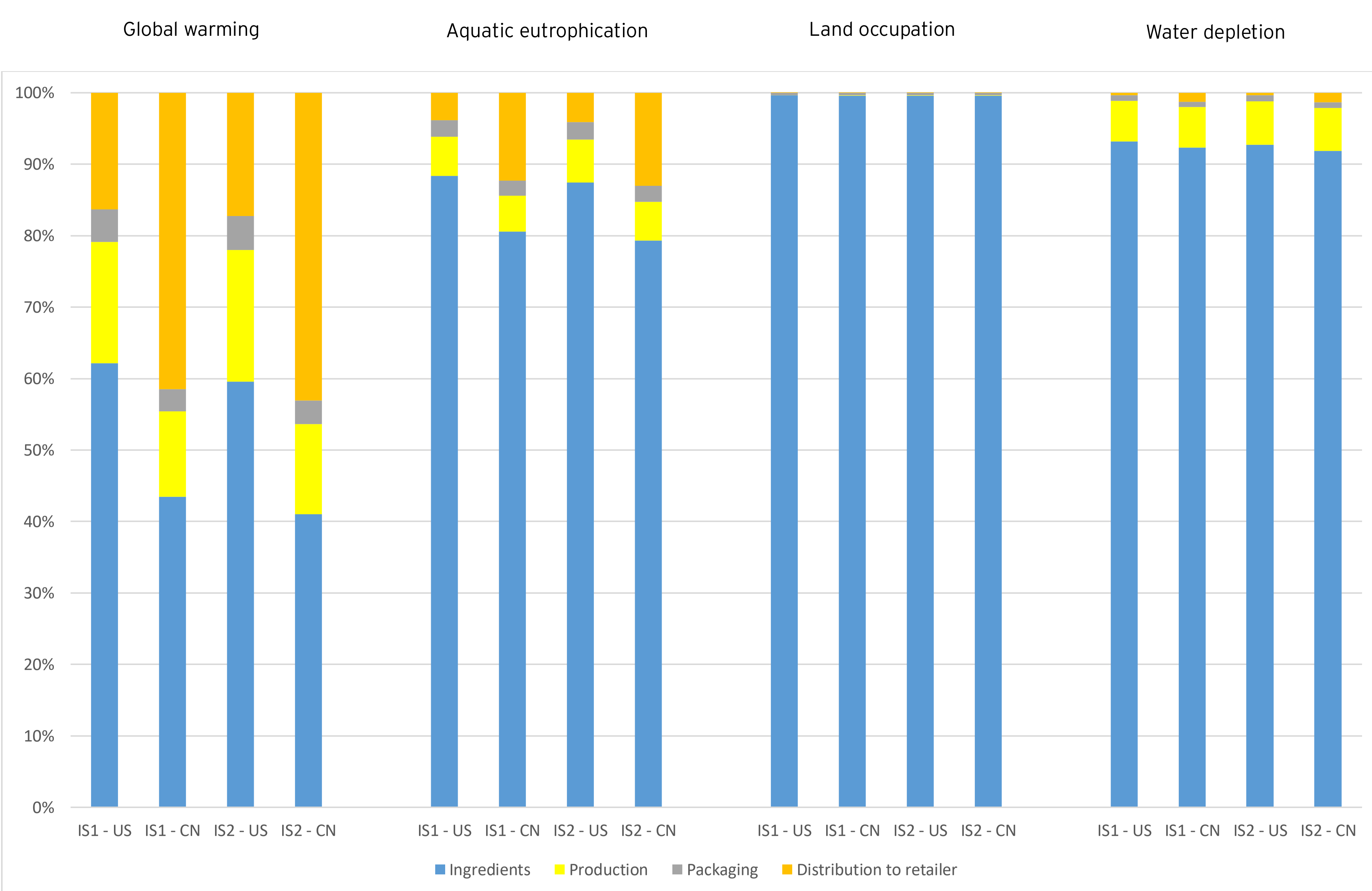

Figure 5 – Contribution analysis for all IS scenarios for the four environmental indicators (left to right: global warming; aquatic eutrophication; land occupation; water depletion)

5.1.2 Ingredient production – detailed analysis

As the ingredient production is the main contributor for each of the environmental indicators for IS, a more detailed analysis of the contribution of those ingredients to the indicator results is provided here. Those ingredients (and the processes associated with producing them) contributing more than 2% to the overall result for that particular indicator are shown below. Because the ingredient lists for IS1 and IS2 do not differ significantly, the results are only shown for IS1 – US.

Table 22 – IS1 processes/ingredients that contribute more than 2% to each indicator result

Global warming	Contribution	Aquatic eutrophication	Contribution	Land occupation	Contribution	Water depletion	Contribution
Sunflower oil	11.6%	Sunflower oil	44.8%	Sunflower oil	47.9%	Sunflower oil	67.7%*
Yeast extract proxy	8.1%	Yeast extract proxy	12.9%	Soybean protein	21.8%	Coconut oil	56.7%*
Soybean protein	8.0%	Soybean protein	10.4%	Coconut oil	19.6%		
Methylcellulose proxy	4.8%	Coconut oil	7.7%	Yeast extract proxy	7.3%		
Coconut oil	3.4%	Methylcellulose proxy	3.8%	Heme substrate	2.2%		

*Note, for water depletion, these amounts are the net freshwater consumption (that is, the freshwater taken from reservoirs minus freshwater returned to reservoirs) with the denominator being the water depletion indicator as given in Table 21 and are positive, so, on a netted basis, they contribute to water depletion. They add up to greater than 100% of the total water depletion indicator because of the wastewater treatment process in the IS production process, which has a net negative contribution to water depletion (the process returns more freshwater to reservoirs than it takes). Wastewater treatment reduces the water depletion indicator by -80%, whereas all other processes are net positive contributors.

It is evident that sunflower oil has the largest contribution for the four environmental indicators for IS1 – US. Soybean, coconut oil, yeast extract proxy and the methylcellulose proxy all have a significant contribution to the indicator results as well. Reducing the amount of sunflower oil in the IS may provide the biggest benefit in terms of improving the environmental performance with respect to the four environmental indicators above; however, the oil would have to be replaced with other ingredients and the net change in the environmental indicators would have to be evaluated further.

6. Uncertainty

Inventory uncertainty is assessed on a qualitative and quantitative basis. Three types of uncertainty are addressed: parameter uncertainty, scenario uncertainty and model uncertainty (Table 23). These are discussed in the next sections.

Table 23 – 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.

6.1 Parameter uncertainty

Parameter uncertainty for direct emissions data, activity data and emission factor data was discussed for significant processes based on the data quality indicators described in Section 3.3. In general, data quality was very good or good for main contributing processes, both for activity data and emission factors. However, in this section, sensitivity analyses will be performed using a Monte Carlo simulation function in SimaPro using embedded parameter uncertainty within the respective databases, the electricity grids used in IS production, as well as the share of crops used in the feed for the pig scenarios.

6.1.1 Uncertainty analysis

The uncertainty analysis considers the range of uncertainty in estimating the flows of material and energy in the systems and the uncertainty in the emissions. It excludes the uncertainty associated with the characterization factors used to transform the inventory results into impact indicator results, but the uncertainties associated with using the Tier 1 emission factors for enteric fermentation and manure management from IPCC (2006) were included manually. An uncertainty analysis using Monte Carlo simulation in SimaPro was conducted for the IS1 and PS1 scenarios for the US and the IS2 and PS2 scenarios for China to test for changes in the directionality of the results and not to understand changes in relative performance. This simulation uses embedded uncertainties within the ecoinvent and Agri-footprint databases and generated uncertainties for new data sets based on the Pedigree matrix uncertainty embedded in SimaPro and shown in Table 14. The outcome presented here is a comparison of the IS against the pork scenarios to determine the frequency of runs where the environmental indicator results for the IS were lower than those for the pork scenario. The results are shown in Table 24.

Table 24 – Results of Monte Carlo simulation for the four selected environmental indicators and two scenario comparisons

Scenario	% of 500 runs where the potential environmental indicator result of IS was lower than PS			
	Global warming	Aquatic eutrophication	Land occupation	Water depletion
IS1 and PS1 – US	100%	100%	100%	100%
IS2 and PS2 – China	100%	100%	100%	100%

Both IS scenarios always had lower results for the four selected environmental indicators than the equivalent pork scenarios.

6.1.2 Pig feed component sensitivity

The feed components for the US and Chinese scenarios were used because they represent typical pig production operations in those countries. While there are limited studies on Chinese pig production, those that exist for US pig production include pig feed components similar to those used in this study. For example, in Thoma et al. (2011) and Kebreab et al. (2016), the corn and soybean meal proportions are 75% and 20%, respectively (with the remainder being vitamins, proteins, etc.), similar to those used in this study, with small variations depending on the stage of the feed. It is reasonable, though, to expect some additional primary ingredients in other parts of the US.

In the absence of clear data, a number of different feed proportion scenarios were tested to examine the sensitivity of the environmental indicators to pig feed components and share. Table 265 presents the different feed components for each sensitivity analysis in this category; each is labelled on the first row that corresponds to the results in Table 26.

Table 25 – Different scenarios for sensitivity analysis with respect to pig feed components

Feed type	PS2 – US – Baseline	PS2 – US – 1 (more soybean)	PS2 – US – 2 (more corn)	PS2 – US – 3 (use China feed)	PS2 – CN – Baseline	PS2 – CN – 1 (more soybean)	PS2 – CN – 2 (more corn)	PS2 – CN – 3 (more barley)	PS2 – CN – 4 (use US feed)
Corn	75%	65%	85%	65%	65%	60%	75%	60%	75%
Soybean (meal)	25%	35%	15%	20%	20%	30%	15%	15%	25%
Barley	0%	0%	0%	15%	15%	10%	10%	25%	0%

For simplicity, only the results for PS2 – US and PS2 – CN are calculated. The environmental indicator results for the different feed proportions/components are provided in Table 26.

Table 26 – Environmental indicator results with respect to different pig feed components

Environmental indicator	PS2 – US – Baseline	PS2 – US – 1	PS2 – US – 2	PS2 – US – 3	PS2 – CN – Baseline	PS2 – CN – 1	PS2 – CN – 2	PS2 – CN – 3	PS2 – CN – 4
Global warming (kg CO_2e)	7.32	7.28 (-1%)	7.35 (0%)	7.08 (-3%)	7.14	7.06 (-1%)	7.09 (-1%)	7.26 (2%)	6.97 (-2%)
Aquatic eutrophication (g PO_4^{3-}eq P-lim)	1.48	1.40 (-5%)	1.57 (6%)	1.30 (-12%)	1.47	1.39 (-5%)	1.55 (5%)	1.46 (-1%)	1.51 (3%)
Land occupation (m^2 org. arable-y)	5.92	6.63 (12%)	5.21 (-12%)	4.94 (-16%)	11.0	12.1 (10%)	10.2 (-7%)	10.8 (-2%)	11.1 (1%)
Water depletion (m^3)	0.549	0.483 (-12%)	0.614 (12%)	0.478 (-13%)	0.675	0.601 (-11%)	0.710 (5%)	0.715 (6%)	0.634 (-6%)

There are significant differences in the environmental indicator results when feed proportions are modified, but none that change the conclusions of this study. When additional soybean is added to the US feed, the land occupation result increases because of the lower yield of soybean in the US compared to corn; water depletion decreases because of the lower irrigation needs compared to corn. When additional corn is added to the US feed, the land occupation result decreases because of the higher yield and water depletion increases because of the higher irrigation needs. The addition of barley to the US feed, displacing the two other constituents, reduces the global warming and aquatic eutrophication results, because of the lower on-farm energy and fertilizer requirements, and the land occupation result, because of the higher yield of barley compared to soybeans.

Similar results are seen for the Chinese scenarios. When soybean is added to the Chinese feed, the land occupation result increases the most because of the low yield of soybeans compared to the rest of the constituents. The rest of the changes to the environmental indicator results are not significant and do not change the conclusions of this study.

6.1.3 Manufacturing in China

One of the largest contributors to the environmental indicator results, especially global warming, for the IS1 and IS2 – China scenarios was the transportation from the US to China. As a point of interest, the environmental indicator results were quantified when the location of production of the IS was moved to China. This means that heme, sunflower oil and soybean concentrate, electricity, water, etc. are produced in China (except coconut oil, which is still transported from the Philippines). All transport distances were kept consistent: 1,500 km distance for transportation of IS bulk ingredients and heme within China and 1,500 km freezer truck transport of products to retailers. For the sake of simplicity, only the IS2 scenario was quantified.

The environmental indicator results for this modified IS2 scenario where the product is manufactured in China are compared against the IS2 – US and IS2 – CN scenarios presented previously in Table 27.

Table 27 – Environmental indicator results for IS2 – US, IS2 – CN and IS2 when manufacturing in China

Environmental indicator	IS2 – US (previously reported in Table 21)	IS2 – CN (previously reported in Table 21)	IS2 – manufactured in CN
Global warming (kg CO_2e)	1.98	2.87	2.2
Aquatic eutrophication (g PO_4^{3-}eq P-lim)	0.599	0.660	0.566
Land occupation (m^2 org. arable-y)	3.21	3.21	3.14
Water depletion (m^3)	0.111	0.113	0.140

It is noted that the largest difference in the environmental indicator results when production of IS is moved to China is for the global warming and aquatic eutrophication indicators. Compared to sending the IS to China from the US, manufacturing the IS in China reduces the global warming result by 23% and the aquatic eutrophication result by 14%. These reductions are due to eliminating the need for refrigerated truck and freighter transport between the US and China. However, the water depletion increases 24% due to higher water use for crops grown in China (changes to land occupation are less than 1%).

While these results do not change the overall conclusions of this study, it does provide a potential opportunity for Impossible Foods to improve the environmental performance of their products in China for two of the four indicators considered.

6.1.4 Distribution distances

All ingredients were assumed to travel 1,500 km, and the distribution of the final product was also assumed to be 1,500 km from production to retailer; this was based on the width of the US that was discussed previously. To test the sensitivity of this study's conclusions to this factor, a number of different distances for ingredient travel and final product travel were examined. Only IS2 – US is examined here. It was assumed all other scenarios would change in a similar fashion because the 1,500 km assumption was used in all scenarios.

The environmental indicators for the IS2 scenarios for when the ingredient distribution distance is varied from 1,500 km and the retailer distribution distance is maintained at 1,500 km are shown in Table 28.

Table 28 – Environmental indicator results when distance for ingredient transport is varied

Environmental indicator	IS2 – US Ingredient distance (ID) = 500 km	IS2 – US ID = 1,000 km	IS2 – US ID = 1,500 km (baseline)	IS2 – US ID = 2,000 km	IS2 – US ID = 2,500 km	IS2 – US ID = 10,000 km
Global warming (kg CO_2e)	1.92	1.95	1.98	2.01	2.04	2.46
Aquatic eutrophication (g PO_4^{3-}eq P-lim)	0.595	0.597	0.599	0.601	0.603	0.633
Land occupation (m^2 org. arable-y)	3.21	3.21	3.21	3.21	3.21	3.21
Water depletion (m^3)	0.111	0.111	0.111	0.111	0.111	0.111

The global warming result changes approximately 1.5% from the baseline for each 500 km change in the ingredient transport distance; all other environmental indicator results do not change. This variable does not have the potential to change the conclusions of this study.

The environmental indicators for the IS2 scenarios for when the retailer distribution distance is varied from 1,500 km and the ingredient transport distance is maintained at 1,500 km are shown in Table 28.

Table 29 – Environmental indicators when distance for distribution to wholesale distributor, retailer and/or restaurant is varied

Environmental indicator	IS2 – US Retailer distance (RD) = 500 km	IS2 – US RD = 1,000 km	IS2 – US RD = 1,500 km (baseline)	IS2 – US RD = 2,000 km	IS2 – US RD = 2,500 km	IS2 – US RD = 10,000 km
Global warming (kg CO_2e)	1.75	1.86	1.98	2.09	2.21	3.92
Aquatic eutrophication (g PO_4^{3-}eq P-lim)	0.583	0.591	0.599	0.607	0.615	0.736
Land occupation (m^2 org. arable-y)	3.21	3.21	3.21	3.21	3.21	3.21
Water depletion (m^3)	0.111	0.111	0.111	0.111	0.111	0.111

The global warming result changes approximately 5.6% from the baseline for each 500 km change in the retailer distribution distance; all other environmental indicator results do not change. This variable does not have the potential to change the conclusions of this study.

6.2 Scenario uncertainty

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 environmental indicators of the pig slaughterhouse activities, may be of interest.

6.2.1 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 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 sensitivity analysis leverages the caloric and protein data provided in Table 7 containing the nutritional information for IS1, PS1, IS2 and PS2, left to right. Table 30 shows the environmental indicator results for all scenarios using a functional unit of 1,000 calories. It is noted that the biggest difference in caloric content due to cooking is for pork; when the pork product is cooked (PS2), its per mass calories increased by 36% compared to PS1, whereas for the IS products, the calories per 100 g decreased negligibly.

Table 30 – Environmental indicator results per 1,000 calories of food

Scenario	Global warming (kg CO_2e)	Aquatic eutrophication (g PO_4^{3}-eq P-lim)	Land occupation (m^2 org. arable-y)	Water depletion (m^3)
IS1 – US	0.88	0.27	1.46	0.05
PS1 – US	2.54	0.51	2.06	0.19
Difference	65%	47%	29%	75%
IS2 – US	0.86	0.26	1.39	0.05
PS2 – US	1.87	0.38	1.51	0.14
Difference	54%	31%	8%	66%
IS1 – China	1.26	0.30	1.46	0.05
PS1 – China	2.48	0.51	3.82	0.23
Difference	49%	42%	62%	79%
IS2 – China	1.24	0.29	1.39	0.05
PS2 – China	1.82	0.38	2.81	0.17
Difference	32%	24%	50%	72%

This difference in caloric content between the products results in a decrease in the difference between the indicator results for the IS2 and PS2 scenarios compared to when just the mass of food is used as the functional unit (as shown in Table 21). This difference is lowest for the land occupation indicator, where the difference between IS2 and PS2 – US is 8%. Regardless, the results show that when caloric content is used as the functional unit, there is no difference to the conclusion that modeled environmental indicators are lower for the IS scenarios than for the pork scenarios. The smaller difference in land occupation between IS2 and PS2 when using a caloric functional unit make the conclusions slightly less certain, although the significant differences found when using both mass (Table 21) and protein (Table 31) for functional units show that the land occupation is generally lower for the IS.

Table 31 shows the environmental indicator results for all scenarios using a functional unit of 1 g of protein. It is noted that after cooking, the protein content of the IS increased by approximately 6%, while the protein content, on a per mass basis, in the pork patty decreased by approximately 13% (USDA, 2019; USDA, 2019).

Table 31 – Environmental indicator results per 1 g of protein in food

Scenario	Global warming (kg CO_2e)	Aquatic eutrophication (g PO_4^{3}-eq P-lim)	Land occupation (m^2 org. arable-y)	Water depletion (m^3)
IS1 – US	0.017	0.005	0.028	0.001
PS1 – US	0.047	0.010	0.038	0.004
Difference	65%	47%	28%	74%
IS2 – US	0.015	0.005	0.024	0.001
PS2 – US	0.054	0.011	0.044	0.004
Difference	73%	59%	45%	80%
IS1 – China	0.024	0.006	0.028	0.001
PS1 – China	0.046	0.010	0.071	0.004
Difference	49%	42%	61%	79%
IS2 – China	0.022	0.005	0.024	0.001

Scenario	Global warming (kg CO_2e)	Aquatic eutrophication (g PO_4^{3}-eq P-lim)	Land occupation (m^2 org. arable-y)	Water depletion (m^3)
PS2 – China	0.053	0.011	0.082	0.005
Difference	59%	55%	70%	83%

Because the decrease in protein content after cooking for the pork patty is relatively small, the differences between IS and PS scenarios in the environmental indicators are still high. The results show that when protein content is used as the functional unit, there is no difference in the conclusion that all environmental indicator results are lower for the IS scenarios than for the pork scenarios.

6.2.2 Mass allocation

Testing the sensitivity of the environmental indicators 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 pork meat available for grinding into sausage: using mass allocation, 57% of the impacts are allocated to the grindable sausage and using economic allocation, 92% of the impacts are allocated to the grindable sausage. Table 32 shows the environmental indicator results when PS1 - US and PS1 – CN using mass allocation are compared against the IS1 – US and IS1 – CN results.

Table 32 – Environmental indicator results for PS1 – US and PS1 – CN using mass allocation compared against there IS-counterparts

Scenario	Global warming (kg CO_2e)	Aquatic eutrophication (g PO_4^{3}-eq P-lim)	Land occupation (m^2 org. arable-y)	Water depletion (m^3)
IS1 – US	2.09	0.640	3.47	0.115
PS1 – US (mass allocation)	4.76	0.941	3.67	0.342
Difference	56%	32%	5%	66%
IS1 – China	2.98	0.701	3.47	0.116
PS1 – China (mass allocation)	4.66	0.932	6.84	0.420
Difference	36%	25%	49%	72%

Using mass allocation reduces the difference between the environmental indicator results of the pork scenarios and the IS scenarios compared to the results shown in Table 21 because the grindable meat in the pork scenarios is allocated less of the impacts than prior. However, for most of the environmental indicators, the difference is still significantly high. The difference is lowest for the land occupation indicator, where the difference between IS1 and PS1 – US is 5%. While the smaller difference in land occupation between IS1 and PS1 when using mass allocation makes the conclusions slightly less certain, the application of mass allocation in this case is not appropriate as the economic value of the products is quite different, necessitating the need for economic allocation.

It is noted that because most of the contributors to the environmental indicator results are prior to processing (upstream of retail distribution), changing the allocation factor for the fresh meat co-product (versus the other co-products) results in an equivalent change in the environmental indicator results, such that a 10% reduction in the fresh meat allocation factor leads to an approximately 10% reduction of each of the indicator results.

6.3 Model uncertainty

IMPACT 2002+ v.2.12 was used to quantify three of the environmental indicators considered in this study, with ReCiPe Midpoint (H) v1.12 used to quantify the water depletion indicator. To examine the differences in environmental indicator results using a different LCIA method, all scenarios were run using the ReCiPe Midpoint (H) method. In this analysis, global warming (indicator in IMPACT 2002+) and climate change (indicator in ReCiPe Midpoint), land occupation (indicator in IMPACT 2002+) and agricultural land occupation (indicator in ReCiPe Midpoint), and aquatic eutrophication (indicator in IMPACT 2002+) and freshwater eutrophication (indicator in ReCiPe Midpoint) are proposed to be similar. Note that although IMPACT 2002+ traditionally uses 500-year GWPs, these have been changed to 100-year GWPs for all results in this work and thus that will not be a methodological difference between IMPACT 2002+ and ReCiPe (which uses 100-year GWPs). The results for the three environmental indicators for all scenarios run using ReCiPe Midpoint (H) are shown in Figure 6.

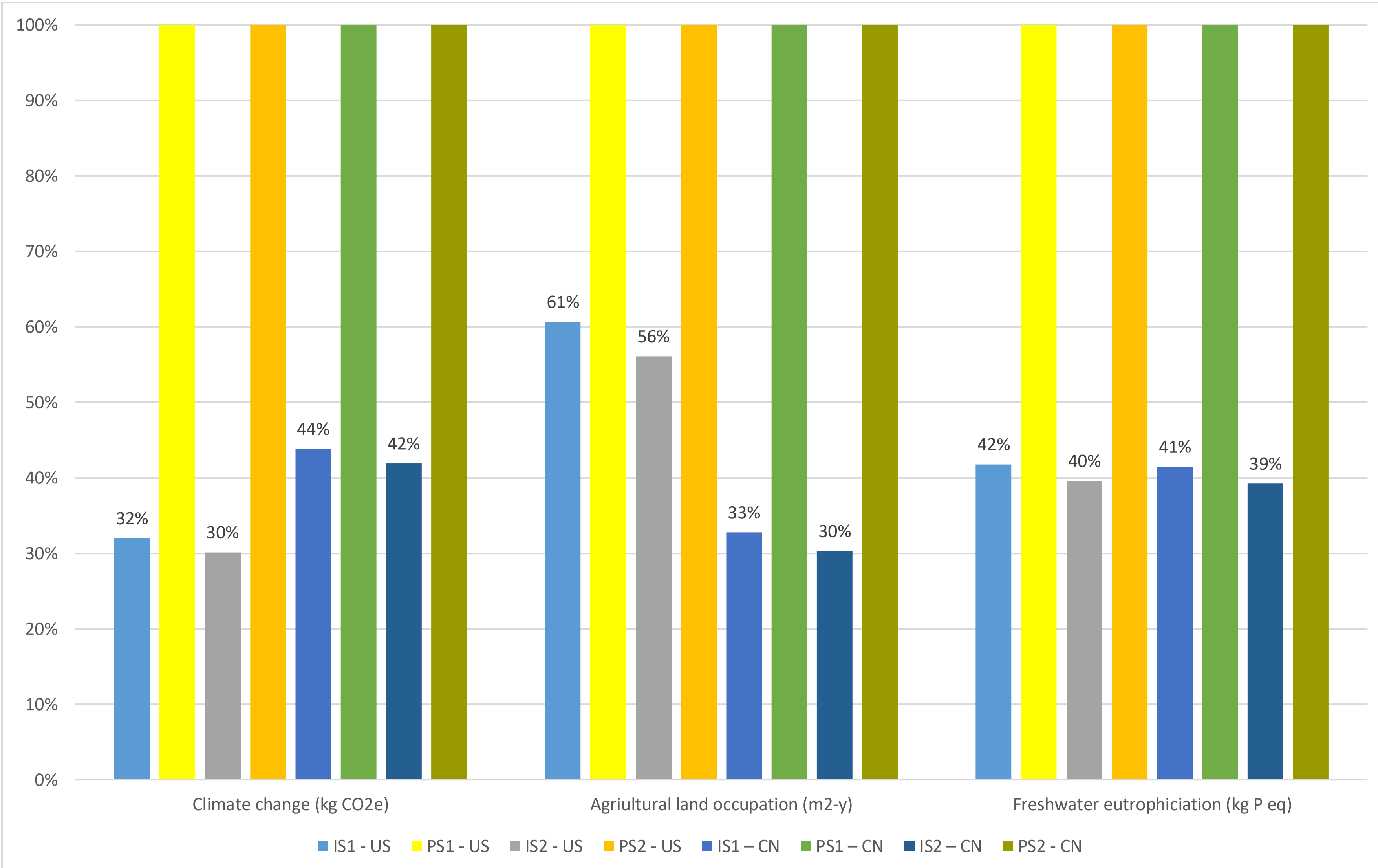

Figure 6 – Environmental indicators quantified using ReCiPe Midpoint (H) Method

There are no differences between the IMPACT 2002+ method and ReCiPe Midpoint method conclusions for the environmental indicators shown above, indicating that these conclusions are not sensitive to the specific LCIA method used.

7. LCA applications and limitations

The evidence presented in this report 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 Foodscompares the production of two varieties of the IS against a traditional pork sausage produced in the US and China. 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.

This LCA can be used to provide the results for the four selected environmental indicators for the two IS varieties studied in this work, as well as the primary contributors to those results. It also facilitates the identification of areas within the production process and ingredient list where improvements can be made as to those environmental indicators.

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 meat-based equivalents:

- The pig production feed used in this study is based on specific farming operations in specific regions of the US and China. As well, it is recognized that activity factors for on-farm operations, such as water intensity, energy use, and type and quantity of feed, are not the same across different parts of both the US and China; however, due to simplicity, this heterogeneity was not considered. While those farming operations are intended to be best representatives of pig farming feed in those regions, they cannot be considered representative of average production for those countries. It is noted that the use of the IPCC (2006) emission factors for manure management and enteric fermentation are meant to be representative of the respective regions. Regardless, there is insufficient public data to develop country-wide LCAs for pig production for comparison to Impossible Foods products and that was not the focus of this LCA. The results in this work are consistent with previous pig/pork production LCA values for the four environmental indicators of focus.
- The use of database processes for some agricultural processes, specifically global processes where China-specific processes did not exist, may modify the results, but these are not expected to significantly change the conclusion of the results given that updated data for yield and fertilizer use was used where available.
- 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.
- There were a number of assumptions made related to the distances travelled with respect to ingredients and final products, namely the 1,500 km assumption within the US and China; it is recognized that this is an estimate and the specific actual distances may vary, but a sensitivity analysis with higher and lower distances showed that it did not change the conclusions of this study.

- Only four environmental indicators 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 environmental indicators available to evaluate the overall environmental performance of the studied products.
- Different LCIA methods were used to calculate the environmental indicator results because they were not all available in a single one; a sensitivity analysis was conducted using the same method for all environmental indicators 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.

8. Conclusion

This LCA compares the IS, a PBMA produced in the US, with a traditional pork sausage patty produced in both the US and China. 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 the study is to compare the environmental profile made up of four environmental indicators, namely global warming, aquatic eutrophication, land occupation and water depletion, associated with the IS varieties against their functionally equivalent PS patty and understand the extent to which the results for those particular environmental indicators for the IS varieties are lower than for their pork equivalents.

The following are the key findings from this work, focused on the assessments made here over both IS varieties and their functional pork equivalents:

- 1 kg of IS shows a global warming result between 4.2 kg CO_2e and 5.3 kg CO_2e (58% and 73%) lower than 1 kg of PS patty, with the higher result for the IS when it is distributed in China.
- 1 kg of IS shows an aquatic eutrophication result between 0.77 g PO_4^{3-}eq and 0.88 g PO_4^{3-}eq (52% and 60%) less than 1 kg of PS patty, as it avoids some crop fertilizer and manure application emissions present in pig production.
- 1 kg of IS shows a land occupation result between 2.45 m^2·org. arable·year and 7.79 m^2·org. arable·year (41% to 71%) less than 1 kg of PS patty. The largest contribution for the IS is the production of sunflower oil, which has a much lower yield than other crops in the ingredients.
- 1 kg of IS shows a water depletion result between 0.44 m^3 and 0.56 m^3 (79% to 83%) less than 1 kg of PS patty. This is due to the much lower demand for agricultural irrigation for the IS ingredients than for the pig feed ingredients and high water withdrawal (and low water returned) for the pig production and slaughterhouse stages.

For the IS and PS products, the production of raw inputs (i.e., ingredients) is generally the main contributor to the environmental indicator results. For IS, the ingredients contribute close to half of the global warming result, but distribution also contributes significantly (between 41% and 43%) to the IS1 – China and IS2 – China scenarios because of the long distribution distance from the US to China. The ingredients (and their associated background processes) contribute more than 90% to the other three environmental indicator results.

In considering the results of this study, it should again be noted that while the nutritional content, an important feature of food and objective behind the consumption of food, has not been directly considered, a sensitivity analysis showed that had a caloric or protein-based functional unit been used, the conclusions would not have changed, although the land occupation indicator was especially sensitive to the caloric functional unit. The intention here is to portray an environmental comparison for the four environmental indicators 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 environmental indicators of concern discussed in this study, to using IS varieties studied in this work instead of pork products.

9. Critical review

A critical review was performed by a third-party 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 33.

Table 33 – Members of the critical review panel

Member	Title and organization	Role	Competencies
Jean-François Ménard	Senior analyst, CIRAIG	Head of the review panel	Experience in LCA and carbon footprint (performed several studies in various sectors and participated to the carbon footprint pilot project in Québec).
Dr. Benjamin Goldstein	Postdoctoral Fellow at the School for Environment and Sustainability at the University of Michigan. He will be starting as an Assistant Professor at McGill University in January 2021.	Member of the review panel	Academic and professional experience in LCA and carbon footprint (performed several studies in food, energy, municipalities, and recycling sectors).
Dr. Rylie Pelton	CEO and President, LEIF LLC; Research Scientist, University of Minnesota, Institute on the Environment	Member of the review panel	Academic and professional experience in identifying production, consumption and infrastructure transition strategies that improve global sustainability through applications of life cycle assessment and developing decision support tools for organizations and institutions to integrate sustainability metrics into decision/policy-making processes.

The critical review was performed according to the guidelines in the ISO-14044 standards (ISO, 2006). The steps of the critical review process are described in Table 34. The Critical Review Report completed by CIRAIG is included after this report. The comments from the Critical Review panel are included subsequent to the report.

Table 34 – Critical review process

Step	Description	Outcome
Goal and scope report review	Review of the goal and scope report by a member of the CIRAIG	First review note sent by the CIRAIG and update of the goal and scope report by EY
Final report review	Review of the final report by all members of the critical review panel	Second review note sent by the CIRAIG and update of the final report by EY
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 EY	Critical review report sent by the CIRAIG to be attached to the final report

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Appendix A – IS ingredients

Table 35 – Heme ingredients and production

Table removed to protect proprietary data. This data was available to the Critical Review Panel during their review.

Table 36 – IS1 ingredients and bulk production

<table>
<tr><th>Output</th><th>SimaPro input</th><th>Units</th><th>Comments</th></tr>
<tr><td>IS1 – Bulk</td><td>IS1 – Bulk</td><td>kg</td><td></td></tr>
<tr><td>Waste from ingredient production</td><td>Municipal solid waste {RoW}| treatment of, sanitary landfill | Alloc Def, U</td><td>kg</td><td>5% waste assumed to landfill</td></tr>
<tr><td>Wastewater from cleaning water</td><td>Wastewater, unpolluted {GLO}| market for | Alloc Def, U</td><td>L</td><td>Proxy for wastewater sent to municipal system</td></tr>
<tr><th>Ingredient/input</th><th>SimaPro input</th><th>Units</th><th>Comments</th></tr>
<tr><td>Water</td><td>Tap water {CA-QC}| market for | Alloc Def, U</td><td>kg</td><td>Proxy for Chicago, IL, water</td></tr>
<tr><td>Heme</td><td>Heme</td><td>kg</td><td>See Table 35</td></tr>
<tr><td>Coconut oil</td><td>Coconut oil</td><td>kg</td><td>See Table 38</td></tr>
<tr><td>50% NaOH</td><td>Sodium hydroxide, without water, in 50% solution state {CA-QC}| chlor-alkali electrolysis, membrane cell | Alloc Def, U</td><td>kg</td><td></td></tr>
<tr><td>Yeast extract</td><td>Fodder yeast {RoW}| ethanol production from whey | Alloc Rec, U</td><td>kg</td><td>Proxy used</td></tr>
<tr><td>Texturized vegetable protein</td><td>Soybean protein concentrate, from crushing (solvent, for protein concentrate), at plant (Agri-footprint); Agri-footprint process modified</td><td>kg</td><td>Proxy used; see Table 41</td></tr>
<tr><td>Methylcellulose</td><td>Carboxymethyl cellulose, powder {RoW}| production | Alloc Def, U</td><td>kg</td><td>Proxy used</td></tr>
<tr><td>Food starch</td><td>Potato starch {RoW}| production | Alloc Def, U</td><td>kg</td><td>Proxy used</td></tr>
<tr><td>High oleic sunflower oil</td><td>Refined sunflower oil, from crushing (solvent) – Agri-footprint process modified</td><td>kg</td><td>Adapted Agri-footprint process to use ecoinvent v3.1 processes; see Table 40.</td></tr>
<tr><td>Vitamin C</td><td>Citric acid {RNA}| production | Alloc Def, U</td><td>kg</td><td></td></tr>
<tr><td>Cultured dextrose</td><td>Sugar, from sugarcane {RoW}| cane sugar production with ethanol by-product | Alloc Def, U</td><td>kg</td><td>Proxy used</td></tr>
<tr><td>(Preservative</td><td>Sodium nitrate {RoW}| production | Alloc Rec, U</td><td>kg</td><td>Proxy used</td></tr>
<tr><td>Transportation of all ingredients</td><td>Transport, freight, lorry 7.5-16 metric ton, EURO3 {GLO}| market for | Alloc Def, U</td><td>t·km</td><td>Transportation of products, except coconut oil and water to Chicago, IL (assumed to be 1,500 km)</td></tr>
<tr><td>Carbon dioxide</td><td>Carbon dioxide, liquid {RoW}| market for | Alloc Def, U</td><td>kg</td><td></td></tr>
<tr><td>Water</td><td>Tap water {RoW}| market for | Alloc Def, U</td><td>kg</td><td>Includes process, cleaning and clean-in-place (CIP) water</td></tr>
</table>

Ammonia for refrigeration	Ammonia, liquid {RoW}| market for | Alloc Def, U	kg	Assumption based on 8 kg charge per ton of refrigeration and 10% annual leakage
Processing energy	Electricity, medium voltage {Illinois}| market for | Alloc Def, U - updated	kWh	Includes motors, pumps, bands and refrigerators; see Appendix E for grid share using electricity-specific ecoinvent v3.1 processes
Freezer transport	Freezer transport	t·km	Transportation from processing facility to forming facility Estimated distance of 100 km; see Table 47

Amount removed for proprietary reasons. This data was available to the Critical Review Panel during their review.

Table 37 – IS2 ingredients and bulk production

Output	SimaPro input	Units	Comments
IS2 – Bulk	IS2 – Bulk	kg	
Waste from ingredient production	Municipal solid waste {RoW}| treatment of, sanitary landfill | Alloc Def, U	kg	5% waste assumed to landfill
Wastewater from cleaning water	Wastewater, unpolluted {GLO}| market for | Alloc Def, U	L	Proxy for wastewater sent to municipal system
Ingredient/input	**SimaPro input**	**Units**	**Comments**
Water	Tap water {CA-QC}| market for | Alloc Def, U	kg	
Coconut oil	New process: Coconut oil - PH to US below	kg	See Table 38
Heme	Heme	kg	See Table 35
50% NaOH	Sodium hydroxide, without water, in 50% solution state {CA-QC}| chlor-alkali electrolysis, membrane cell | Alloc Def, U	kg	
Yeast extract	Fodder yeast {RoW}| ethanol production from whey | Alloc Rec, U	kg	Proxy used, no Alloc Def available
Texturized vegetable protein	Soybean protein concentrate, from crushing (solvent, for protein concentrate), at plant (Agri-footprint); Agri-footprint process modified	kg	Proxy used; see Table 41
Methylcellulose	Carboxymethyl cellulose, powder {RoW}| production | Alloc Def, U	kg	Proxy used
Food starch	Potato starch {RoW}| production | Alloc Def, U	kg	Proxy used
High oleic sunflower oil	Refined sunflower oil, from crushing (solvent) – Agri-footprint process modified	kg	Adapted Agri-footprint process to use ecoinvent v3.1 processes; see Table 40.
Vitamin C	Citric acid {RNA}| production | Alloc Def, U	kg	

<table>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Cultured dextrose</td><td>Sugar, from sugarcane {RoW}| cane sugar production with ethanol by-product | Alloc Def, U</td><td>kg</td><td>Proxy used</td></tr>
<tr><td>Preservative</td><td>Sodium nitrate {RoW}| production | Alloc Def, U</td><td>kg</td><td>Proxy used</td></tr>
<tr><td>Transportation of all ingredients</td><td>Transport, freight, lorry 7.5-16 metric ton, EURO3 {GLO}| market for | Alloc Def, U</td><td>t·km</td><td>Transportation of products, except coconut oil and water to Chicago, IL (assumed to be 1,500 km)</td></tr>
<tr><td>Carbon dioxide</td><td>Carbon dioxide, liquid {RoW}| market for | Alloc Def, U</td><td>kg</td><td></td></tr>
<tr><td>Water</td><td>Tap water {RoW}| market for | Alloc Def, U</td><td>kg</td><td>Includes process, cleaning and CIP water</td></tr>
<tr><td>Ammonia</td><td>Ammonia, liquid {RoW}| market for | Alloc Def, U</td><td>kg</td><td>Assumption based on 8 kg charge per ton of refrigeration and 10% annual leakage</td></tr>
<tr><td>Processing energy</td><td>Electricity, medium voltage {Illinois}| market for | Alloc Def, U - updated</td><td>kWh</td><td>Includes motors, pumps, bands and refrigerators; see Appendix E for grid share using electricity-specific ecoinvent v3.1 processes</td></tr>
<tr><td>Freezer transport</td><td>Freezer transport</td><td>t·km</td><td>Transportation from processing facility to forming facility
Estimated distance of 100 km</td></tr>
</table>

Amount removed for proprietary reasons. This data was available to the Critical Review Panel during their review.

Table 38 – Coconut oil, including transport

Output	SimaPro input	Amount	Units	Comments
Coconut oil	Coconut oil (for IS1 and IS2 ingredients)	1	kg	
Ingredient/input	**SimaPro input**	**Amount**	**Units**	**Comments**
Coconut oil	Coconut oil, crude {PH}| production | Alloc Def, U - Mod	1	kg	
Transportation of coconut oil from the Philippines to the US	Transport, freight, sea, transoceanic tanker {GLO}| market for | Alloc Def, U	23.1963	t·km	Distance from Los Angeles to Manila
Transportation of coconut oil from the Philippines to the US	Transport, freight, lorry 7.5-16 metric ton, EURO3 {GLO}| market for | Alloc Def, U	0.2	t·km	200 km truck distance within the Philippines

Table 39 – Crude sunflower oil; modified process

Output	SimaPro 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 40); allocation=80%
	Sunflower seed meal, from crushing (solvent), at plant/AR Economic – Agri-footprint process modified	350	kg	Allocation=20%
Ingredient/input	**SimaPro input**	**Amount**	**Units**	**Comments**
Hexane	Hexane {GLO}| market for | Alloc Def, U	1	kg	
Sunflower seed production	Sunflower seed {ROW}| sunflower production | Alloc Def, U – modified	1	ton	Modified only as per Table 62
Transport from sunflower seed to sunflower oil processor	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}| market for | Alloc Def, U	0.2	t-km	Transport from sunflower seed to sunflower oil processor
Water	Tap water {RoW}| market for | Alloc Def, U	0.248	ton	
Electricity	Electricity, medium voltage {Comed}| market for | Alloc Def, U - updated	27	MJ	
Steam	Steam, in chemical industry {GLO}| market for | Alloc Def, U	500	kg	

Table 40 – Refined sunflower oil; modified process

Output	SimaPro input	Amount	Units	Comments
Refined sunflower oil	Refined sunflower oil, from crushing (solvent) – Agri-footprint process modified	1,000	kg	Allocation = 98.75%
	Soap stock (sunflower solvent crushing) – Agri-footprint process modified	37.95	kg	Allocation = 1.25%
Ingredient/input	**SimaPro 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 39
Activated charcoal for removal of impurities	Activated bentonite {GLO}| market for | Alloc Def, U	8.08	kg	
Diesel for refining	Diesel, burned in building machine {GLO}| market for | Alloc Def, U	342.45	MJ	
Electricity	Electricity, medium voltage {Comed}| market for | Alloc Def, U - Mod	54.8	kWh	
Steam	Steam, in chemical industry {GLO}| market for | Alloc Def, U	731.5	kg	

Table 41 – Soybean protein concentrate; modified process

Output	SimaPro input	Amount	Units	Comments
Soybean protein	Soybean protein concentrate {US} - proxy for Soybean protein	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 {GLO}| market for | Alloc Def, U	164	m^3	
Ingredient/input	**SimaPro input**	**Amount**	**Units**	**Comments**
Ethanol for cleaning	Ethanol, without water, in 99.7% solution state, from fermentation {GLO}| market for | Alloc Def, U	128	kg	
Diesel for heat	Diesel, burned in building machine {GLO}| market for | Alloc Def, U	410	MJ	
Hexane for refining	Hexane {GLO}| market for | Alloc Def, U	0.8	kg	
Soybean input	Soybean {US}| production | Alloc Def, U – updated	1	ton	As per Table 62
Electricity	Electricity, medium voltage {Comed}| market for | Alloc Def, U - Mod	1,080	MJ	
Steam	Steam, in chemical industry {GLO}| market for | Alloc Def, U	720	kg	

Table 42 – Forming – IS1 – US and CN

Output	SimaPro input	Amount	Units	Comments
Patty	Formed patties (IS1)	0.95	kg	
Food waste	Municipal solid waste {RoW}| treatment of, sanitary landfill | Alloc Def, U	0.05	kg	5% waste assumed to landfill
Wastewater from cleaning water	Wastewater, unpolluted {GLO}| market for | Alloc Def, U	0.83	L	Proxy for wastewater sent to municipal system
Ingredient/input	**SimaPro input**	**Amount**	**Units**	**Comments**
Bulk product	IS1 bulk product	1	kg	
Carbon dioxide	Carbon dioxide, liquid {RoW}| market for | Alloc Def, U	0.2501	kg	
Water	Tap water {RoW}| market for | Alloc Def, U	0.365	kg	
Ammonia	Ammonia, liquid {RoW}| market for | Alloc Def, U	0.0043	kg	Assumption based on 8 kg charge per ton of refrigeration and 10% annual leakage
Processing energy	Electricity, medium voltage {Illinois}| market for | Alloc Def, U - updated	0.03724	kWh	

Table 43 – Cooking and forming – IS2 – US and CN

Output	SimaPro input	Amount	Units	Comments
Product	Formed IS patties (IS2)	0.95	kg	
Food waste	Municipal solid waste {RoW}| treatment of, sanitary landfill | Alloc Def, U	0.05	kg	5% waste assumed to landfill
Wastewater from cleaning water	Wastewater, unpolluted {GLO}| market for | Alloc Def, U	0.25	L	
Ingredient/input	**SimaPro input**	**Amount**	**Units**	**Comments**
Bulk product	IS2 bulk product	1	kg	
Carbon dioxide	Carbon dioxide, liquid {RoW}| market for | Alloc Def, U	0.2501	kg	CO_2 injected during processing
Water	Tap water {RoW}| market for | Alloc Def, U	0.365	kg	
Ammonia	Ammonia, liquid {RoW}| market for | Alloc Def, U	0.0043	kg	Based on 8 kg charge of ammonia per ton of refrigeration and 10% annual leakage
Processing energy	Electricity, medium voltage {Illinois}| market for | Alloc Def, U - updated	0.037589	kWh	
Transportation	Transport, freight, lorry 7.5-16 metric ton, EURO3 {GLO}| market for | Alloc Def, U	0.1	t·km	
Energy for cooking	Heat, central or small-scale, natural gas {RoW}| market for heat, central or small-scale, natural gas | Alloc Def, U	0.106	MJ	

Table 44 – Packaging process – all

Output	SimaPro input	Amount	Units	Comments
Packaging	Packaging for 1 kg of patties	1	pc	
Ingredient/input	**SimaPro input**	**Amount**	**Units**	**Comments**
Packaging – Plastic film	Packaging film, low density polyethylene {GLO}| market for | Alloc Def, U	0.0181	kg	Per kg product basis
Packaging – Cardboard box	Corrugated board box {GLO}| market for corrugated board box | Alloc Def, U	0.0486	kg	Per kg product basis

Table 45 – IS1 – US and IS2 – US distribution

Output	SimaPro input	Amount	Units	Comments
Freezer transport	Patties delivered to retailer	1	kg	
Ingredient/input	**SimaPro input**	**Amount**	**Units**	**Comments**
Product	Formed IS patties (IS1 or IS2)	1	kg	
Transportation from processing facility to retailer	Freezer transport	1.5	tkm	Assume 1,500 km

Table 46 – Distribution of IS1 – CN and IS2 – CN to China and retailer

Output	SimaPro input	Amount	Units	Comments
Freezer transport	Patties delivered to retailer	1	kg	
Ingredient/input	**SimaPro input**	**Amount**	**Units**	**Comments**
Product	Formed IS patties (IS1 or IS2)	1	kg	
Transportation	Freezer truck transportation	1.5	t·km	Road transport within China (1,500 km for 1 kg); see Table 47
Transportation	Freezer freight transportation	10.751	t·km	Distance from Los Angeles to Shanghai (10,751 km for 1 kg); see Table 48
Transportation	Freezer truck transportation	3.242	t·km	Distance from Chicago, IL, to Los Angeles (3,242 km for 1 kg); see Table 47

Table 47 – Freezer truck transportation

Output	SimaPro 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 {GLO}| market for | Alloc Def, U	-3.52E-6	kg	Removed additional emissions from these because only energy increases 27%
	Brake wear emissions, lorry {GLO}| market for | Alloc Def, U	-3.03E-6	kg	
	Tyre wear emissions, lorry {GLO}| market for | Alloc Def, U	-3.49E-5	kg	

Ingredient/input	SimaPro input	Amount	Units	Comments
R-134a	Refrigerant R134a {GLO} | market for | Alloc Def, U	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 {GLO}| market for | Alloc Def, U	1.27	tkm	Freezer transport requires 27% more energy than non-refrigerated, as per Tassou et al. (2009)
Emissions to air	**SimaPro 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. IMPACT 2002+ currently uses GWP = 400; adjusted to 1300, as per IPCC (2014).

Table 48 – Freezer freighter transportation

Output	SimaPro input	Amount	Units	Comments
Freezer transport	Freezer transport	1	tkm	
Ingredient/input	**SimaPro input**	**Amount**	**Units**	**Comments**
R-134a	Refrigerant R134a {GLO} | market for | Alloc Def, U	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 {GLO}| market for | Alloc Def, U	1.27	t·km	Freezer transport requires 27% more energy than non-refrigerated, as per Tassou et al. (2009)
Emissions to air	**SimaPro 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. IMPACT 2002+ currently uses GWP = 400; adjusted to 1300, as per IPCC (2014).

Appendix B – Pig/pork processes

Table 49 – Feed production – PS1 and PS2 – US

Output	SimaPro input	Amount	Units	Comments
Pig feed - US	Pig feed - US	1	kg	
Ingredient/input	**SimaPro input**	**Amount**	**Units**	**Comments**
Corn	Maize grain {US}| production | Alloc Def, U - updated	0.75	kg	See Table 62 and Table 63 for updates
Soybean	Soybean meal {US}| soybean meal and crude oil production | Alloc Def, U - updated	0.25	kg	See Table 62 and Table 63 for updates
Electricity	Electricity, medium voltage {MRO, US only}| market for | Alloc Def, U - updated	0.293	kWh	See Table 64 for updates
Manure (from application)	Application of manure - US	0.410	pc	See Table 51; 0.410 pc because 2.44 kg feed/kg live weight
Drying heat	Heat, central or small-scale, natural gas {RoW}| market for heat, central or small-scale, natural gas | Alloc Def, U	0.126	MJ	
Transport	Transport, freight, lorry 7.5-16 metric ton, EURO3 {GLO}| market for | Alloc Def, U	0.20	km	Assume 200 km distance

Table 50 – Pig production – PS1 and PS2 – US

Output	SimaPro input	Amount	Units	Comments
Live pig	Live pig ready for slaughter (US)	1	kg	
Manure	Manure for application – US	0.410	pc	See Table 51; 0.410 pc because 2.44 kg feed/kg live weight
Emissions to air from manure management	See Table 10			
Emissions to air from manure enteric fermentation	See Table 10			
Ingredient/input	**SimaPro input**	**Amount**	**Units**	**Comments**
Pig feed	Pig feed – US	2.44	kg	Amt. from Pelletier (2010); see Table 49
Water	Tap water {RoW}| market for | Alloc Def, U	12.75	kg	
Pig production energy	Electricity, medium voltage {MRO, US only}| market for | Alloc Def, U - updated	0.148	kWh	
Pig production energy	Heat, central or small-scale, natural gas {RoW}| market for heat, central or small-scale, natural gas | Alloc Def, U	0.541	MJ	

Table 51 – Manure application – PS1 and PS2 – US

Output	SimaPro input	Amount	Units	Comments
Manure application	Manure for application - US	1	pc	On a per kg live weight basis
Emissions to air	See Table 11			
Ingredient/input	SimaPro input	Amount	Units	Comments
Energy	See Table 11			

Table 52 – Slaughterhouse – US

Output	SimaPro input	Amount	Units	Comments
Pig meat, fresh	Pig meat, fresh, at slaughterhouse	0.57	kg	Foreground process from Agri-footprint adapted to include only ecoinvent v3.1 processes; economic allocation of 92% used
Co-product	Pig co-product, food grade, at slaughterhouse	0.103	kg	Foreground process from Agri-footprint adapted to include only ecoinvent v3.1 processes; economic allocation of 8% used
Co-product	Pig co-product, feed grade, at slaughterhouse	0.28	kg	Foreground process from Agri-footprint adapted to include only ecoinvent v3.1 processes; economic allocation of 0% used
Co-product	Pig co-product, other, at slaughterhouse	0.0473	kg	Foreground process from Agri-footprint adapted to include only ecoinvent v3.1 processes; economic allocation of 0% used
Ingredient/input	SimaPro input	Amount	Units	Comments
Live pig	Live pig ready for slaughter (US)	1	kg	See Table 56
Water	Tap water {RoW}| market for | Alloc Def, U	2.47	kg	
Process energy	Electricity, medium voltage {MRO, US only}| market for | Alloc Def, U - updated	0.383	MJ	See Table 64 for updates
Process energy	Heat, district or industrial, other than natural gas {RoW}| heat production, at coal coke industrial furnace 1-10MW | Alloc Def, U	0.24	MJ	

Table 53 – Forming – PS1 – US only

Output	SimaPro input	Amount	Units	Comments
Patty	Pork sausage patty (PS1)	0.95	kg	
Food waste	Municipal solid waste {RoW}| treatment of, sanitary landfill | Alloc Def, U	0.05	kg	5% waste assumed to landfill
Ingredient/input	SimaPro input	Amount	Units	Comments
Meat	Pig meat, fresh, at slaughterhouse	1	kg	

Carbon dioxide	Carbon dioxide, liquid {RoW}| market for | Alloc Def, U	0.2501	kg	
Water	Tap water {RoW}| market for | Alloc Def, U	0.365	kg	
Ammonia	Ammonia, liquid {RoW}| market for | Alloc Def, U	0.0043	kg	Assumption based on 8 kg charge per ton of refrigeration and 10% annual leakage
Processing energy	Electricity, medium voltage {MRO, US only}| market for | Alloc Def, U - updated	0.03724	kWh	See Table 64 for updates

Table 54 – Cooking and forming – PS2 – US

Output	SimaPro input	Amount	Units	Comments
Product	Pork sausage patty (PS2)	0.95	kg	
Waste	Municipal solid waste {RoW}| treatment of, sanitary landfill | Alloc Def, U	0.05	kg	5% waste assumed to landfill
Ingredient/input	**SimaPro input**	**Amount**	**Units**	**Comments**
Meat	Pig meat, fresh, at slaughterhouse	1	kg	
Carbon dioxide	Carbon dioxide, liquid {RoW}| market for | Alloc Def, U	0.2501	kg	CO_2 injected during processing
Water	Tap water {RoW}| market for | Alloc Def, U	0.365	kg	
Ammonia	Ammonia, liquid {RoW}| market for | Alloc Def, U	0.0043	kg	Assumption based on 8 kg charge of ammonia per ton of refrigeration and 10% annual leakage
Processing energy	Electricity, medium voltage {MRO, only}| market for | Alloc Def, U - MOD	0.037589	kWh	
Transportation	Transport, freight, lorry 7.5-16 metric ton, EURO3 {GLO}| market for | Alloc Def, U	0.1	t·km	Assume 100 km distribution from slaughterhouse to cooking/forming location
Energy for cooking	Heat, central or small-scale, natural gas {RoW}| market for heat, central or small-scale, natural gas | Alloc Def, U	0.106	MJ	

Table 55 – Feed production – CN

Output	SimaPro input	Amount	Units	Comments
Pig feed - CN	Pig feed - CN	1	kg	
Ingredient/input	**SimaPro input**	**Amount**	**Units**	**Comments**
Manure (application)	Manure for application - CN	0.373	pc	See Table 58; 0.373 pc to align with 2.68 kg feed/kg live weight
Corn	Maize grain {ROW}| production | Alloc Def, U - updated	0.65	kg	See Table 62 and Table 63 for updates
Soybean	Soybean meal {ROW}| soybean meal and crude oil production | Alloc Def, U - updated	0.20	kg	See Table 62 and Table 63 for updates
Barley	Barley grain {ROW}| barley production | Alloc Def, U - updated	0.15	kg	See Table 62 and Table 63 for updates
Electricity	Electricity, medium voltage {CN}| market for | Alloc Def, U - updated	0.293	kWh	See Table 64 for updates

Drying heat	Heat, central or small-scale, natural gas {RoW}| market for heat, central or small-scale, natural gas | Alloc Def, U	0.126	MJ	
Transport	Transport, freight, lorry 7.5-16 metric ton, EURO3 {GLO}| market for | Alloc Def, U	0.314	km	Distances from Zhou et al. (2018)

Table 56 – Pig production – CN

Output	SimaPro input	Amount	Units	Comments
Live pig	Live pig ready for slaughter (CN)	1	kg	
Manure production	Manure for application - CN	0.373	pc	See Table 58; 0.373 pc to align with 2.68 kg feed/kg live weight
Emissions to air from manure management	See Table 10			
Emissions to air from manure enteric fermentation	See Table 10			
Ingredient/input	**SimaPro input**	**Amount**	**Units**	**Comments**
Feed	Pig feed – CN	2.68	kg	Amount from Zhou et al. (2018); See Table 55
Water	Tap water {RoW}| market for | Alloc Def, U	12.75	kg	
Pig production energy	Electricity, medium voltage {CN}| market for | Alloc Def, U - updated	0.616	kWh	
Pig production energy	Heat, district or industrial, other than natural gas {ROW}| market for | Alloc Def, U	0.0012	MJ	From diesel

Table 57 – Slaughterhouse – CN

Output	SimaPro input	Amount	Units	Comments
Fresh meat	Pig meat, fresh, at slaughterhouse	0.57	kg	Foreground process from Agri-footprint adapted to include only ecoinvent v3.1 processes; economic allocation of 92% used
Co-product	Pig co-product, food grade, at slaughterhouse	0.103	kg	Foreground process from Agri-footprint adapted to include only ecoinvent v3.1 processes; economic allocation of 8% used
Co-product	Pig co-product, feed grade, at slaughterhouse	0.28	kg	Foreground process from Agri-footprint adapted to include only ecoinvent v3.1 processes; economic allocation of 0% used

Co-product	Pig co-product, other, at slaughterhouse	0.0473	kg	Foreground process from Agri-footprint adapted to include only ecoinvent v3.1 processes; economic allocation of 0% used
Ingredient/input	SimaPro input	Amount	Units	Comments
Live pig	Live pig ready for slaughter (CN)	1	kg	See Table 56
Water	Tap water {RoW}| market for | Alloc Def, U	2.47	kg	
Process energy	Electricity, medium voltage {CN}| market for | Alloc Def, U - updated	0.383	MJ	See Table 64 for updates
Process energy	Heat, district or industrial, other than natural gas {RoW}| heat production, at coal coke industrial furnace 1-10MW | Alloc Def, U	0.24	MJ	

Table 58 – Manure application – CN

Output	SimaPro input	Amount	Units	Comments
Manure	Manure emissions from application	1	pc	On a per kg live meat basis
Emissions to air	See Table 11			
Ingredient/input	SimaPro input	Amount	Units	Comments
Energy	See Table 11			

Table 59 – Forming – PS1 – CN

Output	SimaPro input	Amount	Units	Comments
Patty	Pork sausage patty (PS1)	0.95	kg	
Food waste	Municipal solid waste {RoW}| treatment of, sanitary landfill | Alloc Def, U	0.05	kg	5% waste assumed to landfill
Ingredient/input	SimaPro input	Amount	Units	Comments
Meat	Pig meat, fresh, at slaughterhouse	1	kg	
Carbon dioxide	Carbon dioxide, liquid {RoW}| market for | Alloc Def, U	0.2501	kg	
Water	Tap water {RoW}| market for | Alloc Def, U	0.365	kg	
Ammonia	Ammonia, liquid {RoW}| market for | Alloc Def, U	0.0043	kg	Assumption based on 8 kg charge per ton of refrigeration and 10% annual leakage
Processing energy	Electricity, medium voltage {CN}| market for | Alloc Def, U - updated	0.03724	kWh	See Table 64 for updates

Table 60 – Cooking and forming – PS2 – CN

Output	SimaPro input	Amount	Units	Comments
Product	Pork sausage patty (PS2 – CN)	1	kg	
Waste	Municipal solid waste {RoW}| treatment of, sanitary landfill | Alloc Def, U	0.05	kg	5% waste assumed to landfill
Ingredient/input	SimaPro input	Amount	Units	Comments

Pork	Pig meat, fresh, at slaughterhouse (CN)	1	kg	
Carbon dioxide	Carbon dioxide, liquid {RoW}| market for | Alloc Def, U	0.2501	kg	CO_2 injected during processing
Water	Tap water {RoW}| market for | Alloc Def, U	0.365	kg	
Ammonia	Ammonia, liquid {RoW}| market for | Alloc Def, U	0.0043	kg	Based on 8 kg charge of ammonia per ton of refrigeration and 10% annual leakage
Processing energy	Electricity, medium voltage {CN}| market for | Alloc Def, U - MOD	0.037589	kWh	
Transportation	Transport, freight, lorry 7.5-16 metric ton, EURO3 {GLO}| market for | Alloc Def, U	0.1	t·km	Assume 100 km distribution to cooking/forming
Energy for cooking	Heat, central or small-scale, natural gas {RoW}| market for heat, central or small-scale, natural gas | Alloc Def, U	0.106	MJ	

Table 61 – PS1 and PS2 – US and CN distribution

Output	SimaPro input	Amount	Units	Comments
Freezer transport	Patties delivered to retailer	1	kg	
Ingredient/input	SimaPro input	Amount	Units	Comments
Product	Formed pork patties (PS1 or PS2)	1	kg	
Transportation from processing facility to retailer	Freezer transport	1.5	t·km	Assume 1,500 km

Appendix C – Land use data based on crop yield

The crop yields from specific crops used in the IS and pig feed were updated to reflect more recent and local conditions, where available. Below is a listing of the crop, the modeled origin, the modelled process in which the crop is used, the occupation variable that was changed, the representative years for the crop yields, the average yield of those years for a particular year, and the data source. The average yield for a time period of one year was used as the "occupation" input in the processes to be modelled.

Table 62 – Crop yields modified from background processes in this LCA

<table>
<tr><th>Crop</th><th>Origin</th><th>Process</th><th>Variable modified in process</th><th>Representative years</th><th>Land occupation (per kg crop over representative years)</th><th>Reference</th></tr>
<tr><td rowspan="2">Sunflower seed</td><td>US (South Dakota)</td><td>Sunflower seed {ROW} | sunflower production | Alloc Def, U</td><td>Occupation, arable, non-irrigated, intensive</td><td>2017 Census</td><td>5.21 $m^2 \cdot a$</td><td>USDA (2020)</td></tr>
<tr><td>China (for sensitivity analysis)</td><td>Sunflower seed {ROW} | sunflower production | Alloc Def, U</td><td>Occupation, arable, non-irrigated, intensive</td><td>2015 to 2019 (inclusive)</td><td>3.66 $m^2 \cdot a$</td><td>FAO (2019)</td></tr>
<tr><td>Coconut</td><td>Philippines</td><td>Coconut, husked {PH} | production | Alloc Def, U</td><td>Occupation, arable, irrigated, intensive</td><td>2015 to 2019 (inclusive)</td><td>2.47 $m^2 \cdot a$</td><td>FAO (2019)</td></tr>
<tr><td rowspan="2">Corn</td><td>US (Iowa)</td><td>Maize grain {US} | production | Alloc Def, U</td><td>Occupation, arable</td><td>2017 Census</td><td>0.93 $m^2 \cdot a$</td><td>USDA (2020)</td></tr>
<tr><td>China</td><td>Maize grain {ROW} | production | Alloc Def, U</td><td>Occupation, arable</td><td>2015 to 2019 (inclusive)</td><td>1.67 $m^2 \cdot a$</td><td>FAO (2019)</td></tr>
<tr><td rowspan="2">Soy</td><td>US (Iowa)</td><td>Soybean {US} | production | Alloc Def, U</td><td>Occupation, arable, irrigated</td><td>2017 Census</td><td>3.34 $m^2 \cdot a$</td><td>USDA (2020)</td></tr>
<tr><td>China</td><td>Soybean {ROW} | production | Alloc Def, U</td><td>Occupation, arable, non-irrigated, intensive</td><td>2015 to 2019 (inclusive)</td><td>5.58 $m^2 \cdot a$</td><td>FAO (2019)</td></tr>
<tr><td rowspan="2">Barley</td><td>China</td><td>Barley grain {ROW} | production | Alloc Def, U</td><td>Occupation, arable, non-irrigated, intensive</td><td>2015 to 2019 (inclusive)</td><td>2.47 $m^2 \cdot a$</td><td>FAO (2019)</td></tr>
<tr><td>US (for sensitivity analysis)</td><td>Barley grain {US} | production | Alloc Def, U</td><td>Occupation, arable, non-irrigated, intensive</td><td>2015 to 2019 (inclusive)</td><td>1.93 $m^2 \cdot a$</td><td>FAO (2019)</td></tr>
</table>

Appendix D – Fertilizer use data

The amount of fertilizer used for specific crops used in the pig feed was updated to reflect more recent and local conditions, where available. Below is a listing of the crop, the modelled process in which the crop is used, the origin of the crop, the representative years for the fertilizer use the type of fertilizer and amount used per kg of crop (this was calculated from the reference provided and then multiplied by the yield in Table 62), and the data source. For coconuts in the Philippines and sunflowers in South Dakota, no modifications to the fertilizer use were made because no recent data was available.

Table 63 – Fertilizer use modified from background processes in this LCA

Crop	Origin	Representative years	N-fertilizer (kg/kg crop)	P-fertilizer (kg/kg crop)	K-fertilizer (kg/kg crop)	Reference
Corn	US (Iowa)	2014 to 2018 (last year available for data, inclusive)	0.015	0.007	0.009	USDA (2019)
	China	2010	0.035	0.0004	0.0005	Zhou et al. (2018)
Soy	US (Iowa)	2014 to 2018 (last year available for data, inclusive)	0.006	0.021	0.034	USDA (2019)
	China	2010	0.029	0.002	0.003	Zhou et al. (2018)
Barley	China	2010	0.066	0.0006	0.0001	Zhou et al. (2018)

Appendix E – Electricity grid share

Electricity is required by both the IS, pig production and pork production processes. It is also used in a lesser extent in other stages of the life cycle of the products. The production mix or grid mix (i.e. the relative contribution of electricity production modes to the total generation in each region) is given in Table 64 for the regions used in this study. The grid mix is used to modify existing ecoinvent v3.1 electricity processes to include the appropriate share of electricity generation in 2019 (note the previously existing per-electricity.

Table 64 – Grid mix for regions and countries in the various scenarios in 2018 or 2019, where data is available

Countries and regions	Process modified	Coal	Oil	Gas	Nuclear	Hydro	Wind	Solar	Geothermal	References
Illinois (2018 data)	Electricity, high voltage {RFC} | market for | Alloc Def, U; labelled as electricity, high voltage {Comed} | market for | Alloc Def, U	32%	0%	27%	36%	0%	3%	0%	0%	Comed (2019)
Iowa (2019 data)	Electricity, high voltage {MRO, US only} | market for | Alloc Def, U	36%	0%	13%	8%	0%	43%	0%	0%	EIA (2020)
China (2018 data)	Electricity, high voltage {CN} | market for | Alloc Def, U	71%	0%	0%	4%	19%	5%	2%	0%	IEA (2020)

*Numbers may not add up to 100% due to rounding

CIRAIG[MC/TM]

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 LIFE CYCLE ASSESSMENT OF IMPOSSIBLE® SAUSAGE COMPLIANT WITH ISO 14040-44 STANDARDS

AUGUST 2020

and Sustainability

@ca.ey.com

POLYTECHNIQUE MONTRÉAL

This report was prepared by the International Reference Centre for the Life Cycle of Products, Processes and Services (CIRAIG).

Founded in 2001, CIRAIG was created to provide businesses and governments with cutting-edge academic expertise on sustainable development tools. CIRAIG is one of the world's leading life cycle expertise centers. It collaborates with numerous research centers around the world and actively participates in the Life Cycle Initiative of the United Nations Environment Program (UNEP) and the Society of Toxicology and Environmental Chemistry (SETAC).

CIRAIG has a recognized expertise in life cycle tools including Life Cycle Environmental Analysis (LCA) and Life Cycle Social Analysis (LCA). CIRAIG has experience, complementing their expertise, with other tools such as Life Cycle Cost Analysis (LCCA) as well as carbon and water footprints. Its activities include applied research projects in several key activity sectors, including energy, aeronautics, agri-food, waste management, pulp and paper, mining and metals, chemicals, telecommunications, the financial sector, the management of urban infrastructures, transport, and the design of "green" products.

WARNING

With the exception of complete documents produced by the CIRAIG, such as this report, a written consent by a duly authorized representative of CIRAIG or Polytechnique Montréal must be obtained prior to any use of the name CIRAIG or Polytechnique Montréal in a public disclosure related to this project.

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 Ernst & Young LLP (below "EY") as part of the process of critical review of a comparative life cycle assessment study of Impossible® Pork from Impossible Foods Inc.

The critical review has been performed by:

- Jean-François Ménard (JFM), Analyst at CIRAIG, reviewer of the Goal and scope report and president of the review committee for the Final report;
- Dr. Rylie Pelton (RP), CEO and President, LEIF LLC, technical expert of the review committee for the Final report; and
- Dr. Benjamin Goldstein (BG), Post-doctoral Research Fellow at the School for Environmental and Sustainability at the University of Michigan, 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 EY, the consulting company mandated by Impossible Foods Inc. to perform the life cycle assessment study. The critical review proceeded as follows:

1. The Goal and scope report was sent to CIRAIG by EY on February 20, 2020;
2. The review of the Goal and scope report was performed by Jean-François Ménard and the review report was sent to EY on March 2, 2020;
3. The amended Goal and scope report was sent to CIRAIG by EY on March 10, 2020;
4. The review of the amended Goal and scope report and of EY's responses to the first review comments was performed by Jean-François Ménard and the review report was sent to EY on March 17, 2020;
5. The draft Final report was sent to the review committee by EY on June 15, 2020;
6. The review of the draft Final report was performed by the review committee and the review report (the ISO check-list was completed by Jean-François Ménard) was sent to EY on July 01, 2020;
7. The amended Final report and the responses to the first round of review comments was sent to the review committee by EY on August 10, 2020;
8. The review of the amended Final report and the responses to the first round of review comments was performed by the review committee and the review report (the ISO check-list was completed by Jean-François Ménard) was sent to EY on August 18, 2020;
9. The second amended Final report and the responses to the second round of review comments was sent to the review committee by EY on August 20, 2020;
10. The review of the second amended Final report and the responses to the second round of review comments was performed by the review committee and the review report (the ISO check-list was completed by Jean-François Ménard) was sent to EY on August 24, 2020;

11. The third amended Final report and the responses to the third round of review comments was sent to the review committee by EY on August 25, 2020;
12. The review of the third amended Final report and the responses to the third round of review comments was performed by the review committee and the review report (the ISO check-list was completed by Jean-François Ménard) was sent to EY on August 26, 2020;
13. The fourth amended Final report and the responses to the fourth round of review comments was sent to the review committee by EY on August 27, 2020;
14. The review of the fourth amended Final report and the responses to the fourth round of review comments was performed by the review committee and the review report (the ISO check-list was completed by Jean-François Ménard), including the final review statement was sent to EY on August 28, 2020.

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 project was provided.

5 Review of the Goal and scope 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?	N/A, this is the G&S report only.		
	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?	N/A, this is the G&S report only.		
	Does the report allow the results and interpretation to be used in a manner consistent with the goals of the study?	N/A, this is the G&S report only.		

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.	See comment #5	See Response #5	OK
	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.	See comment #16 N/A, this is the G&S report only. N/A, this is the G&S report only. N/A, this is the G&S report only.	See Response #16	OK
	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: ☐documentation and justification of allocation procedures; ☐uniform application of allocation procedures.	N/A, this is the G&S report only.		
	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;	N/A, this is the G&S report only.		

	☐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; ☐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;	N/A, this is the G&S report only.		

	☐ 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.	N/A, this is the G&S report only.		

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

Requirements		Reviewer's comments	Practitioners' responses	Issue resolved? (Y/N)
	Analysis of material and energy flows to justify their inclusion or exclusion	N/A, this is the G&S report only.		
	Assessment of the precision, completeness and representativeness of data used	N/A, this is the G&S report only.		
	Description of the equivalence of the systems being compared in accordance with 4.2.3.6 of 14044;	N/A, this is the G&S report only.		
	Description of the critical review process			
	Evaluation of the completeness of the LCIA	N/A, this is the G&S report only.		
	Statement as to whether or not international acceptance exists for the selected category indicators and a justification for their use			
	Explanation for the scientific and technical validity and environmental relevance of the category indicators used in the study			
	Results of the uncertainty and sensitivity analyses	N/A, this is the G&S report only.		
	Evaluation of the significance of the differences found	N/A, this is the G&S report only.		
	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);	N/A, this is the G&S report only.		

		☐ 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

#	Lines/ figure/ table	Reviewers' comments	Authors' answers	Issue resolved? (Y/N)
1	61	LCA does not evaluate the environmental impacts of product systems but only quantifies environmental indicators based on the elementary flows inventory related to the functional unit. The ISO standards uses the expression "potential environmental impacts". At the very least, that expression should be used whenever making reference to the impacts of the compared systems.	Modified language throughout.	OK
2	66-67	Only considering four impact indicators provides a limited perspective and hides potential problem shifting between the compared options. As for a carbon footprint, using such a limited perspective forbids making conclusions as to the environmental preference of either one option. You can focus on those four impact categories in the core of the report but the other impact categories (midpoint and endpoint levels) should at least be analysed and the results shown in a sensitivity analysis or an appendix.	Language added to reflect additional impact categories will be analyzed with results presented in an Appendix.	OK

3	79	As stated above, you are considering a limited set of impact indicators, the use of “full life cycle” could be interpreted as meaning complete, thus considering all impact indicators available.	Language referring to “full life cycle” removed.	OK
4	80	As stated above, the environmental performance should be evaluated based on a complete set of impact indicators.	See Response #1.	OK
5	83	ISO uses the expression “LCAs intended to support comparative assertions intended to be disclosed to the public”.	Language added to reflect this	OK
6	Table 2	• Global warming: is enteric fermentation really a hot spot for the ground pork system? • Water use: how about the water drank by the animals as they grow for the ground pork system? • Eutrophication: fertilizer run-offs for both systems or is it included in “use of fertilizers”?	• Enteric fermentation is about 20%+ of overall GHG emissions but removed because feed production is obviously the dominant process • Not that significant (compared to feed production) but added • Language added to include for ground pork as well as PBMAs	OK OK OK
7	137	LCA does not only consider emissions but all inventoried elementary flows. Replace “This LCA focuses on the life cycle emissions” by “This LCA focuses on the life cycle assessment”.	Language modified.	OK
8	139	There is a repetition in the text, remove “, descriptions of the in-scope life cycle stages”.	Language modified.	OK
9	139	There is just one functional unit considered in this LCA study.	Language modified.	OK
10	Table 3	You have not defined the functional unit yet, remove the 1 kg reference from the name of the scenarios.	Language modified.	OK
11	165-166	The PBGP burgers are sold frozen, is it the same for the ground pork burgers? If not, the storage electricity consumption will be different all the way to the moment of preparation at the consumer’s home.	Language has been modified as the client has modified the scenario slightly. The PBGP is a sausage and are sold unfrozen.	OK

12	173	As stated above, the PBGP burgers are transported frozen, which requires according to ecoinvent 3.6 about 33% more energy than refrigerated transport. If not the same for the ground pork burgers, even if only the US scenario was considered, the distribution would need to be included.	Language has been modified as the client has modified the scenario slightly. The PBGP is a sausage and are sold unfrozen.	OK
13	184-186	• The boundaries are set at the exit gate of the distribution truck once it arrives at the retailer, so the excluded processes are those from the retailer's door to the end-of-life. • See my previous comments as to the appropriateness of considering identical processes from the retailer's door to the kitchen stove between the compared systems.	Language has been modified as the client has modified the scenario slightly. The PBGP is a sausage and are sold unfrozen.	OK
14	Table 4	The high suspended solids content wastewater stream seems analogous to manure, will the possible nitrogen or phosphorus runoffs and N_2O emissions following agricultural land application be considered?	Yes the wastewater will be modelled as suspended solids wastewater in Ecoinvent	OK
15	Table 5	• The "Cultivation and harvesting of crops" sub-stage is shared by the PBGP system. There is possible use of manure in that stage even for the PBGP system. • Feed can be produced at processing plants and not always, if ever, at the farm. • I do not see why enteric fermentation contributes to the "Manure management" sub-stage. The nutrient leaching needs to be allocated to both the crop production system and the pig production system, it is not a closed loop-system.	• Language added to Table 4 to reflect first point • Language included to incorporate the difference • Language fixed to reflect methane emissions. Nutrient leaching included as well in crop production.	OK OK OK
16	Table 6	Are the burgers of the same size and mass? What people are eating are burgers of a certain size, not	The Impossible Sausage is sent to customers without a casing but is flavoured to replace ground	The term sausage is then confusing, the

		mass, if the density of the burgers is not the same than a functional unit based on the actual serving (e.g. 1 burger) would be more appropriate.	pork in any dish. The client is no longer serving them as "burgers" but just as flavoured ground pork analog. We believe the functional unit of "1 kg of food" is sufficient to capture the function of each.	description of the product in section 1.1 should be revised to reflect the intended use. Does the PBGP replace ground pork in a 1-to-1 mass ratio? One single packaging of less than 1 lb of most PBMA ground substitutes is often used in recipes in place of 1 lb of ground meat.
17	213-214	You are not doing a carbon footprint but an LCA, the GHGPPS is not the relevant standard to use.	Removed language.	OK
18	214-217	See my previous comments as to the maybe not identical processes from the retailer's door to the kitchen stove between the compared systems.	See Response #13	OK
19	244-246	It is not clear if indirect land use changes (ILUC) will be included in the assessment. Will only associated GHG emissions be included?	Language added to reflect this. Only direct land use will be considered.	OK
20	253	If you are only focused on four impact categories, why not use the most recent LCIA methods for each (e.g. IPCC 2013, AWARE).	See Response #2	OK Aligning with the previous study results seems to be the main reason why IMPACT 2002+ was chosen.
21	257	How is reporting only land occupation at the inventory level compatible with accounting for land use changes (direct or indirect). Different types of	Land use change GHGs will be incorporated into global warming potential. Land occupation will be	So you will use the IMPACT 2002+ land occupation

		land use have different potential impacts on biodiversity, will you record land use for each type? This will increase the number of indicators for this impact category.	reported as a primary midpoint indicator, but as noted above in Response #2.	indicator? If so, it should be stated clearly, lines 262-263 are confusing in that context. This will also depart from what was done in the previous study.
22	259-266	See my previous comments as to the incompleteness of the set of environmental indicators used.	See Response #2	OK
23	269-270	If you want to only include eutrophication, why limit yourself with freshwater eutrophication, marine eutrophication is also an environmental issue (https://oceanservice.noaa.gov/facts/eutrophication.html). There are LCIA methods that include marine eutrophication (ReCiPe and IMPACT World+).	See Response #2 re: reporting on all indicators.	OK Reporting on all IMPACT 2002+ indicators which do not include marine eutrophication.
24	274	You said previously that you would be reporting land use at the inventory level, it is not clear then how it will be reported and considered.	See Response #2 – will report on all endpoint categories, but of particular interest to the client is the midpoint categories of land use and water use.	OK The land occupation midpoint indicator result is the result of the LCIA characterization step.
25	275	As for land use, water use has different impacts on human health and biodiversity depending on where the water is used. Will you account for the different regions where water is used separately? This will increase the number of indicators for this impact category. There are LCIA methods that account for water scarcity.	See Response #2 – will report on all endpoint categories, but of particular interest to the client is the midpoint categories of land use and water use.	OK The water use indicator result is not the result of the LCIA characterization step, it only accounts for the

		Not accounting for the local water stress essentially means you are reporting the water use at the inventory level (i.e. simply as liters), as for the land use (i.e. simply as m^2.y).		total volume of water used, wherever it is used, it is an aggregated inventory result.
26	285	In the "cut-off by classification" approach, the recycling burdens are allocated to the users of the recycled materials (i.e. materials produced by recycling), those materials are then not burden free. The initial primary materials production is indeed not allocated to the recycled materials, the cut-off boundary is at the exit gate of the unit process where products become waste to be recycled.	Language modified.	OK If manure is sold to crop producers than economic allocation could be used. On what basis will the system expansion be done to account for manure used as fertilizer?
27	287-293	It is not clear what allocation approach will be used for the compared systems. In particular, ground pork is probably not the most expensive pork meat on the market, economic allocation would then result in a reduced environmental footprint for this co-product compared to more valuable cuts of pork meat.	Language modified.	OK A sensitivity analysis should be done to test the choice of mass allocation for the pork products. Your argument seems to support economic allocation.
28	303	Impact indicators are the sum of the characterized emissions from the included unit processes, what you have described is the procedure to complete the inventory. The LCIA phase of LCA still needs to be completed to calculate the indicator results. Those are not measured.	Language modified	OK
29	Tables 7 and 8	Does the DEFRA data cover all impact categories? There are transport processes in the ecoinvent database.	Adjusted to include Ecoinvent databases to cover al impact categories.	OK

		Does the EPA electricity production data cover all impact categories? There are U.S. grid mixes available in the ecoinvent database. GHGenius only provides GHG emissions data for transport fuels (there are some production (activity) data for crops related to biofuels). There are natural gas production, transport and use processes in the ecoinvent database. IEA data detail the grid mix not the emissions factors, there are Chinese grid mixes available in the ecoinvent database.		
30	Table 11	Replace “GWP factors” by “Characterization factors”. Monte-Carlo simulations can also be used to asses the influence of parameter (direct emission, activity and emission factor) data uncertainty.	Language modified.	OK
31	339	You have suggested that the packaging for both compared products are similar but in order to exclude their end-of-life, they would have to be qualitatively and quantitatively identical, is that the case?	Yes we are assuming they are qualitatively and quantitatively identical.	OK This should be clearly stated.
32	339-340	The use of manure as fertilizer can be seen as a recycling process, the cut-off approach would require to not include the transport, land application and associated nutrient run-off. An alternative scenario, i.e. system expansion, would be to include it and credit the system for the avoided chemical fertilizers.	Language modified.	OK Like I said, the choice of mass allocation for the pork products should be tested in a scenario (sensitivity) analysis.
33	343-346	You are not doing a carbon footprint but an LCA, there are uncertainties associated with the characterization factors for the other impact categories.	Language modified	OK It is not clear if you will do Monte-Carlo simulations.

34	352	The inventoried elementary flows are converted into the relevant impact indicators through the LCIA phase. The indicator results are reported.	Language modified.	OK
35	354	You have not specified how biogenic carbon flows will be treated, those are especially relevant in a agricultural products LCA.	Language modified.	OK You have not specified how biogenic carbon will be treated. By default, IMPACT 2002+ considers it neutral and gives is a 0 (zero) characterization factor.
36	359-360	On the contrary, you are studying agricultural products, biogenic emissions need to be included in the inventory. The contribution analyses should be done at the impact indicator result level, not the inventory.	Language modified.	OK
37	362-363	The reference to Monte-Carlo simulations should have been made in the previous section (4.3). Will such simulations be conducted? Do the Impossible Foods data include uncertainty? If not, how will it be generated in order to be accounted for in the uncertainty analysis? The Pedigree matrix approach is used for ecoinvent data, it could be used for the compared systems primary and secondary data that do not already include uncertainty information.	The Impossible energy data reflects actual data in their processing facility; data for raw ingredients will come from ecoinvent. Table 10 is not significantly different than Pedigree matrix approach – is the reviewer asking for us to switch to Pedigree matrix to valuate data quality?	There is always uncertainty associated with inventory data. The Pedigree matrix can be used to generate uncertainty information (geometric standard deviation for a lognormal distribution) for data that do not already include such

				information. This information can then be used in Monte-Carlo simulations. This is not the same as data quality assessment.
38	372-373	You are not doing a carbon footprint but an LCA, the reference to the GHGPPS should be removed.	Language modified	OK
	Table 13	You are not doing a carbon footprint but an LCA, “carbon footprint report” references should be replaced by “final LCA study report”.	Language modified	OK

6 Review of the Final report

6.1 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?	No analysis is provided for the other IMPACT 2002+ impact/damage categories.	Analysis (and goal and scope) limited to those four environmental indicators. Limitations noted.	Y
	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?	Some documentation of the LCA modelling is missing in the Appendixes affecting transparency and reproducibility.	Added.	Y
	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 by the Impossible Sausage.	No “overall” environmental preference is to be claimed. Goal is not intended to be related to overall environmental preference.	Y

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.	Grid mixes provided. Cut-off criteria added.	Y
	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: ☒documentation and justification of allocation procedures; ☐uniform application of allocation procedures.	The details of the foreground processes inventory calculations are not provided. See comments See comments	Details are provided.	Y

	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; ☐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	No justification for the choice of environmental indicators was provided. No detailed calculation procedure for the inventory-level indicators.	Justification was provided; no inventory-level indicators were used.	Y

	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.	 To be provided. To be provided.		

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.	N/A	
X	Description of the critical review process			
	Evaluation of the completeness of the LCIA	Only a partial set of environmental indicators has been analyzed.	Consistent with goal; limitations recognized.	Y
	Statement as to whether or not international acceptance exists for the selected category indicators and a justification for their use	Two of the four environmental indicators were taken from a published LCIA method. The other two are inventory-level indicators	All four indicators were taken from a published LCIA method.	Y

		and the specific calculation procedure was not detailed.		
	Explanation for the scientific and technical validity and environmental relevance of the category indicators used in the study	No justification for the choice of environmental indicators was provided.	Justification for the choice is provided.	Y
X	Results of the uncertainty and sensitivity analyses			
	Evaluation of the significance of the differences found	Significance of the differences was not specifically addressed.	Language addressing significance threshold provided.	Y
	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.)”.			

6.2 Reviewer’s comments and authors’ answers

See Excel file “EY_Impossible_Foods_Critical_review_comments_2020-08-28.xlsx”

Comment No.	Reviewer initials	paragraph (§), Figure, Table	comment (gen., tech., ed.)	Reviewer comment	Reviewer suggested action(s)	Authors response	Issue resolved (Y/N)	Authors response2	Issue resolved (Y/N)2	Authors response3	Issue resolved (Y/N)3
1	JFM		gen.	A good guiding principle when writing an LCA repport is reproductibility, i.e. being sufficiently transparent to insure that, if so desired, a reader would be able to reproduce the modelling of the system and obtain the same results. Confidentiality issues can prevent complete transparency of the final report, but the		No response.	Y				
2	JFM	Executive summary	gen.	The relevant comments addressing the core of the report will need to be considered in the review of the executive summary		Yes, addressed in Exec Summary where necessary	Y				
3	JFM	1.1, § 5	tech.	- The Land occupation and Water consumption indicators are not impact category indicators found in the IMPACT 2002+ life cycle impact assessment (LCIA) method, but life cycle inventory-level indicators. Simply looking at the amount of land and water used gives an incomplete picture as the context of where and how this use occurs is not considered and greatly infliuences the associated environmental burden on human health and biodiversity. - No justification is given as to why only consider the four selected environmental indicators. As was said in the G&S report review, such a limited range of indicators only provides a limited perspective and hides potential problem shifting between the compared options and forbids making conclusions as to the environmental preference of either one product. - No analysis of the results for the other IMPACT 2002+ impact/damage (midpoint/endpoint) categories is provided, only	Simply call them environmental indicators, the two others (Global warming potential and Aquatic eutrophication potential) are also environmental indicators, even if also IMPACT 2002+ midpoint indicators. This goes for the rest of the report as well.	Throughought the report, the term impact category was replaced with environmental indicator. Land occupation, and the associated units, is an IMPACT 2002+ impact category and is used throughout. We also moved to use the ReCiPe indicator of water depletion to have a midpoint indicator that can be used for direct comparison, so reference to water consumpion has been removed. Furthermore, justification for the use of only four environmental indicators is provided throughout.	OK, but care must be taken not to equate environmental impacts and environmental indicators. For example, "Certain processes may generate potential environmental impacts over a longer period than the current year" cannot be replaced by "Certain processes may generate environmental indicators over a longer period than the current year". In this case, "emissions" could have been used as this sentence relates to inventory modelling.	Language modified throughout to remove reference to "impacts" where indicaotrs or emissions make more sense.	Y		
4	JFM	1.3, § 4	ed.	Pig or swine is the animal and pork is the meat.	Use the term pork correctly and consistently throughout the report.	Text modifications throughout to reflect the fact that pig is the animal (live) and pork is the meat (after the pig is slaughtered).	Y				
5	JFM	Figure 2	tech.	The cooking sub-stage is missing for the PS2 product.		Language and blocks adjusted	Y				
6	JFM	Table 4	tech.	The cooking sub-stage is missing for the PS2 product.		Language adjusted	Y				
7	JFM	3, § 4	tech.	- The 3.01 version of the ecoinvent database was published in 2013, the 3.3 version was publisehd in 2016. Which version exactly of the ecoinvent database was used to model the background processes included in the compared systems? What system model, or allocation model, was used? - What version of the Agri-footprint database and what allocation model was used? This database uses USLCI and ELCD data for background processes, which are not consistent with the ecoinvent modelling, you could have used the Agri-footprint foreground datasets as templates and connect them to ecoinvent data for the background processes. - The ecoinvent database includes for most of the modelled activities infrastructure, the Agri-footprint databse does not. As no infrastructure was considered for the Impossible Sausage and		ecoinvent version 3.1, default, allocation is used to model background systems; language updated to include this. Infrastructure processes were excluded from inventory calculation using SimaPro; language updated to include this. The reviewer's comment was taken and all foreground processes that were taken from Agrifootprint were modelled using ecoinvent background processes.	Y				
8	JFM	Table 8	tech.	Some excluded ingredients, i.e. indicated with a "**", appear in Appendices A and B with their associated process datasets, e.g. salt, and some indicated without a "**", i.e. included ingredients, are not associated with a process dataset, e.g. cultured dextrose,	Check included and excluded ingredients. As some ingredients were not found directly in the LCI databases, it would be good to clearly indicate those cases and what available datasets were used as proxy.	Updated this Table with modeled processes and background/foreground databases. Updated all Appendices with processes, but with amounts included for reviewers.	Y				
9	JFM	3.1.1, § 2	tech.	You say you modified ecoinvent and Agri-footprint datasets to reflect more recent yield and fertilizer use data. It would have been good to provide the modelling of the modified datasets. (Same thing for the feed constituents production datasets in		Appendix C was added with crop yield data and sources. Appendix D was added with fertilizer use per crop	OK, but land occupation flows are quantified in m^2.a, i.e. surface x time of occupation. The yield gives the amount of crop per surface area, what was the time period considered in the new calculations of the occupation flows?	While the yields are given in m^2, they represent that land occupation for the year (although averaged over a number of years). A note is added to the text in that section to reflect this.	Y		
10	JFM	3.1.1, § 3	tech.	You say you modified the Mexican grid mix dataset available in ecoinvent to reflect more recent data. It would have been good to provide the modelling of the modified grid mix. (Same thing for the modified US RFC and MRO and Chinese grid		Included Appendix E with electricity grid share and details of the change to the electricity ecoinvent processes. All electricity processes included as well (only the share was modified).	Y				
11	JFM	3.1.1, § 5	tech.	Appendices A and B show no refrigeration inputs for the heme production. Other than low solid waste wastewater (I was surprised to see the choice of ecoinvent dataset to model its treatment, "treatment of wastewater, unpolluted", as it is the effluent of a fermentation plant), there are no waste flows coming from the heme production.		The waste from the heme process has two streams - low and high solids. It goes through centrifugal separation and the first output is modelled using household water and the second output is a solid food waste product that is modelled as landfill. Ammonia for refrigeration was mistakenly removed from the inventory - added back in. Language was updated and model was updated to	OK, but the dataset "Municipal solid waste {RoW}| market for | Alloc Def, U" includes more than just landfilling.	Changed to Municipal solid waste {RoW}| treatment of, sanitary landfill | Alloc Def, U	Y		
12	JFM	3.1.2, § 2	tech.	Appendices A and B show no waste, solid waste or wastewater, flows coming out of primary and secondary processing, which is a bit surprising since this is a food industry. I do not see any inputs for cleaning the installations, which must be required, are those		Cleaning is done with water which is included in the water use. Wastewater was added to the model as per Comment #12	OK, but I do not see the wastewater output.	Apologies. Left out - 0.83 L water/kg product added to product assembly for cleaning water wasteater. The rest is CIP and process water. Added 0.25 L/kg product for cooking/forming or forming part.	Y		
13	JFM	3.1.2, § 3	tech.	How was modelled the product losses treatment? It does not		Clarified in the model. 0.95 kg of sausage out of the IF process,	OK, but the dataset "Municipal solid waste {RoW}| market for | Alloc Def, U" includes more than just landfilling.	Changed to Municipal solid waste {RoW}| treatment of, sanitary landfill | Alloc Def, U	Y		
14	JFM	3.1.3	tech.	The modelling of the plastic film and carboard box is not		Added	Y				
15	JFM	3.1.4	tech.	The modelling of the distribution transport is not presented in Appendices A and B. Why not use the freezer transport datasets available in ecoinvent, there is more than just an increased		Refrigerated transport not included in ecoinvent 3.1. Took the approach of BG below from Comment #112. Noted in the text as well.	Y				
16	JFM	3.2	tech.	The detail of the pork scenario modelling is not presented in the	Provide the detailed modelling, including how some process	Added	Y				
17	JFM	3.2.3	tech.	Some of the crops grown to feed the pigs, and as ingredients to the Impossible Sausage, use manure as fertilizer, is the modelling of the associated emissions consistent?		As the pig farm, especially in Iowa, is typically co-located with the crop farm, the manure is applied to the pig process specifically. The ecoinvent crop processes do not have manure	Y				
18	JFM	Table 16	tech.	It is surprising that the 100 km transport of Impossible Sausage bulk mix between manufacturing and forming facilities contributes more than the 1,500 km transport of the ingredients. I can understand the freezer transport of the packaged final		Outcomes have been adjusted slightly.	Y				
19	JFM	Table 17	tech.	- Distribution and ingredients transport distances, i.e. activity data, are based on assumptions, as such their data quality cannot be considered "Very good", "Good" at the most I would think. The truck transport environmental data comes from the Agri-footprint database, itself based on European ELCD data. Modelling American and Chinese truck transport with such datasets cannot be given "Very good" scores for all criteria but maybe the Reliability one (I have not checked the Klein et al. 2012 literature reference). - ecoinvent electricity generation datasets are mostly based on European data, somewhat adapted to other regional contexts. This can be seen in the Pedigree Matrix criteria scores for the		All assessments were changed to Pedigree scale and re-adjusted to reflect best available information	OK, but it would be good to include in Table 14 the qualitive rating (very good, good, etc.) of the Pedigree Matrix scores, to better connect with the assessment in the text. Convert the scores for the background data into a qualitative assessment, i.e. is the data of sufficent quality?	Added	OK, but still the question of the overall quality of the data is not adressed (cf. the environmental data were given good to poor quality).	Language adjusted	Y
20	JFM	Table 20	tech.	- Reading section 3.2, I understood the electricity generation was modelled using ecoinvent datasets, you however indicate in Table 19 that is was modelled using USLCI datasets. Considering the numerous data gaps in the latter LCI database and inconsistencies with the former one, which mostly used to model background processes, I would not have kept the same quality assessment (already indicated in the previous comment to be overly-generous). - See previous comment as to the data quality for the truck transport.		As per previous comments, modifications were made to the ecoinvent modelled processes to incorporate updated electricity generation share data. See Appendix E. Soybean production data quality differences was an error and adjusted.	OK but see previous comment.	See Comment #19	See previous comment, activity and environmental data range from poor to very good.	Language adjusted	Y
21	JFM	4	tech.	There are many multifunctional processes included in the ecoinvent database, various allocation approaches are used to treat them. You seem to have used the ecoinvent datasets as they are, it should then be clearly indicated that the allocation		Language modified and adjusted where needed.	Y				
22	JFM	4, § 2	tech.	From the pig producer's perspective, giving an environmental credit for the avoided synthetic fertilizers due to the application of the manure he produces is consistent with a system expansion approach. Giving the same credit to the crop farmer that uses the manure is not consistent, is this what you did when you say " The reduced fertilizer requirements as a result were modelled using the manure application process"? Since the producer and the user of manure are both included in the systems, care must be taken	Provide the detailed modelling of the effect of using pig manure in growing the crops for pig feed and Impossible Sausage ingredients.	In ecoinvent agriculture processes, manure is not included. Therefore, the use of manure to replace fertilizer, and the inclusion of it in the pig processes, is consistent.	Y				
23	JFM	4, § 4	tech.	I take it then that the economic allocation version of the Agri-footprint LCI database was used. If so, why does Appendices A and B show the mass allocation version of the soybean protein		ecoinvent 3.1 was used. All language was updated to reflect this. Ecoinvent uses economic allocation for soybean protein concentrate.	Y				
24	JFM	5.1, § 1	tech.	Since not all results are impact category indicator results, it would be better to simply refer to environmental indicator results. Your referring to the "impacts for those four indicators" is then incorrect (and inconsistent with the statement that LCIA results do not represent actual impacts), simply refer to the		See Response #3	Y				
25	JFM	Table 21	tech.	- The Land occupation indicator you use is also an inventory-level indicator, as the indicator for the impact category with the same name provided in the IMPACT 2002+ LCIA method is reported in m^2 organic arable crop eq. - How were calculated the water consumption indicator results? It would be good if you provided more details on the methodology? - 50%+ reduction of indicator results for the Global warming and Aquatic eutrophication impact categories are significant differences, but how significant are the differences for the inventory-level indicators? This is closely related to inventory data uncertainty. This question is then partly dealt with the		The land occupation indicator was used is the midpoint indicator in IMPACT 2002+; the units were updated throughout. RECIPE was used to calculate water depletion (this is new). Inventory indicators are no longer used. Where new processes are used, uncertainties have been added using Pedigree in SimaPro and/or typical uncertainties for emission factors.	Y				
26	JFM	5.1, § 3	ed.	I think you meant to say the Impossible Sausage scenarios water consumption results are 65% to 71% lower than the pork scenarios. The higher water consumption for the pork scenarios is		Language adjusted as the results have changed.	Y				
27	JFM	Figures 4,5,6,7	tech.	It would be better if all scenarios and indicators were shown in the same figure (in landscape format if necessary) and contributions normalized to the highest total (system) result (set at 100%). That way it would be easier to see the contribution of		This was modified.	Y				
28	JFM	5.1.1	tech.	It would be best if the text did not refer to the impacts of life cycle stages, processes or activities but refer to their contribution to the (total or overall) indicator results. The same holds at the system level, not to refer to the impacts of the systems but to refer to their (total or overall) indicator results.		Updated language to refer to the indicator results specifically.	OK, but there are still references to the impacts.	See Comment #3			
29	JFM	Table 22	tech.	It would be good to provide the contribution of each ingredient		Distribution added	Y				
30	JFM	5.1.2, § 2	tech.	- I take it you meant the contribution of the ingredients production is just over 2%, however it is not clear if that 2% value is relative to the total Global warming indicator result or to just the ingredients production stage result, as the transportation of the ingredients and the energy used to manufacture the Impossible Sausage are not the remaining contributors to the total results as the distribution transport is also an important contributor to the total result (even more so for the IS2 system). - Do you mean the coconut oil production itself (not the growing of coconut) contributes over 6% to the total Aquatic eutrophication indicator result? If other agricultural processes, such as fertilizer use, contribute significantly more, why not	Clarify the contribution analysis text.	Noted. Language clarified re: what the contribution actually means.	Y				
31	JFM	6	tech.	Monte-Carlo simulations quantitatively assess the influence of inventory data uncertainty, so you have not just qualitatively		Updated language.	N, language not changed.	Language changed.	Y		
32	JFM	Table 23	tech.	All LCIA impact category characterization factors have an		Updated language	Y				
33	JFM	6.1	tech.	- See my previous comments regarding data quality. - There is uncertainty information associated with almost all flow values in ecoinvent datasets, there is no such information for most of the flows in Agri-footprint datasets (especially the copied USLCI and ELCD ones). The Monte-Carlo simulation then does not consider the uncertainty associated with all the included processes. Did you adjust the Pedigree Matrix criteria scores for	Provide the details of the uncertainty modelling for the adapted inventory datasets, if that is the case.	Pedigree scores were updated as best as possible within SimaPro. All flows are ecoinvent, as per previous comments.	OK, but the language refering to the data quality assessment seems to to have been changed to account for the updated assessment.	OK	See Comments #19 and 20.	See Comment #19/20	Y
34	JFM	6.1.2, § 3	tech.	Why only present the results for the Land occupation indicator, feed production has non-negligible contribution to the other		Fair, other indicators are provided now, but yes smaller contribution for sure.	Y				
35	JFM	6.1.2, § 4	tech.	Does wheat have a higher yield than soy in China? How is the reverse increase in the Land occupation result explained when		Modified so no longer relevant	Y				
36	JFM	6.1.3, § 1	tech.	What dataset was used to model the Quebec grid mix, I could not obtain the 4.5 g CO2 eq./kWh value you indicate?		This sensitivity was removed to incorporate the one suggested by Benjamin Goldstein to study the impact of moving IS	Y				
37	JFM	6.1.3, § 2	tech.	If you are using the ecoinvent v3.01 database, then the Quebec grid mix still includes a share from nuclear generation, the		Removed as per Comment #36	Y				
38	JFM	6.1.3, § 3	tech.	Why only present the results for the Global warming indicator?		With sensitivity adjusted, all indicators for IS1 and IS2 CN vs. IS1	Y				
39	JFM	6.1.3, § 4	tech.	There would be other changes to the system by moving the Impossible Sausage production facilities to Quebec, e.g. transport distances, ingredients sourcing, which could result in problem		Removed as per Comment #36	Y				
40	JFM	6.2	tech.	- Allocation was also used for many of the crops produced as Impossible Sausage ingredients and pig feed components. - You show a mass allocation factor of 57% for the slaughtering process, does that mean that 43% of the carcass mass is converted to by-products? Changing the allocation approach is a legitimate sensitivity analysis. In this case however, I do agree		Just further clarified that allocation implication here and then in the Allocation section	OK, but see new comment.	See Response #173	Y		
41	JFM	6.3, § 1	tech.	The Land use impact category of ReCiPe (it considers a much wider range of land occupation types, and also considers some land transformation types whereas IMPACT 2002+ does not. The impact assessment model differs then between the two LCIA methods. That is the whole point of the sensitivity analysis, to see how different LCIA models treat the same inventory and whether the conclusions reached depend solely on the choice of LCIA method. Were the results for the IMPACT 2002+ Land occupation impact category considered in the sensitivity analysis (in m^2 organic arable crop eq.) or only the selected Land occupation indicator results (in m^2.a)? In that regards, the Freshwater eutrophication, even the Marine eutrophication, impact categories should also be considered. The		Freshwater was also included. RECIPE was used to understand if changing the method changed the result. Language was clarified to reflect this.	Y				
42	JFM	Figure 8	tech.	It would be better to show the results obtained with both methods side by side for all systems and indicators, all related to the system with the highest result for each indicator, per LCIA method. It is not so important to see if the ReCiPe results are higher or lower than the IMPACT 2002+ results but to see if both		Fair RECIPE presented on its own though to show same conclusions are reached.	Y				
43	JFM	6.3, § 3	tech.	- Again, the important information is not that the ReCiPe results are higher or lower than the IMPACT 2002+ results, it is if they reach the same conclusions. If they don't then this might be due to the fact that for example IMPACT 2002+ uses GWP500a and ReCiPe uses GWP100a. - it is not clear if the GHG inventory data in Table 10 was entered as inventory (g of gas emitted) or impact indicator results (g CO_2 eq.), the former would have been better. If entered as indicator		Language redfined. And entered as inventory, not as indicator results. ReCiPe results are compared only to itself to determine conclusions.	Y				
44	JFM	7, § 4 2nd bullet	tech.	See my comment on the grid mix sensitivity analysis.		As per Resposne #35, sensitivity analysis of moving IS production to China was implemented. Moving IS production to Quebec was removed.	Y				
45	JFM	8, § 2	tech.	You focussed on a partial set of environmental indicators, the text should reflect that choice and limitation.		Noted as limitation	OK, but I would suggest "it is recognized that there are other enviYronmental indicators available to evaluate the overall	Language updated.	Y		
46	JFM	8, § 4	tech.	An attributional approach was used to conduct the comparison, if assessing the consequences of switching or replacing pork sausage by the Impossible Sausage was the intended goal of the study then a consequential approach should have been used,	Do not use the formulation "When replacing…".	Adjusted langauge	Y				
47	JFM	Appendixes A and B	tech.	Since more than one LCI database was used, it would be helpful to indicate from which were taken the process datasets. The datasets were taken from LCI databases not SimaPro, which is just the LCA software used to help in the modelling of the systems, and the LCI and LCIA calculations.	Indicate from which database the process datasets were taken. It would also be better to provide the name of the process datasets used, rather than the name of their reference product. It would finally be good to provide some additional information in a "Comment" column, where assumptions or modelling choices can be detailed, e.g. use of proxy datasets combined based on stoichiometry as may have been done with potassium carbonate	Included	OK, but the details of the adapted Agri-footprint datasets are not provided (except for pig slaughterhouse in China).	Added in sunflower oil (crude and refined) and soybean protein concentrate	Y		
48	JFM	Appendix C	tech.	The results for the Water consumption (inventory) category are different from those provided in the core of the report, how were		Error	Y				
49	RP	pg2, 2nd bullet	tech.	The term water consumption is used throughout the document, however, it I believe that water withdrawals is the actual metric used. Water consumption is specifically the quantity of water that is evapotranspired or physically embedded within a product, whereas the water consumed by pigs is recycled to the hydrological system through excretion, so should not all be considered as part of the 'water consumption'. This is also the case with feed crops, not all irrigated water withdrawals are 'consumed'. Additionally, I assume based on the description here and throughout the document that the quantities of water are specifically referrring to 'blue' water and not 'green' water, but this should be clarified. Finally, the terms water use and water consumption need to be made consistent throughout as they imply different things. If the irrigation water quantity is used, and the total water that the hogs drink and is used in cleaning	A recent article evaluating the actual water consumption of feed crops has just been published (https://iopscience.iop.org/article/10.1088/1748-9326/ab9a6a) that could be helpful here for an estimate of water consumption from feed crops going to hogs in the US, if that is the metric you'd like to stay with (but further revisions to the hog production stage would be necessary since these are withdrawals and not pure consumption), or can change the terminology throughout the text to read Water Use (which implies withdrawals and not consumption).	Water consumption replaced with water depletion as the RECIPE method was used for this. Language reflected throughout.	N	Water consumption/water use replaced with water withdrawal when talking about inventory-level water changes throughout.	Y, with potential exception in regard to the 'net water' that is indicated in table 22 caption regarding sunflower and coconut inputs. See comment number 13 in third round of comments.	Adjusted language as per Response #195	Y

50	RP	Figure 2	gen.	slight inconcsistency between figure 1 and 2 with regard to	should include the cooking process for PS2 to be equivalent to the	See Response #5	Y				
51	RP	Table 4	gen.	In section 'cultivation and harvesting of crops', last sentence, says 'emissions from this substage arise from...' but these are not all	Exchange the term 'emissions' for 'impacts'	Exchanged the term "emissions" for "impacts"	Y				
52	RP	Table 4	gen.	In section 'cultivation and harvesting of crops', "emissions from this substage primarily arise from"...seems to be an over simplification. Corn, for example, is the primary crop used in pig feed, and about a quarter of the impacts come from fossil fuel use in fertilizer production, but another quarter comes from N2O emissions from fertilizer application, and another quarter comes from lime (from application emissions, not embedded emissions) and fuel use from farm equipment. Further, both manure and		Language clarified.	Y				
53	RP	Table 4	ed.	In section 'manure management and application', second	add a comma between 'storage' and 'eutrophication'	Comma added	Y				
54	RP	Table 4	tech.	In 'Farrowing, weaning and fattening' section, last sentence, the 'primary emisions from growing pigs' implies that the next will be listed in order of primary contributios, however, energy use for operating pig housing and pig enteric fermentation are both relatively small in comparison to the much larger emissions from	suggest listing in order of primary contributions, otherwise is misleading	Adjusted	N, enteric fermentation is consistently referred to first implying order of primary contributon.	In that Table the sentence reads "The primary impacts from growing pigs are GHG emissions from manure handling, energy use for operating the equipment and pig housing, and enteric fermentation from the pigs themselves". In Table 10 and Section 3.2.2. - order modified as well.	Yes, except in section 3.2.2 1st paragraph "The primary sources of environmental impact in this stage are enteric fermentation, manure management, and on-farm operations." - need to instead list in order of primary contributions (enteric fermentation is not the primary contributor)	Thanks. Completed.	Y
55	RP	Table 5	tech.	In sections 'Initial packaging' and 'transport of pork products to processor' - Secondary processing is often co-located in the US, thus not requiring any transport between primary and secondary processing facilities. Currently 100 km are assumed. Dettling et al 2016 do not assume any transportation to occur during this stage, and Dalgaard is representative of Danish pork systems. It		Assuming this is Table 4, not Table 5: Fair, removed language around those stages and adjusted model accordingly.	Y				
56	RP	2.6	ed.	the term 'direct land use' impacts are frequently referred to in this section, however this term does not have the same		Added "change" where not included prior	Y				
57	RP	3, § 4	gen.	What is meant by 'local and recent crop yields were used'?	Please clarify the scale of 'local' (country, Iowa, hog counties in	See Response #9	Y				
58	RP	Table 8	ed.	zinc gluconate	change to zinc	Language adjusted	Y				
59	RP	Table 8	tech.	* says these products were not modeled directly because they make up less than 1% of product mass, but salt is included in the 'ingredients only, no heme' in appendix b so seems like it was	clarify for consistency	Models were re-written to be more clear and adjustments made to Table 8	Y				
60	RP	3.1.2	tech.	Is wastewater treatment included in primary processing? A substantial amount of wastewater is generated (from animal		Yes, updated text to be included in 3.1.2 and the models in Appendix A, B	Y				
61	RP	3.2	tech.	The model used data from Pelletier but would be good to describe the manure management system assumed or if it is an average of the types of manure management systems used in the US. There are about 5 overarching management systems used in the US (and it varies not only region to region but state to state (and likel county to county), so would be good to mention which system is assumed for this comparison. Slatted barns are mentioned, but this could be either liquid/slurry systems, solid storage with liquid separation, and/or uncovered lagoon systems, which will have different associated emissions. Likewise, how does this compare with the system used in China? By description, it sounds like this may be a solid storage system without liquid		Pelletier uses liquid/slurry system; Zhou hybrid system. Text added. Fair point re: the GHG emissions.	Y				
Refle	RP	3.2.2	tech.	Are Sow related emissions allocated to the pig meat? This is usually a fairly signficant portion of total life cycle emissions in hog production, and should be incuded if it is not.		Yes it is included in the models themselves	N, sow emissions would be accounted for in pelletier and Zhou, but since enteric fermentation and manure management are calculated with tier 1 ipcc emisison factors, then it is unclear how sow emissions are treated in this case, are they allocated appropriately to the market swine?	Enteric fermentation Tier 1 EFs and Manure Mgmt for Asia are not differentiated between sow and market swine. For Manure management, US - a Tier 1 EF was used. The breeding and market swines were used and a weighted average of the EFs were used to get one emission factor. So yes, allocated to meat. The language in the text was further clarified re: using	Y		
63	RP	Table 11	tech.	Avoided N2O- is this direct N2O emissions or both direct and indirect N2O emissions (indirect being related to the avoided		avoided N2O is both direct and indirect.	Y				
64	RP	Table 12	tech.	Using the naics total sales values may misrepresent the total economic impact of pork meat as it includes the total sales across all meat types that have varying yield compositions. There is substantially less co-products produced than would be seen for pork-only sales values because chicken has a higher carcass yield (lower co-product yield) and more chickens are slaughtered than pork (despite the smaller animal mass, the US produces ~60% more chicken meat than pork). This is also problematic for application to the Chinese scenarios because many of the typical co-products are valued more highly. While the US tends to prefer the economic allocation method in slaughter applications, this is contrary to the ISO 14041 hierarchy of preference, where	Given the substantial implication that allocation in slaughter likely has on the final results, it would be beneficial to develop a sensitivity analysis around this, and could then be used for complying with EU product category rules if marketing in these areas are of interest.	This allocation procedure was also used by other authors: Morningside LCA of plant-based products. Same text is left as JFM also agreed mass allocation does not make sense in this case.	N, see 2nd round comments; at very least a sensitivity analysis around allocation should be done given the potential implications on the overall directionality of results and the high uncertainty in economic allocation assumptions.	Mass allocation sensitivity done. See Comment #173	Y		
65	RP	3.2.7	tech.	Says transportation impacts differ between US and China senarios but both assume 1500 km frozen truck travel. Is it differences in fuel efficiency or fuel type that are causing the		Error in the text - removed language saying they differed.	Y				
66	RP	Table 15	ed.	Would be useful to indicate the stage that the signficant process applies to, or to indicate in the heading that these are significant aggregate processes (ie. transportation from multiple stages, or		Helpful suggestion. Implemented	Y				
67	RP	Table 15	tech.	N2O emission rates are based on the amount of N applied. If manure N is displacing synthetic fertilizer N on a 1:1 kg N-basis, then why is manure N2O so much less (.0171) than the displaced		This has been adjusted - a 75% replacement N for N.	Y				
68	RP	Table 16	ed.	In 'Electricity (RFCW and Mexico), May be an unfinished sentence	Suggest deleting 'Amount of'	Adjusted	Y				
69	RP	Table 19	ed.	Would be helpful to indicate which stages the electricity process is significant for- processing only, on-farm, total?		Electricity was significant for the whole in scope life cycle (>5% of total contribution); only the whole process was considered here	Y				
70	RP	Table 19	tech.	Is the activity data detailing both the amount of manure generated as well as the type of management system? And then these are combined with IPCC emission factors for the management system and quantity of manure? Or is the IPCC emission factors considering the manure management system distribution used in North America and China and simply the		The latter - The emission factors in IPCC Ch 10 - Table 10.14 are leveraged per region per head.	Y				
71	RP	Table 19	tech.	data quality for manure management in the US system is based on data pre-2010, which violates the 'very good' criteria specified in table 14. Manure management has evolved since 2010 and as mentioned earlier there are 5 different types of systems that are	Need to clarify why this data is considered very good in terms of its temporal representativeness or should revise the score accordingly.	Noted and language updated in the table to reflect activity factors and environmental impact factor uncertainty.	Y				
72	RP	4, § 3	ed.	confusing sentence, please revise for clarity "Although for the single feed components the allocation rule is very important, on the level of meat, the influence is relatively small." Also, if allocation has a significant effect on the feed impacts, then how does this result in relatively small impacts in meat production? Feed is one of the primary drivers of impact in meat systems and because of substantional feed aggregation in these livestock lifecycles, one would expect allocation in feed to be important in influencing the overall meat results (particularly in pig and chicken production where feed impacts are equal to or exceed		Explanation provided and clarified tht this is the conclusion of the authors of the references not the authors of this study. Clarified that this is because of the dilutio of different allocation amounts.	Y				
73	RP	4, § 3	tech.	Table 12 and corresponding section imply that the sausage is made from the fresh meat portion which is attributed 50% of the upstream impacts. However, "For pig products in this study during slaughter, an economic allocation was used because of the widely different values in the market. As such these lower value pig parts, ones that may be ground and used in sausage or ground pork products, would be attributed less of the potential environmental impact than more valuable pig products." which conversely implies that the X% of upstream impacts are what is		Yes language was not consistent. Edited for clarity.	Y				
74	RP	5	ed.	The heading 'Inventory Results' implies that the following section would show full inventory tables for each of the	Suggest changing the header to 'inventory impact assessment results' to be consistent with the different LCA stages.	Changed to "results"	Y				
75	RP	5.1	tech.	These are not consistent with each other: "It is notable that the Chinese pork scenarios have a higher global warming potential than that of the US pork scenarios; this is due to the manure management emissions that were estimated to be lower for Asian pork production." lower manure mgmt emissions does not =		Error in text. Adjusted.	Y				
76	RP	5.1, § 5	ed.	change: "One mitigating effort to this difference" to "one effort to		Error in text. Adjusted.	Y				
77	RP	6.1.2	tech.	Are the China pig feed proportions and vice versa US feed proportions representing the impacts of just changes in the feed composition or literally using the Chinese pig feed (with transportation impacts included)? If the former, then we would expect to see the PS-China- using US feed go down considering that exchanging US feed for china feed would increase emissions		This scenario was just adjusted to reflect different feed share now, instead of a replacement of the numbers between US and China, as that may be confusing.	Y				
78	RP	Table 26	tech.	% difference for ISCh should be 14% instead of 17%		Results changed, so not relevant.	Y				
79	RP	6.2	tech.	Sensitivity analysis on displacement of fertilizer from manure application. What if manure is considered a waste product of animal production (since many farmers are unable to apply all the manure because of nutrient phosphorus regulations, and those that do, often overapply as a waste removal option (not necessarily displacing fertilizers, particularly as manure N is not		We did not conduct this sensitivity because of the obvious implications for the conclusions - no displacement of fertilizer would increase runoff and leaching and further increase AEP.	Y				
80	RP	6.3, § 3	tech.	Great to see the IPCC AR5 report GWP values are used. Please clarify whether climate carbon feedbacks are included or not, and whether the biogenic methane value was used for manure and		GWP do not use carbon feedbacks and biogenic methane GWP was used. Updated in text to reflect this.	Y				
81	RP	8	ed.	This is the first section that starts referring to the pork as a 'burger', whereas everywhere else it is a patty. While both are	Suggest changing to patty for consistency	Changed throughout	Y				
82	RP	9	ed.	Will increase credibility of the review if credentials of reviewer	Add Dr. prefixes where relevant.	Adjusted. Thank you.	Y				
83	BG	Executive Summary, § 1	ed.	Not exactly clear to the reader if the country of manufacture is the same for both products or if, for instance, the IS is manufactured in the US and the PS is manufactured in China. China has, until recently, imported a not insignificant amount of pork from the US, so it is not unthinkable that they would import an	Please make sure that this is clear in the executive summary.	Language adjusted	Y				
84	BG	Executive Summary, §	tech.	Does a mass based comparison make sense? Calories or some multidimensional nutritional index might be more suitable.	Make note of the limitations of a mass based functional unit when there are differences in nutritional content.	Language adjusted and also in the body of the document a more fulsome description is provided. This is just the Exec Summary.	Y				
85	BG	Executive Summary, §	ed.	Would be good to add why reductions are lower in China. You seem to provide explanations for the other indicators.	Add details.	This is just the Exec Summary. Added more detail in the document.	Y				
86	BG	Executive Summary, p. 2, § 8	ed.	For consistency, might be best to stick with percentages when discussing relative performance (e.g. 71% lower in China) as opposed to using factors. Also because 35% is technically not 3	Change to percentage.	Adjusted throughout	Y				
87	BG	Executive Summary, §	ed.	Again, the long distance suggests that the IS is produced in the US, but this is never clarified.	State this at the beginning to avoid confusion.	Clarified in text	Y				
88	BG	List of Figures,	gen.	Shouldn't there be a comprehensive list of abbreviations and acronyns at the start of the report?	Add a list of abbreviations and acronyms after the lists of figures and tables.	Added a list of abbreivations and acronyms	Y				
89	BG	1.1, § 5	tech.	Direct water inventories, though illustrative of general resource demands, do not fully capture issues of water scarcity and water stress. This limitation should be listed somewhere in the report. Likewise, IMPACT 2002+ land use IPs do not convey the differential impacts of commandeering land in different regions. For instance, the ecological disruption of caused by a coconut plantation in a biodiversity hotspot, such as the Philippines	Add a note about the limitations of the water inventory and land use indicators in the conclusions. Also, life cycle inventories are not suitable for product comparisons according to the ISO guidelines (ISO 14044 Section 4.1). The comparison of water inventory to ReCiPe (H) should be somewhere in the report (Appendix C) to show that the same conclusions can be drawn using a midpoint indicator. This should also be stated at other	IMPACT used for land occupation, but yes limitation added for this. RECIPE used for water depletion.	Y				
90	BG	1.3, § 2	gen.	Regarding US pork exports, what year(s) are you referring to?	Please clarify in text.	Added year	Y				
91	BG	1.3, § 2	ed.	"direct" environmental impact is probably not the best word, since some of the environmental impacts from livestock are are actually indirect, such as indirect land use change (land use teleconnections/telecoupling) as a result of expanding	Use "commensurate" or something similar.	Fair. Used "proportional"	Y				
92	BG	2.1.1., § 4	tech.	Hybrid LCA, which weds processed LCA with input-ouput accounts, could be used to capture the "immaterials" that nonetheless have	Add a note suggesting that there are ways to overcome these data gaps.	Note added in text	Y				
93	BG	2.1.1, § 5	tech.	Are the specific heating capacities of the IS and the PS similar? If not, they may require appreciably different energy inputs for cooking, which would affect your assumption of system	Please check if this is important.	Other studies(i.e. Beyond Meat LCA: Heller & Keoliean)) assumed no difference in specific heating capacities and the assumption is kept here.	Y				
94	BG	Table 3	tech.	Where in Mainland China are IS1 and IS2 shipped? Many port	Please state port of landing in Table 3.	Shanghai added	Y				
95	BG	Table 4	ed.	"...GHG emissions are the highest source of emissions from this	Rephrase	Clarified to impacts	Y				
96	BG	Table 4	gen.	Would be informative to give the approximate amount of time that a pig spends in each stage of its life cycle. Also useful to note if these are the same for US and Chinese producers, and if the	Add this information to the table. Would be useful for understanding reasons for different environmental impacts of U.S. and Chinese livestock systems.	Added language reflecting this	Y				
97	BG	Table 3	ed.	I think a comma is missing:"The resulting emissions are GHG emissions in the form of methane from anaerobic decomposition, and N2O formed during storage, eutrophication from the nutrients leaching into water and leaching during storage prior	Check and revise as needed.	Revised	Y				
98	BG	2.3, § 2	tech.	Although the IS and the PS are nutritionally similar in their ingredients lists, that does not necessarily translate into nutiritonal equivalency. Human bodies more efficiently uptake animal proteins than most vegetal proteins when compared using the Protein Digestibility Corrected Amino Acid Score. For a more detailed discussion on the pitfalls of mass based comparisons in LCAs of food. Heller, M. C., Keoleian, G. A., & Willett, W. C. (2013). Toward a life cycle-based, diet-level framework for food environmental impact and nutritional quality assessment: A critical review.	Consider doing a sensitivity analysis using PDCAAS instead of mass basis or state the limitations of using mass as a basis of comparison. If not, please make a note of this in the text.	Note made in the context regarding this limitation, but sensitivity done for protein and calories.	Y				
99	BG	Table 7	tech.	Further to the above point, there are appreciable differences between the IS and PS in terms of caloric content (IS 18% lower), protein content (IS 18% lower), and fat (IS 33% lower). This would suggest the need for some type of correction to the IS reference flow to make it nutritionally equivalent to the PS, particularly if one takes into account that the IS and PS are meant to be the	Do a sensitivity analysis to look at the impact of using a caloric/protein basis for the funcational unit. If this isn't done, you should clearly discuss this limitation qualitatively.	See Comment #98	Y				
100	BG	Table 7	tech.	Relatedly, how does cooking affect the nutritional content of both the IS and PS.	If there are significant changes from the values in Table 7, then they should be listed.	Cooking values are added. Functional unit modified to be cooked and raw, as it makes the most sense for the two products. Thank	Y				
101	BG	2.6, § 1	gen.	Severity of impacts from land cover/use change is dependent on	Add this detail to the text.	Added	Y				
102	BG	2	tech.	Cut-off criteria for mass, energy, and environemntal impacts have not been clearly stated in the Goal and Scope as prescribed in ISO 14044: "The cut-off criteria for initial inclusion of inputs and outputs and the assumptions on which the cut-off criteria are	Include a short sub-section that clearly states the cut-off criteria used in building the life cycle inventories. See ISO 14044, section 4.2.3.3.3 for guidance.	Added a new Section 2.4	Y				
103	BG	3, § 4	ed.	Or should read nor. "When neither country specific nor region-	Revise.	Adjusted	Y				
104	BG	3, § 4	ed.	"When neither country specific or region-specific inventories were available, global inventories are used but for agricultural processes, local and recent crop yields were used." This is a very	Provide a short (one sentence) example to aid the reader.	Adjusted	Y				
105	BG	Table 8	ed.	Typo: "Zinc" should read "Zinc"	Revise.	See Response #58	Y				
106	BG	3.1.1, § 4	tech.	The 1,500 km assumption is probably reasonable, but a sensitivity analysis should be performed around this assumption, especially given the important role of transport in the impacts of	Include in sensitivity analysis or discuss qualitatively potential impact on results of this assumption.	Sensitivity related to this value was added	Y				
107	BG	3.1.1, § 4	tech.	Likewise, coconuts are harvested from plantations and sent to a port in the The Philippines for export. Is land transportation prior	If not included, add to the inventory.	Added to inventory	Y				
108	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 Information Administration:	Used EIA data for US markets. Added to Appendix E.	Y				
109	BG	3.1.2, § 3	tech.	Do you account for disposal of the 5% of IS lost at this stage?		Included in model as waste in Appendix A.	Y				
110	BG	3.1.3, § 3	tech.	There appears to be a calculation error: 0.44 kg carboard/4.53 kg sausage = 97.1 g cardboard/kg sausage. 8 sausage packs * 20.5 g plastic/sausage pack/4.53 kg sausage = 36.2 g plastic/kg	Please check.	It seems you calcaulted for 10 lb package, this is 20 lb package. 10 lb = 4.54; 20 lb = 9.07. No modification made.	Y				
111	BG	3.1.4, § 3	tech.	Why not use population weighted average distance from distribution center to estimate the distance to retailer? This would be more accurate.		1500 km is approximated. Quantification of distance for each distribution centre in US would be a burdensome calculation for a contribution that is not significant. Took the approach of previous work for this. No modification made, but sensitivity analysis	Y				
112	BG	3.1.4, § 3	tech.	Reference is from 2011, which refers to a report from 2004. Although likely out of date by now, Tassou et al. (2009) paper provides a summary of ratio of refrigerator use to fuel use in refrigerated transport (Table 1). They find a range of 15-25%, which makes your assumption of 8% seem low. Tassou, S. A., De-Lille, G., & Ge, Y. T. (2009). Food transport refrigeration - Approaches to reduce energy consumption and environmental impacts of road transport. Applied Thermal	Check supplied reference and update model as needed.	Fair this is low. Using the data in the paper for medium rigid - - 27% higher energy use and associated refrigerant emissions - a new model was built for transport. Leveraging the CO2 emissions increase only may neglect any changes to the other indicators, so refrigerant emissions were added separately based on loading rates and leaking in the paper. Freezer freighter added as well.	Y				
113	BG	Table 9	tech.	In Section 3.1.1. para. 2 you state that you used a 1% mass cut-off rule for including ingredients in the IS. Table 9 suggests that you omitted as much of 7% of the animal feed in the Chinese case. This suggests a lack of consistency in cut-off rules between the two systems. There should be a clearly stated cut-off rule in the	Clearly state cut-off rules in goal and scope and apply consistently across study (see above).	Language updated throughout.	Y				
114	BG	3.2.1, § 3	tech.	You used data for a single year of US corn production to update the fertilizer and yields. Given seasonal variability, it would	Consider using average values across years to avoid seasonal variations.	Average was used. See Appendix C. Great suggestion	Y				

115	BG	3.2.1, § 3	tech.	Spatial LCAs of US pork production suggest that differences in irrigation needs and electric grids across the US can produce substantial variation in embodied energy and GHGs for corn produced in different regions (Smith et al., 2017). Iowa, in particular, has low irrigation demands for corn production. Corn for swine also appears to be consumed relatively locally. This might mean that irrigation, energy, and GHGs for feed in your system are overestimated. See: Smith, T. M., Goodkind, A. L., Kim, T., Pelton, R. E. O., Suh, K., & Schmitt, J. (2017). Subnational mobility and consumption-based environmental accounting of US corn in animal protein and ethanol supply chains. Proceedings of the National Academy of	Add a note about variation in resource intensity and related GHGs of feed production across U.S.	Section added in 3.2.1	Y				
116	BG	Table 14	ed.	Description of "Fair" data quality with respect to completeness contains identical text to the "Poor" scenario. Should read "Data from less than 50% of sites over an adequate time period or from	Update if my reading is correct.	Revised	Y				
117	BG	Table 17	tech.	The assessment of data quality is adequate. However, the coconut oil data is 26 years old, which would suggest "Poor"	Explain how the data were updated to 2014 to support your assessment of the data quality.	Fair, revised.	Y				
118	BG	Table 19	tech.	eGrid is neither the most spatially resolved nor most up to date model of electrical generation in the U.S. The Energy Information Administration contains historical data and projections for all of the ISO regions, including the sub-grid supplying metro Chicago,	As noted above, consider using these data to make your model more accurate. See: https://www.eia.gov/electricity/data/browser/	Used EIA data for US markets. Added to Appendix E.	Y				
119	BG	Table 19	tech.	The USDA performed the Census of Agriculture in 2017. This contains data on planted area and production, which can be used to estimate yields, at the county level across the contiguous U.S. If you know where your feed is originating, you can use these data to make the model more accurate and to capture the wide variation in agricultural intensity across the U.S. Uncertain	Consider using these data. See: https://www.nass.usda.gov/AgCensus/ or make a note of the limitation of using national averages for large countries like the U.S. and China.	Thanks. Model adjusted to include data was taken from the Ag Census. Specific to Iowa was used.	Y				
120	BG	4, § 3	tech.	You used an economic allocation key for the multifunctional pork production system. Given that the outputs of feed production and pork production are intended to provide sustenance, a nutritional allocation, such as protein content or energy content, may be	Perform a sensitivity analysis would show if this impacts results or add a note about the potential impacts of mass vs. nutritional allocation.	We would argue the economic allocation is the more relevant allocation procedure because of the considerable difference in the economic value of the cuts. We don't consider the nutritional allocation to be sufficiently different among the cuts. A sensitivity	Y				
121	BG	Table 21	ed.	A minus sign is missing from the IS1-PSI China scenario for aquatic	Please revise if my reading is correct.	Revised	Y				
122	BG	Table 21	ed.	Land occupation units listed as "m2-y" in heading. IMPACT 2002+	Please revise.	Correct throughout to m2 org arable-y	Y				
123	BG	Table 21 footnote	ed.	You state that there was no significant difference in water results when switching from an inventory method to ReCiPe (H). This is vague.	Quantify what you mean by no significant change. This note is particularly important in an ISO context since an LCI study alone shall not be used for comparisons intended to be used in comparative assertions intended to be disclosed to the public (ISO 14044 Section 4.1). The comparison with the ReCiPe (H) should be stated in the limitations and executive summary to ensure that readers know that although inventory approach was used for the water comparison, in contravention of ISO guidance, this has been vetted against an LCIA method. A figure in the appendices	RECIPE was used instead for water depletion. This was removed	Y				
124	BG	Table 21	tech.	Curious that the eutrophication potential is lower for the Impossible Sausage when consumed in China compared to the U.S. All of the production processes are identical. The only	Check for errors.	Adjusted as results changed.	Y				
125	BG	5.1, § 3	tech.	Comparison of the IS to PS in U.S. context assumes homogeneous water intensity of pork production across the country. Spatial-LCAs suggest otherwise. https://iopscience.iop.org/article/10.1088/1748-9326/ab9a6a/pdf	Add a note on spatial heterogeniety of water intensity in U.S. pork production and how this might affect this comparison.	Added	Y				
126	BG	5.1, § 4	ed./tech.	Sentence reads a little contradictory: "It is notable that the Chinese pork scenarios have a higher global warming potential than that of the US pork scenarios; this is due to the manure management emissions that were estimated to be lower for Asian pork production." Table shows Chinese pork to be less carbon intensive. Perhaps omit this sentence altogether, since the differences between the carbon intensities of US and Chinese pork are negligible enough to fall into uncertainty range. This is a	Remove sentence.	Revised	Y				
127	BG	Table 24	gen.	It would be useful to see how much the Monte Carlo results presented as a bar chart showing the average value over 500 runs and error bars. Would allow the reader to gauge how uncertainty impacts relative performance of the compared systems. Alternatively, you could state that the uncertainty analysis was performed to test for changes in directionality of the	Show a figure of the MCS results or add a statement directionality vs. relative performance.	Added a statement re directionality	Y				
128	BG	6.1.2	tech.	As you note, the quality and content of pig feed also has an impact on environmental impacts. From my understanding, pigs, unlike cattle and broilers, are true omnivores that can eat a wide variety of feeds, including waste feedstocks (see references below). Mackenzie, S. G., Leinonen, I., Ferguson, N., & Kyriazakis, I. (2016). Can the environmental impact of pig systems be reduced by utilising co-products as feed? Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2015.12.074 Salemdeeb, R., zu Ermgassen, E. K. H. J., Kim, M. H., Balmford, A., & Al-Tabbaa, A. (2017). Environmental and health impacts of using food waste as animal feed: a comparative analysis of food waste management options. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2016.05.049	Consider adding note for use of waste feed in China.	Added a qualifier for the additional content of feed, but did not conduct a sensitivity analysis related to this only to differing amounts of major crops in the feed.	Y				
129	BG	6.1.3	tech.	You mentioned the idea of producing IS in China in Section 5.1.		Great idea. Added to the sensitivity analysis.	Y				
130	BG	6.2	tech.	You could test the caloric allocation method here or the impacts		Yes, see above comments. Sensitivity to calories and protein	Y				
131	BG	6.3, § 4	tech.	Appears that IS1-China is less than 100% of baseline value and IS2-US is above 105% baseline value, so it doesn't stand that differences between the two methods for land use ranged	Please check and revise accordingly.	This was removed so no longer relevant.	Y				
132	BG	7	tech.	Seems to be a few limitations that have not been listed. i) Use of inventory for water instead of midpoint indicator ii) Aspatiality of life cycle inventories for feed iii) Transport assumptions iv) Mass as a basis of comparison as opposed to other equally	Either add here or make notes at relevant sections in the main text.	i) Used ReCiPe instead of inventory calculation. All other limitations were added.	Y				
133	BG	Table 27	ed.	Benjamin Goldstein is currently a Postdoctoral Fellow at the School for Environment and Sustainability at the University of Michigan. He will be starting as an Assistant Professor at McGill	Please update.	Adjusted	Y				

Comment No.	Reviewer initials	Section and paragraph (§), Figure, Table	Type of comment (gen., tech., ed.)	Reviewer comment	Reviewer suggested action(s)	Authors response	Issue resolved (Y/N)	Authors response2	Issue resolved (Y/N)2
134	JRM	5.1, §2	tech.	IS1 and IS2 are functionally not equivalent as the second is pre-cooked., as this may change the cooking time at the consummers' house. In order to compare them, the use stage would need to be included in the boundaries. Their results can be compared but the comparison would need to be put in this larger context		They are not meant to be compared to each other. Language adjusted wherever this may be seen as a comparison and clarified in a few areas.	Y		
135	JRM	5.1, §5	tech.	Based on Table 22, the Water depletion result is dominated by sunflower and coconut oil production, thus during processes upstream from IS production. I do not then understand what you mean by "the vast majority of that water is re-used by the system". Water depletion is calculated as withdrawal minus the water returned to the watershed from which it was taken. I do not see how water used for coconut production in the Philippines can be used in	Clarify what is meant by this re-use of water.	Language not clear, was meant to be within the coconut oil system, but just removed this part.	Y		
136	JRM	Figure 4	tech.	The results are normalized to the highest score (set at 100%) for each comparison between the IS and the pork product. No comparison between compared pairs can be done (ISUS and ISCN for example). This need to be clearly indicated		Languaged added to reflect this	Y		
137	JRM	5.1.2, §2	tech.	I would be surprised if the amount of sunflower oil can be reduced without increasing the amount of (an)other ingredient(s), the net outcome of the change would need to be verified		Languaged added to reflect this	Y		
138	JRM	6.1.4, §1	ed.	The sentence "It was assumed that IS1 – US, IS1 – CN and their PS equivalents, and IS2 – CN would not behave significantly different than just the US scenarios because even when IS2 is shipped to China, the primary transport impact contributor is from the distribution of the product from Chicago to Shanghai, not from the US based ingredients transport and the Chinese retailer distribution."	Please clarify.	Languaged simplified.	Y		
139	JRM	6.1.4, §3 and 4	tech.	You consider a 1.6% and a 5.6% change in result for a 33% change in parameter value significant? I would not.	Remove the word "significantly".	Removed	Y		
140	JRM	6.2, §6	tech.	The first sentence is confusing, to what stage are you referring to? Sensitivity analyses test the sensitivity of the conclusions to uncertainties in the modelling associated with methodological choices (e.g. data sources, allocation method). Applying mass allocation to the slaughterhouse inventory is a practical application of sensitivity analyses, but in this case, may not be appropriate as mass allocation makes no distinction between coproducts in terms of their possible responsability as to the activity generating them, i.e. the driver for pig rearing and slaughter is the production of the valuable cuts of meat, they should then be considered differerent from the low value coproducts.	Rephrase.	Mass allocation done.	Y		
141	JRM	8, 1st bullet	ed.	The use of the products is not included in the analysis.	Remove "and consummed".	Removed	Y		
142	JRM	Appendixes, Tables 39, 50, 56	tech.	I am doubtful a micro gas turbine would be used to produce the heat to cook the products in Chicago, the general U.S and China.	Verify dataset used to model heat to cook products.	Fixed: Energy for cooking: Heat, central or small-scale, natural gas {RoW}| market for heat, central or small-scale, natural gas | Alloc Def, U	Y		
143	JRM	Appendix A, Tables 43	tech.	Increasing the total t.km by 27% to represent the extra energy for freezer transport also increases the included tire, brake and road wear emissions (metals in air, water and soil), which are not energy related	Correct	Removed 27% of the emissions from road wear, tyre wear, and brake wear in the inventory.	Y		
144	JRM	Appendix A, Table 51	tech.	US (MRO) electricity was used for the Chinese system?	Verify.	No error in transcription. CN used.	Y		
145	JRM	Appendix B, Table 53	tech.	There is no US slaughterhouse table.	Correct	Added	Y		
146	JRM	Appendix C	tech.	Land occupation flows are quantified in m2.a, i.e. surface x time of occupation. The yield gives the amount of crop per surface area, what was the time period considered in the new calculations of the occupation flows?		See Comment #9	Y		
147	RP	throughout	gen.	The ReCiPe water depletion indicator is still an indicator of water use (withdrawals), so will need to have a extraction to water consumption ratio applied in order for water consumption to be estimated – (ie. The characterization factor for the water depletion category is 1 so will need to apply this as the flow input). See table 10.2 in https://www.rivm.nl/bibliotheek/rapporten/2016-0104.pdf	Either explain that the water depletion indicator is representative of water use because consumption was not estimated, or apply the appropriate abstraction/consumption ratios indicated in table 10.2 and discussion in https://www.rivm.nl/bibliotheek/rapporten/2016-0104.pdf	Intention was for total water "use"/depletion. Consumption is not estimated. Language added to beginning re: clarity, but reader is also directed to source.	Y		
148	RP	section 1.3, 2nd paragraph Mekonnen and Hoekstra 2011 reference	gen.	Wrong reference- currently cites the crop water footprint, but livestok is not addressed in that publication.	should cite Mekonnen and Hoekstra 2012 Assessment of the Water Footprint of Farm Animals, which states 29% of global agricultural footprint is from livestock production. Also need to cite Mekonenn and Hoekstra Water footprint of humanity which states agricultural production accounts for 92% of the global water footprint, and so this value should actually be 27%. Additionally, need to change water 'use' to water consumption, because 'use' refers to abstraction or withdrawals, while consumption is depleition (a	Citations changed and added.	Y		
149	RP	section 1.3, last paragraph		Enteric fermentation is much less than manure handling because pigs are nonruminant animals, and should be indicated as such via the order in which signficant environmental indicators applies.	Change order of mention to correspond with primary contibutors in order of contribution	Changed throughout	Yes, except in section 3.2.2, 1st paragraph, see third round comments	Adjusted as per Comment #54	Y
150	RP	section 2.1.2, 2nd paragraph		Slaughter' should be considered part of the 'pork product processing' as it is the process that converts pig to pork.		Updated	Y		
151	RP	section 3.2.1, 1st paragraph		"but also includes wheat"- change this to barley for consistency with tables		Updated	Y		
152	RP	section 3.2.1, 2nd paragraph		Yields are 2017 to reflect the census, only fertilizer use goes to 2018 (but average values are used).	Make text consistent with data tables in appendix	Updated	Y		
153	RP	section 3.2.2, 1st paragraph		List in order of primary contribution- manure management is highest contribution, otherwise there is misperpecption that enteric fermentation is large in pork systems		Updated	No, see third round comments	Adjusted as per Comment #54	Y
154	RP	section 3.2.2, 3rd paragraph		This is contradictory with the manure management system discussed above in section 3.2		Clarified in 3.2.	Y		
155	RP	section 3.2.2, table 10, enteric fermentation and manure management rows		These results say that enteric fermentation is approximately 15% of the total manure management emissions (11.61/77.87), but it is unclear how this was calculated given that the IPCC tier 1 emission factors are used. IPCC has enteric fermentation EF for swine as 1.5 kg CH4/head and the lowest emission factor for manure management possible from table 10.14 is for market swine at 10 kgCH4/head (in the coldest climates), which only results in at most 13% of total manure management emissions. Emission factors for temperate areas (more representative of a Midwest pork production system) have manure management emission factors at greater ranges which further reduces the importance of enteric fermentation relative to manure management. And when factoring in the emissions allocated to market swine from the parent breeding swine (which is unclear whether this was taken into account in these calculations- but which are indeed taken into account in the pelletier data) this ratio would be even further reduced. It has always struck me as odd to call out the enteric fermentation as a large impact as it is typically not in comparable studies (relative to manure management and	Should revisit calculations and define parameters used	Checked the valculations and you are correct. Some changes were made to the numbers and enteric ferment was still 6% of impacts for PS-US, manure management was about 55%. Different for China obviously where Efs (1 and 3) for enteric and manure mangement are much closer.	Y		
156	RP	section 3.2.3, 1st paragraph		"Was avaialble was fertilizer" change for clarity- also is this referring to plant available nutrients or the amount of manure loss/not recovered for application?		Amt replacing the synthetic fertilizer. Language adjusted	Y		
157	RP	table 15		Water depletion: consistency in indicator names		Adjusted	Y		
158	RP	table 15		This is surprising that transportation shows up as the significantly contributing process in both the US and china scenario, one may expect that due to the substantially smaller transportation for the IS1 scenario, that the production impacts from LUC for example from ingredient production may show up		19% for IS1-US and 35% for IS1-CN. Significant.	Y		
159	RP	Table 16, data quality commentary		Why not use average yields for soybean and sunflower? If are using, then should use same language		Used census values from 2017; language made consistent.	Y		
160	RP	Table 18, global warming potential		Should list in order of contribution within each indicator section. Enteric fermentation in pig production is not the primary contribution. Isn't corn a significant contributor to GWP impacts? Feed was called out earlier as the most significant contributor to GWP impacts in upfront text on the system.		Maize grain is 3%. enteric fermentation at 6%.	Yes for order of contribution, but see third round comments regarding corn result of only 3% (comment #204)	We reviewed the contributions again and it does seem there was an error in the way it was presented. The contribution from corn is 17%, significantly higher than enteric fermentation (6%) and electricity (6%), but lower than manure mgmt (54%). This was reflected in an updated significant process identification in Table 18 and then subsequent data analysis. We thank you for the ID of the error and apologies for not completely addressing it further earlier.	Y
161	RP	Table 19		Enteric Fermentation and Manure Management rows - Due to conflicting text, what activity data was used here? Relative portion of market swine to breeding cows and weight? Based on last response, manure management system nor feed are used to calulate related manure emissions or enteric fermentation, IPCC average rations/management systems are instead used, so is		Correct - total simplification of the pork system was provided to only rely on T1 Efs. Activity factors only based on IPCC, but some population data used to quantify relative portion of market to breeding cows/weight for US system	Y		
162	RP	Table 19 - Barley production row		Activity data: says proportion of soy, change to barley production. Also previous data tables discuss barley applying only to the Chinese scenario, so may include note that its applicable to sensitivity analysis		Updated	Y		
163	RP	Section 4, 2nd bullet		says Agri-footprint 'sunflower seed' process, but seems to be a mistake given the section is in regard to coconut oil		Updated	Y		
164	RP	Section 5.1		Water depletion: consistency in indicator names		Updated	Y		
165	RP	Table 22, caption		Need further details on this for clarity. The 'net' discussion could be construed as related to distinctions between withdrawal consumption, or related to Blue water or total water footprint (blue green and grey)? Should clarify upfront that this water depletion is referring to 'blue water' and not green water (I assume). In general it is unclear what the negative contributions (essentially putting water back into the ground) would be - does this additional water get produced through the production process from chemical reactions?		Water put back into surface water extraction (irrigation returned to reservoirs, etc.). Clarification added in the text.	Yes, but see third round comments (comment #195). Irrigation returned to reservoirs implies that you did in fact consider the water consumption (essentially taking water withdrawals for irrigation - water returned to reservoirs = water consumed), so considering that the rest of text has been updated for water withdrawals, it is unclear how and when water consumption gets accounted for (there may be a mismatch between withdrawal and consumption info in the inventory).	The indicator is water depletion from the ReCiPe methodology which is defined as water consumption in the Methods for SimaPro. Water withdrawals was used when speaking about the withdrawal only (literally, the extraction of water for uses). Language was further clarified where necessary. This is also our mistake in incorrectly identifying the definition of water depletion which is water consumed = water withdrawals for irrigation - water returned to reservoirs, as you ntoed it to the right. Language updated	Y
166	RP	Tabe 24		Add 'Potential' to Environmental Impact in column header		Updated	Y		
167	RP	section 6.1.2, paragraph 1		Regarding first sentense- "re-calculat the enteric fermentation and manure management emission factors": IPCC factors are used for enteric fermentation and manure management which is just based on emissions/head, which do not rely on feed to estimate- it is unclear what parameters are used for this recalculation- is it simply that the studies provide animal numbers of market swine to breeding populations to get the weighted average emission factor?		Re-clarified throughout to reduce language related to those studies and only using them for population weighting, where necessary.	Y		
168	RP	Tabe 26		Regarding water depletion between PS2- US(baseline) and PS2 - USI. Is this right? Reducing corn by 10% reduces water depletion by 30%. Likely is a calculation error since water use is not spatialized		Yes! It was incorrectly transcribed! Thanks.	Y		
169	RP	Section 6.2, 3rd paragaph		Biggest different', change to differences; remove 'there'		Updated	Y		
170	RP	Section 6.2, 3rd paragaph		"calories increased by 36% compared to PS1" - Should consider providing an explanation to this since most cooked items have decreased calorie content (where meat increases due to the increase in digestability of collagen protein in meat when cooked).		This data is for meat - data from the USDA. Language clarified.	Y		
171	RP	Table 30		Need caption with the asterisks included referring to the headers		Just removed asterisks because they were provided before.	Y		
172	RP	Section 6.2, 5th paragaph		"protein content in pork patty decreased by 13%" Should cite this- this seems unusual and quick google search can't corroborate		Cited - USDA	Y		
173	RP	section 6.2, last paragraph		I disagree that a sensitivity analysis around alternative ways to allocate slaughter impacts is not warranted. The goal of the study is to compare the potential environmental indicators of concern of IS to PM, and given the substantial influence that the slaughterhouse allocation method has on comparative results, it is exactly the situation where application of the sensitivity analysis function is practical- we know the impacts of pork production will be reduced under alternative allocation scenarios, but does the directionality of the preferability in IS over PM ever change depending on allocation method selected? If a mass balance method is used, ~62% of the indicators could be allocated to pork meat (when you consider that 5% is not economically viable according to the agrifootprint database – which refers to a purpose-based mass allocation approach). There are several questionable assumptions that additionally contribute toward the need for a sensitivity analysis around slaughter allocation method- 1) lots of different types of meat included in the naics code, not specific to pork so could have potentially large variability given overseas markets for secondary pig products, as described in 1st round comments, 2) the allocation is based only on US valuations, so could be very different in China, 3) allocation based on physical relationships is the preferred ISO method (economic being the least preferred method due to issues with comparability across time and across geographies). In light of this, if a mass (or energy allocation) is not of interest, then I recommend at least a sensitivity analysis around the economic allocation method should be performed, perhaps changing the allocation ratio in increments similar to the previous sensitivity assessments. If directionally the conclusions are the same, then greater confidence that IS products result in lower environmental		Mass allocation conducted.	Y		
174	RP	sectio 7, paragraph 3		"to characterize the environmental indicators the two IS varieties studies"- changed to "of the two IS varieties studied"		Updated	Y		
175	RP	section 7, first bullet		Enteric fermentation and manure are based on broader regions, not specific to the Iowa and Chinese region mentioned, so are in fact representative of the average production of these countries respective regions	Suggest distinguishing between feed which represents these specific regions in the US and China, versus manure management/enteric fermentation.	Language updated.	Y		

176	RP	Section 8, last paragraph		"unambiguous" - See above comment on section 3.2.1- if there are multiple ways that impacts can be allocated between meat and co-products (and are known to have substantial effects on results and potentially preferability), then it stands that this should be investigated if the goal is to determine whether there truly is unambiguous benefits, particularly when other studies have used mass or other physical methods as basis for allocating these		Unambiguous removed and mass allocation conducted.	Y		
177	RP			Please add Research Scientist, University of Minnesota, Institute on the Environment		Updated	Y		
178	RP	appendix B, table 46, 47		Manure inputs/outputs are confusing- manure (application) is listed as input to pig production – is this referring to the manure applied to crop fields used for pig feed? But it refers to table 47 as output, with inputs as emissions to air. Need to revise for clarity. Also, live pig manure (is this to make a distinction with the manure generated at slaughter houses)? Otherwise is odd expression.		Adjusted language re: "Live pig manure" and added manure to feed production and removed "emissions to air"	Yes, but see third round comments (comment #203)	See response #203	Y
179	RP	table 47		Change live meat to Live weight basis		Updated	Y		
180	RP	Table 49		What about the inventory for the slaughterhouse for 'pig meat, fresh, at slaughterhouse'? Seem to be missing the US equivalent for table 53. Suggest referring to the appropriate tables in the comments (seem to be missing for the pig meat, fresh at slaughterhouse flows)		See Response #145	Y		
181	RP	Table 52		Manure spreading or application seems to be only referring to the emissions associated with the application to fields, but this does not account for the emissions from the storage management systems themselves. Pig production inventory is missing these and the enteric fermentation emissions even though they are indicated in the main text, should at least refer back to them or better yet, include in these inventories for a consolidated place of flows.		Included in inventories - apologies this was an error.	Y		
182	RP	Appendix C		Why are average years used for all the china scenarios but single year census is used for the US scenarios (except barley which uses an average)? Isn't the issue of having a single year's yield to base estimates applicable to the US crop products? Variability is high year to year		We used the 2017 census as a basis for this information; the previous years was 2012, so would not be as applicable. We gave 50% uncertainty to these values in the Monte Carlo.	Y		
183	BG	List of Figures, Tables, etc.	gen.	For completeness you should include PS1-CN, PS2-CN, etc. to the list of acronyms or add US and CN just to keep things crystal clear for the reader	Update list of acronyms	added US and CN	Y		
184	BG	2.1.1, §4	ed.	Response to comment 92 is adequate, but language could be clearer.	Instead of "not material to this study," say something like "are not significant contritbutors of impacts in agrilcultural systems" or something of the like.	Language updated	Y		
185	BG	Table 5	ed.	Inconsistency between text and table. Table does not mention if uncooked IS and PS are frozen. Language at start of section 2.1.1. suggests uncooked sausages are frozen.	Please check and update relevant text/tables as needed.	Language updated	Y		
186	BG	Tables 24 and 25	ed.	Nice to see the sensitivity anlaysis to different pig feeds. Suggest changing the scenario results to percentages of the baseline to better see the relative change.	Consider using percents instead of impact potentials.	Done	Y		
187	BG	6.1.4, §3	tech.	Would be good to estimate how much transport distance would need to increase to make the IS similar in impacts to the PS (<10% difference). My guess is that this will be bigger than any reasonable distance, which would remove any doubt about the conclusions.	Consider using extreme value analysis for one indicator. Could do the same for transport to retailer.	Added 10,000 km just for an extreme value.	Y		
188	BG	6.2, §4	tech.	Nice to see the sensitivity analysis by caloric content. The 8% difference between IS2 and PS2 is rather small. I would adjust the language to reflect this, specifically with regards to the study conclusions.	Revise "there is no difference in the conclusion that the environmental indicators are all lower for the IS scenarios than for the pork scenarios." to something like "there is no difference to the conclusion that modeled enviornmental impacts are lower for the IS scenarios than for the pork scenarios. Small difference in land impacts between IS2 and PS2 when using a caloric functional units make conclusison in this case less certain, although the significant differences found when using both mass and protein (see Table 31)	Updated	Y		
189	BG	6.2, §4	ed.	Text should read "Table 31" not "Table 30."	Update text.	Updated	Y		
190	BG	6.2, §7	tech.	Use of economic allocation is justified, but different valuations of byproducts in US and Chinese contexts might impact results for PS-CN.	Make note of different valuations of byproducts across national context with mention of how this would affect estimated impacts of Chinese sausage production. Perhaps after Table 12.	Language added	Y		
191	BG	Table 60	tech.	Good job finding more representative electrical grids. Looks like you used data for all of Illinois. I was suggesting in comment 108 that you use PJM/Commentwealth grid, which has a higher share of coal and natural gas, and a lower share of nuclear. See here: https://www.comed.com/SiteCollectionDocuments/SafetyCommunity/Disclosure/Environmental_Disclosure_12_months_ending_09302	Note that the PJM Comed grid supplying IS factory is more carbon intensive than the grid used in the model, but this will only have a slight influence on the results and will not change the conclusions of the study for any of the indicators.	Switched to that grid. Updated values and grid in Appendix E	Y		
192	BG	8, §5	ed.	Although directionality of the conclusions did not change in the sensitivity analysis, relative performance did, specifically for where differences in land impacts dropped to 8% (probably within the uncertainty bands of an LCA). Worth noting.	Add text mentioning that land impacts were especially sensitive to analysis using a nutritional basis of comparison.	Updated	Y		

Comment No.	Reviewer initials	Section and paragraph (§), Figure, Table	Type of comment (gen., tech., ed.)	Reviewer comment	Reviewer suggested action(s)	Authors response	Issue resolved (Y/ N)	Authors response2	Issue resolved (Y/ N)2
183	RP	List of acronyms		United States listed twice, one next to PBMA, and again after RFC		Removed	Y		
184	RP	section 2.3, last paragraph		"vegetal proteins" should be "vegetable"		Adjusted	Y		
185	RP	Table 8		sunflower modified process refers to both table 39 and 40 in appendix, but only table 40 referred to. Also, suggest listing appendix B after table referenxces to avoid confusion with appendix C listed		Updated	Y		
186	RP	section 3.1.2, 2nd paragraph		"the contribution of producion within the facility in the environmental indicators was fully allocated to the IS" is confusing. Consider changing to 'the environemntal indicator contiribution from production within the facility is fully allocated to the IS		Updated	Y		
187	RP	sextion 3.2, 2nd paragraph		"mass-weighted" average should be population weighted average if I am understanding the procedure correctly, unless the IPCC factors were renormalized and scaled to the market and breeder pig weights assumed by the Pelletier and Zhou articles?- if so need to		Updated	Y		
188	RP	Table 9		Make header references consistent with text references	Change to Pelletier et al 2010 and Zhou et al 2018	Updated	Y		
189	RP	section 3.2.1. 2nd paragraph		Regarding the "previous year averaged"- the fertilizer data is from 2014 to 2018 based on appendix- need to make text consistent with data	suggest just listing the data year range since fertlizer is now separated from the yield data year	Updated	Y		
190	RP	section 3.2.2, 1st paragraph		"The primary sources of environmental impact in this stage are enteric fermentation, manure management, and on-farm operations." - need to instead list in order of primary contributions (enteric fermentation is not the primary contributor)		Updated	Y		
191	RP	section 3.2.3, 1st paragraph		" 75% of the nitrogen in the manure was replaced synthetic fertilizer" - remove 'was' before replaced for clarity		Updated	Y		
192	RP	Table 11		Avoided N fertilizer row - suggest changing to avoided synthetic N fertilizer.		Updated	Y		
193	RP	Table 16		Sunflower seed production - data quality commentary column, "and as per USDA" - remove the extraneous 'and'		Updated	Y		
194	RP	Table 18		Why does corn prodution not show up as a signficant contributing process to global warming? This result diverges from previous studies and the literature review presented in section 1.3 and table 2	Suggest making a note in the discussion about why this study does not estimate feed to be a primary contributor to pig impacts despite the literature review of other studies that say otherwise	See Comment #160: We reviewed the contributions again and it does seem there was an error in the way it was presented. The contribution from corn is 17%, significantly higher than enteric fermentation (6%) and electricity (6%), but lower than manure mgmt (54%). This was reflected in an updated significant process identification in Table 18 and then subsequent data analysis. We thank you for the ID of the error and apologies for not completely	Y		
195	RP	table 22 caption		What is the denominator for this? Based on the description earier, should be total blue water withdrawals used across ingredient production, processing, packaging, etc., so the total blue water withdrawal of sunflowers/oil and coconuts/oils (regardless of how much is returned to the system) divided by total blue water withdrawal throughout the product system. As such, its unclear why this would sum to over 100%. Also see response in 'issue resolved column' for comment #165 in 2nd round review.		This is our mistake, we did not define water depletion properly as per ReCiPe. This was adjusted in 1.1. To address your comment, since the net amount has a negative and positive aspect in the inventory, the particular contributions from processes may be net negative/net positive. In this case, coconut production had a net positive water depletion (i.e. it caused water depletion): 0.121 m^3 were returned and 0.206 m^3 was taken - this represents 57% of the contribution to the overall water depletion. Same goes for sunflower oil - the process has a net positive water depletion - 68%. BUT there are other processes which are net negative so that's why those two processes can add up to more than 100% of the total.	Ok, but what are the other processes that are net negativem, and under what circumstances does this occur? See comment number 3 in 4th round comments. An example in which net negative water depletion occurs describing more tangibly why more water is returned to the system than that withdrawn would be useful here (because now it still sounds like it is blue water withdrawn - blue+greenwater returned to system which would be incorrect.)	Added in wastewater treatment - See Comment #212	Y
196	RP	table 32		The differences indicated in the table are not the absolute value differences indicated in the preceding set of tables	suggest removing the negative sign for consistency	Updated	Y		
197	RP	section 6.2.2		The wording in the last paragraph is confusing. I think it is essentially saying that because most of the contribution to the environmental indicators is prior to processing (upstream of retail distribution), that changing the allocation schema or the portion of potential impacts allocated to the fresh meat portion versus co-products in slaughter results in a commensurate change in the environmetal indicators, such that a 10% change in the allocation distirbution results in approximately a 10% change in the environmental	Suggest adjusting the wording of the first sentence in the last paragraph for clarity	Updated.	Y		
198	RP	Table 35		Ammonium sulfate input shows that it uses a Simapro input of Aluminum sulfate, which I believe is in error since ammonium sulfate is an available process		Typo. Adjusted.	Y		
199	RP	Table 37		Is Heme used in IS2 product? Currently isn't in the input list (but is for IS1).		Error. Adjusted	Y		
200	RP	Table 39, 40, 41		Doesn't seem to follow same format as the previous tables in the left column (many rows are left blank, leading reader to wonder if the simapro inputs without corresponding names in the left column are a subset of the inputs that are listed in the left column- e.g. do transport, tap water, electricity, steam processes all fall under the		Adjusted	Y		
201	RP	Table 43		Bulk 'prdouct' - change to 'product'		Adjusted	Y		
202	RP	Table 52		Missing output designations in the left column (doesn't follow the same format as the other tables in that regard)		Adjusted	Y		
203	RP	Table 49, 50, 51, 55, 56		How much of the manure is estimated to be displacing synthetic N? from table 49, .41 'pieces' of manure are input based on 1 piece/kg of live weight generated and 2.44 kg of feed/kg of live weight. But if manure is considered a co-product (and not just waste with emissions), then should be indicated as a co-product of pig production as an output (in table 50 and 56). This information will also help in illuminating the details of the displacement calculations		Fair. This is adjusted and added to table 50/56.	Y		
204	RP	section 3.2.3, 1st paragraph		The "75% of the nitrogen in the manure was replaced synthetic fertilizer and 97% of the phosphorous in the manure replaced synthetic fertilizer. This represents the "avoided" fertilizer." exerpt is referring to the assumptions stated in Nguyen et al, but in Nguyen the assumption is actually referring to the Danish regulations saying that 75% of the total crop fertilizer N has to come from manure fertilizer, which provides all the phosphorus needs except for the amount that is lost to leaching (3%). Currently it is worded like 75% of the N and 97% of the P in manure replaces synthetic, so one would expect the equation for displacement to be: quantity of manure generated/kg live weight*nutrient content of manure*.75 = the total quantity of synthetic N replaced per kg live weight, but if using the Nguyen assumptions then it is assuming that 75% of the synthetic N is replaced with manure N, with an expected equation: total synthetic N required/kg swine*.75 = quantity of sythetic N replaced/kg live weight. If indeed the latter, this might explain why feed (particularly corn feed) contribution to GWP is so much lower than would be expected in comparable studies (thoma and pelletier for example). The method for calculating displacement emissions needs greater explanation as it results in feed not showing up as a	Revise for clarity; include greater details on how displacement of synthetic N fertilzier is calculated since it has a large effect on the feed not showing up as a hotspot. While replacement of 75% of synthetic N is not necessarily likely in US context, it serves as a conservative scenario for comparison for the goal of the study, and reduction potential for ISvs. PS may be even higher (since changing this assumption would result in higher pig emissions)- this should be noted.	See Response to Comment #160 re: issues related to corn, but this is a fair comment too. The amoutn was calculated using the former calculation. Language was modified to reflect the fact that this is not Nguyen's direct approach, but the calculation was performed according to the description above. Note that the calculation in Nguyen was based on the fact that manure N/P availability was the limiting factor.	Y		
205	BG	1.1, §3	ed.	Extra period at end of paragraph.	Remove	Removed	Y		
206	BG	1.3, §3	tech.	Assuming that all the previous studies used a cradle-to-gate scopes, the agreement between studies on the significantly contriubting activities might be due to the fact that no one has looked at the full life-cycle. Cooking could actually be of importance. Correct?	Check and change language to note that the highest contributing processes may be an outcome of scope bias if necessary.	Language updated	Y		
207	BG	3, §2	tech.	You excluded infrastructure. Might this be of consequence if new facilities were built or significant retrofits made to existing facilities for the IS?	Clarify in text to justify the exclusion of infrastructure.	Language updated	Y		
208	BG	Table 8	tech.	Is sugar from sugarcane suitable in a US context? I would expect corn-derived sugars.		Best available process in ecoinvent.	Y		
209	BG	6.2.1, §3	ed.	"superiority" is not a suitable term in this context. Poor suggestion by me from earlier.	Change to "show that predicted land occupation is generally significantly lower for the IS" or something similar.	Language updated	Y		

Comment No.	Reviewer initials	Section and paragraph (§), Figure, Table	Type of comment (gen., tech., ed.)	Reviewer comment	Reviewer suggested action(s)	Authors response	Issue resolved (Y/N)
210	RP	Section 1.1, 3rd paragraph	tech.	"Water depletion was quantified; water depletion is defined in Goedkoop et al. (2009) as water withdrawal (from irrigation sources, for example) minus water return (to a body of water, for example) and does not include water consumption which is evapotranspired or physically embedded in a product." is an incorrect statement as water depletion is a term synonymous with water consumption. The equation for water depletion is: Water withdrawal - water return = water consumption (ie. the water that does not return to nearby water bodies because it is evapotranspird or embedded in a product)		Language updated	Y
211	RP	Section 5, last paragraph	ed.	"the thresholds for evaluating that "supremacy" is still subjective"- Suggest substituting 'supremacy' for 'environmental preferability'		Language updated	Y
212	RP	Table 22 caption	tech.	The exerpt "because there may be net negative contributors to water depletion as the indicator is calculated (i.e. they return more water to the reservoir than they consume because, for example, they may absorb or use water that already exists in a system), which when added across the full inventory, comprise the total water depletion amount." is still unclear how this is calcualted or under what circumstances this occurs- the comment that 'they may absorb or use water that already exists in a system' sounds like this could be alluding to the natural precipitation (green water) that naturally exist in ag systems. If my interpretation is correct, it sounds like the equation then that is used to estimate 'net' water depletion is water withdrawals (blue water) - water returned to system (blue+green water), and if blue+green water return > than blue water withdrawals then water depletion would be net negative. But the 'water depletion' metric refers only to the extractive freshwater withdrawals (blue water) - the portion of the withdrawal that returns to system, and should not include the green water that falls on the crops (that is not taken up by crops). About 40% of crop blue water withdrawals return to the system, so if this study is correctly only accounting for blue water withdrawals and blue water returns then it is still unclear what circumstances would lead to blue water return exceeding blue water withdrawals.		Fair. Clarification is made. Large negative contribution due to wastewater treatment.	Y