A comparative Life Cycle Assessment of plant-based foods and meat foods

Assessing the environmental benefits of plant-based dietary choices through:

a comparison of meal choices, and

a comparison of meat products and *MorningStar Farms*® veggie products

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Executive Summary

Meeting the growing food demands of a population expected to grow to nearly 10 billion by 2050 requires solutions that provide each person's dietary needs with substantially less use of resources and impact on the environment. The present assessment has used the Life Cycle Assessment (LCA) methodology to address the question of whether (and how much) environmental benefit might be obtained by American adults shifting their food consumption toward plant-based options on a meal-by-meal and product-by-product basis.

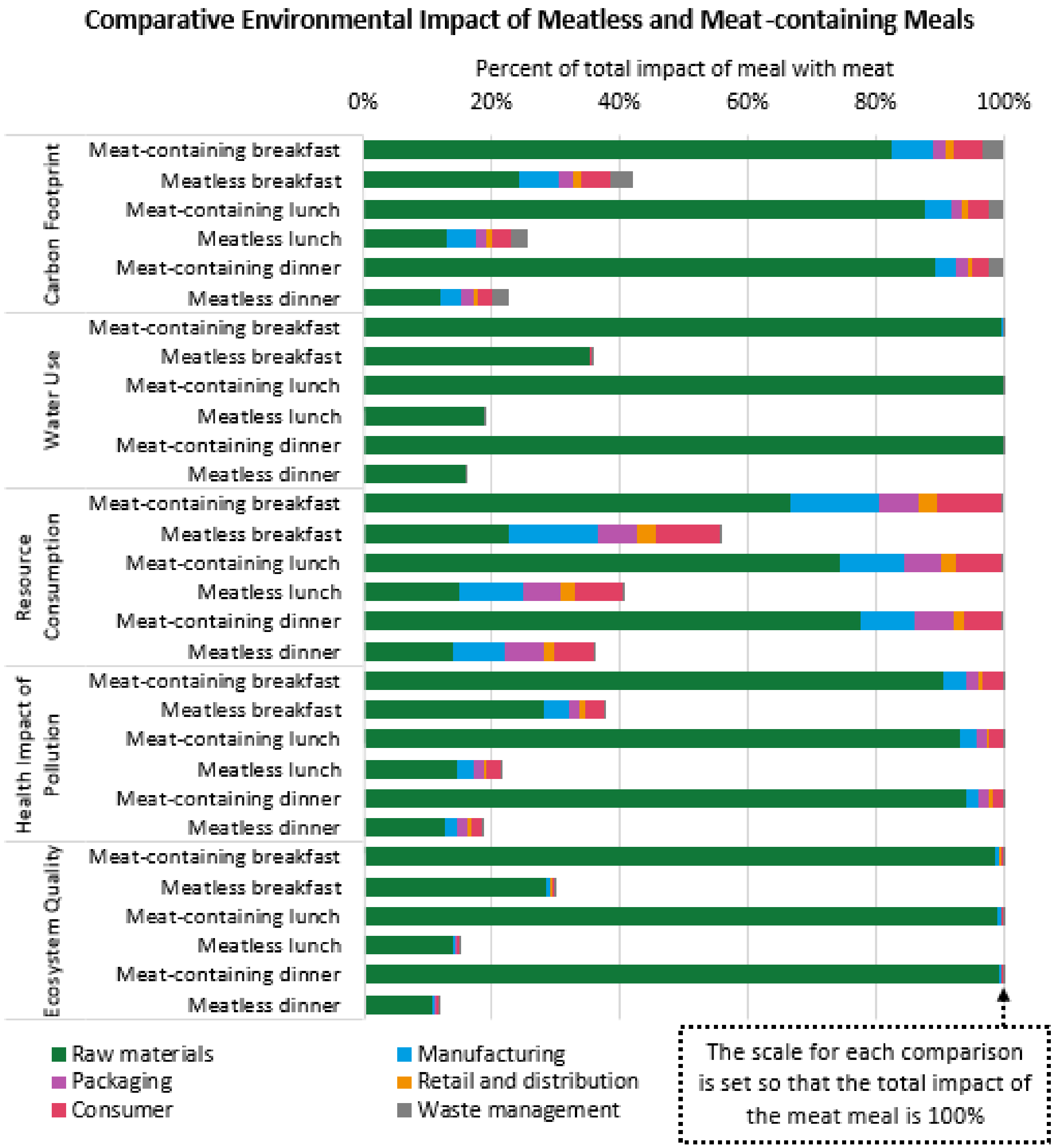
In particular, the LCA has two components: one focused on a comparison of reported meat-containing meals and meatless meals, and the second focused on comparisons of MorningStar Farms® veggie products against comparable meat products. The meal comparisons combine dietary recall data from the National Health and Nutrition Examination Survey (NHANES) with agriculture/resource data from the United States Department of Agriculture (USDA) Economic Research Service (ERS) and the National Marine Fisheries Service (NMFS), and nutrient data from the USDA Agricultural Research Service (ARS) National Nutrient Database. Data from lifecycle inventory (LCI) databases (e.g. Ecoinvent, Agri-footprint) are used to calculate the potential environmental impact of the meals. The meat-containing and meatless meals (NHANES 2011-2012) have been scaled to ensure the same amount of food (by weight) has been present in each[1], and additionally, food groups within both meal types have been scaled to account for food waste. The product comparisons have been based on a detailed assessment of the full life cycle of six example MorningStar Farms® veggie products, as compared to fresh ground beef, frozen burgers or patties of beef, pork or chicken, each based on a 60-gram portion. Meals were not balanced for nutrient content because nutrition was not the primary focus of the LCA. Attempts are not made here to characterize the benefits of wholescale shifts in the overall diet of individuals or of the wider population.

Despite the assumptions made and limitations, these assessments have taken advantage of the best available LCA-related information on food production and have been externally reviewed to validate their conformance with the ISO 14044 standard. The following are among the key findings from this work, where environmental impacts have been put into the categories of Carbon Footprint, Water Use, Resource Consumption, Health Impact of Pollution and Ecosystem Quality:

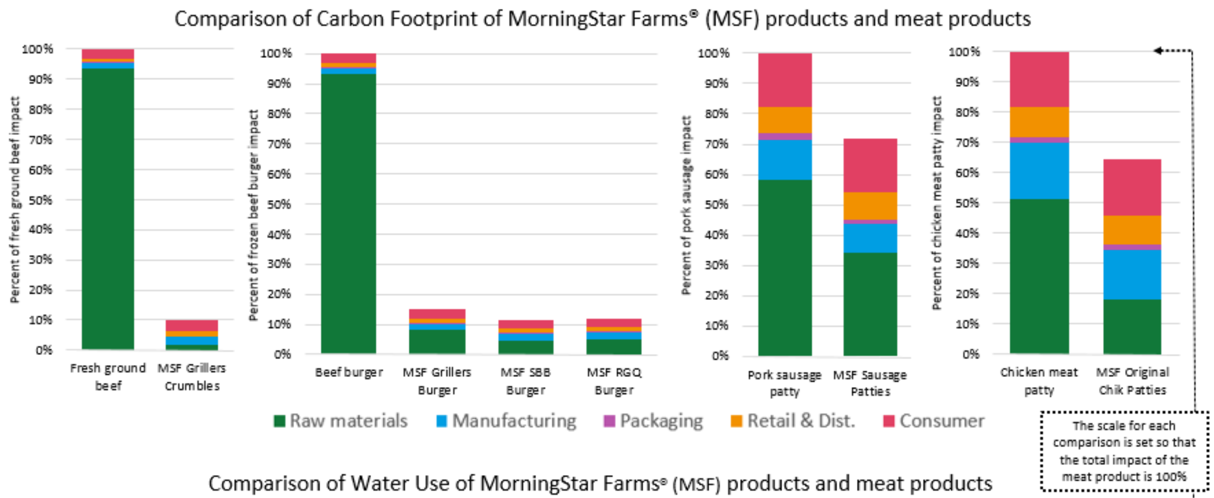
[1] In the original data, meals without meat contain less total weight of food than meals with meat. Although scaling the meatless meals up in size introduces some bias, it is felt to be less biased than to conduct the comparison without adjusting the data, or by adjusting the data on any other available basis. In essence, the dietary data is used to identify proportionately what food products Americans eat when eating meatless and meat-containing meals, and for the purpose of the LCA it is assumed that a given individual at a given meal occasion will eat the same amount (by weight) regardless of the choice to include meat.

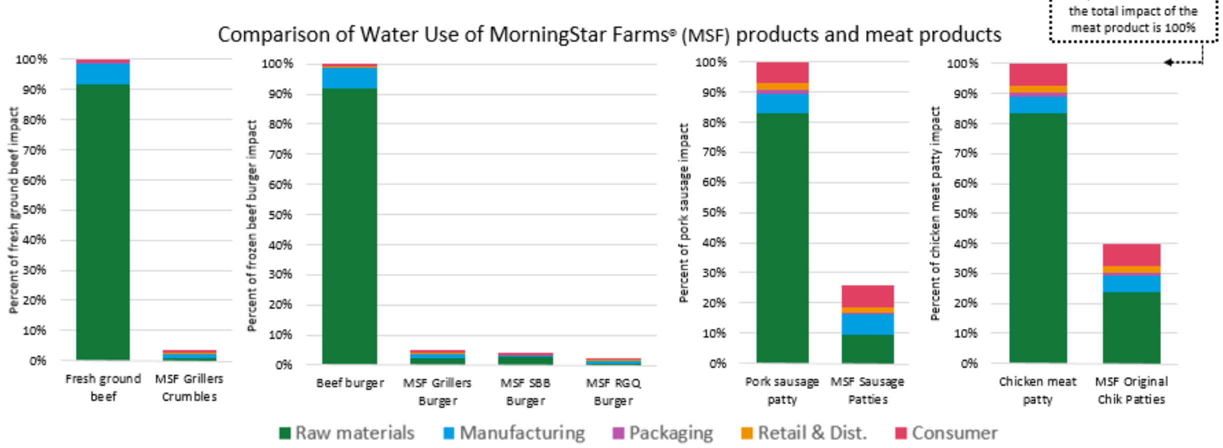
When an American adult chooses to consume a meatless breakfast, lunch or dinner rather than one that contains meat[2], the decreased environmental impact of the meatless meal is a reduction on average of at least 40%, across impact metrics, compared to the meat-containing meal over the entire cycle of producing the raw materials and consuming that meal. The directional trend indicating environmental savings is very consistent and in most cases indicated an improvement greater than the 40% mentioned above. With regard to Carbon Footprint, a switch to a meatless meal results in a 58%, 74% and 77% reduction compared to a meat-containing meal for breakfast, lunch and dinner, respectively. For Water Use, the reductions are 64%, 81% and 84% for breakfast, lunch and dinner. Meatless dinners show the highest amount of environmental savings among all the impact categories, followed by lunches and then breakfasts, primarily because meat-containing dinners contain more meat than breakfast or lunch occasions, as well as the fact that meatless breakfasts were reported to contain a high proportion of dairy.

[2] Meat includes the flesh of any animal, including fish. Meat does not include eggs or dairy. Environmental impact for meat-containing meals is calculated using data for beef, chicken, pork, and fish. The amounts of each food category per meal (NHANES) are shown in Table 6 and how these meals are represented for environmental impact calculations are shown in Table 8.



In comparing specific products, it was found that consuming the *MorningStar Farms®* veggie products, in comparison to a comparable beef, pork or chicken product, results in a reduction ranging from a few percent (considered an indeterminate result) to in some cases more than 90% reduction, across the full product life cycle, depending on the products compared and the environmental indicator in question. Comparison of *MorningStar Farms®* veggie products to beef products generally result in the most extreme benefits (often in the range of 80% or 90% improvement or more across environmental impact metrics), with the results for pork and chicken products ranging from 15% (in the case of the Resource Consumption comparison with breaded chicken patties) to a more than 75% improvement (in the case of the Water Use comparison with pork sausage patties), when compared on a weight basis. A sensitivity analysis examined comparison based on other units such calories or protein content and found the results to be similar





In both the meal and product comparisons we find that the main driver for environmental impacts takes place in the production of raw materials. For all meal types, the production of food raw materials is the most important source of environmental impact in providing the meal, with raw materials being responsible for >50% of the Carbon Footprint of meatless meals, >80% of the Carbon Footprint of meat-containing meals, and >99% of the Water Use of all meal types. The majority of the difference between meat and non-meat products happens in producing the feed that the animals consume, with the additional point that the high level of Carbon Footprint impact of beef raising operations is also a significant factor for the beef comparisons. Put simply, raising animals to feed humans requires the growing of a much larger amount of primary vegetal material than if humans consume more of the vegetable material directly rather than raising the meat. This simple underlying trend explaining the results gives a relatively high confidence to the direction of the conclusions, despite the uncertainty and variability inherent in these complicated systems.

Although a lesser impact than for raw material production, other parts of the food life cycle, especially food manufacture and the consumer use/preparation stage are important contributors of environmental impact, particularly regarding the Carbon Footprint and Resource Consumption indicators.

Across the set of comparisons made here, it has been found that choosing to substitute meat-containing meals with meatless meals is likely to lead American adults, on average, to achieve a lesser environmental impact of that selected meal. The extent of the improvement will vary widely, but an overall reduction on average, of at least 40% environmental impact when switching away from meat, appears to be a good estimate when looking across most set of environmental impact categories examined here, which encompasses a wide range of environmental issues.

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Abbreviations and Acronyms

ARS	Agricultural Research Service
BTU	British Thermal Units
CO_2	Carbon Dioxide
CDC	Centers for Disease Control
CH	Switzerland
DALY	Disability Adjusted Life Years
EURO4	Fourth generation auto emission standards of the European Union
Eq.	Equivalents
ERS	Economic Research Service
GLO	Global
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
kg	Kilogram = 1,000 grams (g) = 2.2 pounds (lbs)
km	Kilometer = 1,000 meters (m)
kWh	Kilowatt-hour = 3,600,000 joules (j)
L	Liter
Lb.	Pound
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LLDPE	Linear low-density polyethylene (plastic)
m^3	Cubic meter
MJ	Megajoule = 1,000,000 joules = 948 Btu
MSF	MorningStar Farms®
MMBTU	Million BTUs
NOAA	National Oceanic and Atmospheric Administration
NHANES	National Health and Nutrition Examination Survey
NMFS	National Marine Fisheries Service
OPP	Oriented polypropylene (plastic)
PDF	Potentially Disappeared Fraction
$PDF*m^2*y$	Potentially Disappeared Fraction per Square Meter for the duration of one Year
RGQ	Roasted Garlic & Quinoa
RER	Europe
SBB	Spicy Black Bean
T	Metric tonne
Tkm	Tonne-kilometer (transporting one metric tonne for one kilometer)
PET	Polyethylene terephthalate (plastic)
U	Unit
US	United States
USDA	US Department of Agriculture
USEPA	US Environmental Protection Agency
WHDPE	Woven high density polyethylene (plastic)

1. Introduction

As the world considers how to meet the demands of a global population expected to grow to nearly 10 billion by 2050, the food sector is becoming an increasing focus of concern regarding whether current consumption habits can be sustained into the future. This is both due to the potential for limited quantities of land, water and other resources to supply food production, as well as concerns about whether the impact of our production systems will exceed the planet's ability to cope with them in areas such as climate change and nutrient cycles, among others. Answering questions about whether humanity can maintain, or advance, the consumption patterns that define modern quality of life while adding as many as 50% more people between now and 2050 requires reconsideration of how we produce the full range of goods and services that define our economy. Looking specifically within the food system, one can consider how this core human need could be met with substantially less impact on the environment, best positioning us to achieve an overall economy in the coming decades that can be considered sustainable.

One could divide questions about how to achieve the necessary environmental improvements in how we meet the food demands of our population into two aspects: *what people eat* and *how what people eat is produced*. Into the first aspect would fall such questions as dietary choice, amounts consumed and also amounts wasted. Into the second aspect would fall questions about agricultural practices and technology and the efficiency with which materials are brought from the farm to the table. The present assessment deals primarily with this first aspect and in particular will evaluate the question of to what extent incremental shifts toward plant-based dietary choices (as opposed to meat-based choices) can be a solution to providing humanity's need for food consumption with a lesser impact.

There is relatively little research published that looks specifically at the question of meat-containing versus plant-based diets, meals or products using a life cycle assessment (LCA) methodology.[3] LCA is an

[3] Compared to prior efforts to answer similar questions, the present study adds significant added detail at the stage of characterizing the meal, the association of food types with meal choices and the representation of the environmental impact of each food type. For example, Pimentel and Pimentel (2003) make a comparative environmental evaluation of plant-based and meat-based diets. In comparison, their characterization of the diets includes relatively few categorizations of food types, considers only energy input and land use as indicators of environmental impact and they are unable to draw on the significant advances in availability of food-related LCA data from the following decade. Further, they consider only food raw material production and not the full food life cycle, as done here. Many others, such as Mogensen et al. (2012) compare results of life cycle inventory data of many food types side-by-side on a comparative basis such as mass or calories. However, such efforts generally do not put these data into the context of the full food life cycle, do not consider how these multiple food types combine to form meals or dietary patterns to provide an indication of the environmental outcomes of potential meal choices as done here. Examples are somewhat more numerous when focusing on the carbon footprint of food. Haalstrom

internationally-recognized approach that evaluates potential impacts of products and services throughout their life cycle, beginning with raw material extraction and including all aspects of transportation, manufacturing, use, and end-of-life treatment. LCA methods are defined by the International Organization for Standardization (ISO) 14040-14044 standards (ISO 2006a; ISO 2006b) and the ISO 14000 series on environmental management generally prescribes LCA as an essential tool for evaluation questions of comparative product environmental performance, as well as for supporting a wide range of decisions based on overall environmental performance. Two key tenets of this methodology are: 1) to consider as wide a range of potential environmental impacts as may be potentially important for a given question, and 2) to include as wide a view as possible of the systems that are affected by a given change or decision. Over recent decades, LCA has become a principal approach to evaluate a broad view of environmental problems and to help make decisions within the complex arena of environmental sustainability and is being used by corporations and governments around the world to identify opportunities to improve the environmental performance of products, inform decision-making on strategy and policy issues, support communication and educational efforts, and much more.

The present assessment uses the LCA methodology to address the question of whether (and how much) environmental benefit might be obtained by Americans shifting their food consumption toward plant-based options on a meal-by-meal and product-by-product basis. The variety of both meat-containing and meatless meals and diets is enormous and the comparison between the two will depend on the specific meals and diets considered. In the present assessment, we address this question in two ways: the first is to consider the meal pattern averages of Americans when they choose meals (breakfasts, lunches and/or dinners) that contain meat and meals that contain none; the second is to consider specific comparisons of common meat products and alternative veggie products.

Through these assessments, it is intended to be able to draw conclusions about whether encouraging Americans to eat more meatless meals in exchange for meat-containing meals would result in an environmental benefit, as well as about whether the specific veggie alternative products offer a relative environmental benefit to meat. This assessment has been sponsored by *MorningStar Farms®* brand, part of The Kellogg Company, with the intention to: a) learn more about environmental impacts associated with meatless versus meat-containing meals; b) to learn more about environmental impacts for its own veggie products; and c) to use learnings to support consumer and employee education and

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et al. (2014) review a list of 14 attempts to characterize the carbon footprint and/or land use benefits of plant-based and meat-based diets (all but one reference is based on European dietary data). In comparison, the present assessment looks at a more complete list of environmental impact categories and generally has a broader view of the food life cycle.

communication regarding the environmental benefits of plant-based dietary choices. The results may also be used within The Kellogg Company to inform future product and supply chain innovation.

2. Goal of the study

2.1 Objectives

This study evaluates the potential net environmental benefit or impact of using meatless versus meat-containing as a criterion for selecting among meals and products. This includes evaluating comparisons of meal choices between meat-containing and meatless meals for American adults, as well as a specific comparison of the veggie foods made by *MorningStar Farms®* and equivalent meat products.

Regarding the comparison of meatless and meat-containing meals, it is not the intention to evaluate or reach a conclusion that *all possible meals* in one of these categories has environmental benefits compared to *all possible meals* in the other category, both because this is likely not true and also because the effort needed to evaluate all possible meals would be extraordinary. Rather, the current assessment considers whether the use of meatless as a basis for meal selection would lead American adults, on average, to reduce or increase the environmental impact of their meal selection (breakfast, lunch or dinner) and by what margin.

The comparison of meals made here is intended to compare meat-containing meals with meatless meals, including differentiation for breakfasts, lunches and dinners on a meal-by-meal basis. It is not the intention of this study to consider wholesale changes of the US population from its current state of predominantly meat eaters to a state of entirely meatless diets. The scale of such a change would likely lead to changes in our food production systems that are not intended to be assessed with the methodology and scope of study chosen here. In addition, for the individual, such a complete move away from meat consumption could have implications (positive or negative) on nutrition and health that are not addressed in this study, which looks at single meals and products rather than the complete diet and nutritional requirements of an individual.

To provide more detailed examples of the potential benefits of plant-based dietary choices, this study also assesses several specific product comparisons. These involve the switch from common meat-based products, involving primarily portions of beef, pork, or chicken to alternatives for these products made primarily from vegetables, legumes and grains and containing no meat. The objective of these comparisons is to provide a few specific examples to complement the more generic assessment of meat substitution in meals. These specific product comparisons address the comparative benefit or impact of these veggie products, which are made by the sponsor of this assessment.

In summary, the specific goals of this study are as follows:

- To identify the difference in potential environmental impacts of meatless meals and meat-containing meals.
- To identify the difference in potential environmental impacts between consumption of beef, pork or chicken products and a selection of six products made by *MorningStar Farms®*.

2.2 Intended audiences

This project report is intended to support MorningStar Farms® communication of the comparative environmental performance of these products and meal choices to internal and external audiences. Audiences could include Kellogg Company employees, business partners, customers, and the public.

The ISO 14044 standard on LCA includes a set of additional specific requirements of those LCAs whose intention is to report specific product-to-product comparisons to a broad audience. It is the intention of this assessment to meet those requirements in cases where explicit statements are made comparing the environmental impact of various products.

3. Scope and boundaries

This section includes the methodological framework of the LCA, a description of the product function and product system, the system boundaries, and data sources. This section also outlines the requirements for data quality as well as review of the analysis.

As described in the above section on the goals of the study, there are two primary components of the present assessment, one dealing with meal averages which are characterized using a combination of dietary intake data, nutrient data, and economic data on consumption of beef, chicken, pork, and fish [4]

[4] Based on 24-hour recall data (NHANES, 2011-2012); Adults 19+) data combined with disappearance data from USDA ERS (USDA 2015a) and NMFS (NOAA 2014) and nutrient data from USDA ARS (USDA 2015b).

("the meal comparison"), and another dealing with specific product substitutions ("the product comparison"). Although much of the scope of the assessment is the same for these two components, the differing objectives and the wide differences in the data sources for each, necessitate some differences in the scope of the assessment for these two components. The following sections will identify specific cases where the study scope differs between these two sections of the assessment. All statements where either the *meal-comparison* or the *product-comparison* are not referenced should be interpreted as applying to both.

Further explained throughout the remainder of this section, Table 1 and Table 2 provide a summary of the key assumptions and data sources used throughout the meals comparison and products comparison.

Table 1: Summary of key assumptions and data sources supporting the ***meals comparison***

	Raw materials	Manufacturing	Packaging	Retail & Dist.	Consumer	Waste mgmt.
Data sources: characterizing amounts of materials	Meals from NHANES (2011-2012): Self-reported 24-hour recall data was used to find averages of reported intake at breakfast, lunch, and dinner, with meals categorized by the presence or absence of meat (meat-containing or meatless).Specificity has been added to the NHANES food group categories using USDA (2015a)[5] and NMFS (NOAA 2014) data. Legumes, grains, pasta and dried fruit have been scaled from wet weight to dry weight (based on USDA 2015b) to match their representation in the LCI data. Amounts of food wasted at retail and the consumer are applied based on Buzby et al. 2014. Feed materials are sourced locally and transported an average of 100 km from their point of production to reach the animal raising operation All food commodities are transported 500 miles by truck to arrive at their next point of processing.	Mfg. energy based on estimation of average amount spent to provide an American meal and IO-LCA data provided by Carnegie Mellon University (CMU 2015).	Packaging is based on a mixture of common packaging materials and an assumed amount of total packaging per meal based on estimates of total waste generation and the amount due to food packaging (US EPA 2011 and Hunt et al. 1990).	All products are represented transported an assumed distance from manufacture to distribution centers and retail. Energy use in retail is based on the IO-LCA database of Carnegie Mellon University (CMU 2015).	Cooking and cleaning is included based on assumptions of a mix of cooking methods and assumed energy use and Water Use, as used for the product comparison in this assessment, scaled to the weight of meals	Amounts of food wasted are based on Buzby et al. 2014. See table 12 for more details. Food disposal is by typical municipal treatment of waste; Packaging disposal based on US EPA (2011) statistics.
Key assumptions	Food ingredients are generally represented by the raw food commodity from which they are derived (e.g., all wheat consumption is represented as wheat grain). Substituted meals are equivalent on a weight basis. The production of turkey meat is adequately represented by the production of chicken meat and a mixture of beef, chicken, pork, and fish adequately represent the <1% of meat consumption that is not beef, pork, poultry or fish.	Plant-Based food requires no systematic difference in manufacture, per weight of food compared to meat food.	Plant-based food is not packaged in a significantly different way, on average, than meat-food.	Plant-based food does not differ materially in average transport logistics; All products except for ground beef are sold frozen.	Cooking a meatless meal does not systematically differ from how one cooks meat-containing meal	Disposal routes and processes are the same for plant-based and meat food products.
Environmental impact data sources	Impact of raw food ingredients: Ecoinvent (v3.1, SCLCI 2015)[6], Agri-footprint (Blonk 2014) and other databases, with some adaptations made to best reflect other available information. Beef, chicken, pork and fish modeled directly for this project based on best available references.	Ecoinvent v 3.1 used for energy, fuels and other inputs	Ecoinvent v 3.1 used to represent packaging material production	Ecoinvent v 3.1 used for energy, fuels and other inputs	Ecoinvent v 3.1 used for energy, fuels and other inputs	Ecoinvent v 3.1 used to define waste processes

[5] Where it is desired to understand the consumption of food categories by American adults at a greater level of specificity than that provided by NHANES, data on the disappearance of foods in the US has been used (USDA 2015a and NOAA 2014), as this is the best known data source for use as an approximation of consumption of these food types by human adults in the US, even though such consumption is not the only means by which food commodities recorded in these databases disappear. For example, consumption by children or animals are likely to also be responsible for some of the disappearance of these materials.

[6] References throughout the report to the Ecoinvent v3.1 refer to the “cut-off system model” version of this database.

*Table 2: Summary of key assumptions and data sources supporting the **products comparison***

	Raw materials	Mfg.	Packaging	Retail & dist.	Consumer
Modelling assumptions – Meat products	Beef, Chicken and Pork meat product ingredients are based on assumptions about typical burger, sausage and patty composition, including similarities in formulation to MorningStar Farm® products (e.g., similar amount of breading, spices). Feed materials are sourced locally and transported an average of 100 km from their point of production to reach the animal raising operation. All food commodities are transported 500 miles by truck to arrive at their next point of processing	Manufacturing energy taken from an available source of hamburger production facility	Assumption of plastic bag or film, with paper sheets to separate patties. The cardboard used in product distribution is assumed to be recycled. The other tertiary packaging materials (e.g., plastic pallet wrap) are sent to municipal waste systems.	Distances modelled as being identical to the MorningStar Farms® information mentioned below. All transport is frozen, except ground beef.	Stovetop prep of 4 servings at once (arbitrary choice). Also includes storage in refrigerator/freezer cleaning of dishes after meal
Data sources – MSF products comparison	Inputs of raw materials are based on product ingredient lists provided by MorningStar Farms®. Meat products are represented as ground meat, with spices and breading added where appropriate in the same proportions as in the MSF database. Transportation data based on actual origin countries and transportation modes reported by MorningStar Farms®, along with assumptions about distances from these points of origin	Mfg. data from two of MorningStar Farms® production facilities All information is allocated to products based on weight	Based on MorningStar Farms® updated flexible film packaging, including weights and materials, as well as palletization configuration	Distribution to retail distribution centers based on reported MorningStar Farms® average distances; Transport from the distribution center to store based on assumed distance. All transport and storage is frozen. Energy use for cold storage is based on Humbert and Guidnard, 2015	Identical to the meat products mentioned above, with frozen storage for all products. Energy use for cold storage is based on Humbert and Guidnard, 2015.
Environmental impact data sources	Impact of raw food ingredients from Ecoinvent (v3.1, SCLCI 2015)[7], Agri-footprint (Blonk 2014) and other leading databases, with some adaptations made to best reflect other available information Some commodities, such as beef, chicken, and pork modeled directly for this project based on best available references. In particular, Eshel et al. (2014) is used to characterize feed intake and content. Data for quinoa was gathered directly from Kellogg's quinoa supplying farm	Ecoinvent v 3.1 used to represent production of electricity, water, fuels	Ecoinvent v 3.1 used to represent packaging materials	Ecoinvent v 3.1 used to represent electricity, fuels and transport	Ecoinvent v 3.1 used to represent electricity and fuel

[7] References throughout the report to the Ecoinvent v3.1 refer to the "cut-off system model" version of this database.

3.1 General description of the systems studied

In addition to the general descriptions below, specific data pertaining to the data and assumptions used to characterize each system can be found in the Appendices. The sections below first characterize the subjects of the meals comparison and the latter sections characterize the subjects of the products comparison.

Meal Systems

Meatless and meat-containing meal classifications and characterization

Food group composition for meat-containing and meatless meals in the LCA have been sourced from the dietary component of the National Health and Nutrition Examination Survey (NHANES) and complimented with (disappearance) data from the United States Department of Agriculture (USDA) Economic Research Service (ERS) and the National Marine Fisheries Service (NMFS), and nutrient data from the USDA Agricultural Research Service (ARS) National Nutrient Database. NHANES is conducted continuously, in two-year cycles, by the National Center for Health Statistics, a part of the Centers for Disease Control and Prevention (CDC), with the goal of evaluating the health and nutrition status of the noninstitutionalized civilian population of the United States (CDC 2015a). The food groups reported through the NHANES have been made more specific where possible by using agriculture/resource data from the USDA ERS (2015a) and the NMFS (NOAA 2014).[8] In addition, when needed, USDA ARS data have been utilized to convert cooked ingredients to their raw form. See Table 6 and Table 8 for further details on how these data sources and other assumptions have been applied to arrive at the representation of foods consumed.

The most recent cycle of publically available dietary data was used for this LCA analysis; self-reported dietary data from 4,948 male and female adults (19+ years) in the 2011 – 2012. NHANES utilizes a 24-hour recall to collect dietary data; participants are asked to provide a detailed description of foods consumed in the previous 24-hour period and self-define the associated eating occasion during which the foods were consumed (CDC 2015b, ARS 2014). Therefore, it is possible to capture information about foods reported to be consumed at breakfast, lunch, and dinner (it is also possible to capture snacks and other eating

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[8] Where it is desired to understand the consumption of food categories by American adults at a greater level of specificity than that provided by NHANES, data on the disappearance of foods in the US has been used (USDA 2015a and NOAA 2014), as this is the best know data source for use as an approximation of consumption of these food types by human adults in the US, even though such consumption is not the only means by which food commodities recorded in these databases disappear. For example, consumption by children or animals are likely to also be responsible for some of the disappearance of these materials.

occasions, however, these data were not captured for this report). This allows the food production portion of the meal life cycle to be characterized.

Because the dietary data from NHANES is self-reported, under-reporting or over-reporting may influence the estimated intakes. In addition, the present analysis captures only food group intake at meals and not snacks or other eating occasions, which means conclusions cannot be drawn about overall dietary intake. It is the intention of this assessment to focus on individual meal occasions and not total daily intake or dietary patterns. Lastly, the data used reflects a sample of the population and does not reflect actual intake by any specific individual. The nutritional content represented by meals constructed with NHANES/USDA/NMFS data has not been considered in the choice of this data source because the purpose of this report is to assess environmental impact of dietary changes, rather than the nutritional adequacy of those changes.

For the LCA analysis, we used the intake of reported food groups based on the following NHANES classifications:

- meat, poultry, fish and mixtures;
- milk and milk products;
- eggs;
- legumes, nuts and seeds;
- grain products;
- fruits;
- vegetables;
- fats, oils, and salad dressings; and
- sugars, sweets, beverages

All groups are quantified in grams for each meal occasion. A meat-containing meal included any of the following sub-categories within the *meat, poultry, fish and mixtures* food group, whereas meatless meals did not contain any of the following:

- meat, nonspecific as to type;
- beef;
- pork;
- lamb, veal, game, other carcass meat;
- poultry;
- organ, sausages, lunchmeats, spreads;
- fish and shellfish;
- meat, poultry, fish with nonmeat items;
- frozen shelf-stable plate meals, with meat;
- vegetables with meat, poultry, fish

Within the meat category of the NHANES data, there are three sub-categories whose descriptions imply a mixture of meat and other food products. These three categories are “Meat, poultry, fish with nonmeat items,” “Frozen, shelf-stable plate meals, w/ meat,” and “Vegetables with meat, poultry, fish.” As shown in Table 8, for calculations these categories are represented here as mixtures of meats, vegetables and grains. For categories described as meat and vegetable mixtures, a 50/50 ratio between these two components is assumed. Where categories are described as meats, grains, vegetables, a ratio of one third each, meats, grains and vegetables is assumed. In both cases, the rationale is to make an even distribution in the absence of any better basis for differentiation. Where results are shown by food category, these three categories of mixtures containing meat are grouped together as "mixtures with meat" to provide a transparent view of their influence on the results. For calculations of environmental impact, the meat in the following categories is considered to be a combination of meat types (meat, nonspecific as to type; lamb, veal, game, other carcass meat; organ, sausages, lunchmeats, spreads; meat, poultry, fish with nonmeat items; frozen shelf-stable plate meals, with meat; vegetables with meat, poultry, fish). We classified these meat mixtures as a combination of beef, chicken, pork, and fish. Disappearance data[9] from USDA ERS (USDA 2015c) and NMFS (NOAA 2014) was used to specify proportions of these meat types (see Table 8 for details of how meats and other food groups are represented based on a combination of the NHANES data and that from USDA ERS and NMFS). Of note, all poultry is represented as chicken, based on the assumption that among those meats for which life cycle inventory data are available, chicken is the most similar to turkey in terms of raising and feed, requirements.

All intake for foods within a category were used to produce a meal average for breakfast, lunch, and dinner within meat-containing and meatless meals, and the weight of each food category within each meal type is presented in Table 6, with food categories of meatless meals weight-adjusted (to make total meal weights equivalent between meat-containing and meatless meals. Note that food categories for both meat-containing and meatless meals are further adjusted to account for waste (see Table 7). As described in more detail below, meatless meals have been scaled up to account for their lesser weight. These meal averages do not necessarily represent people who consider themselves vegetarian or intend to choose a vegetarian meal option. An attempt is made to provide a basis for comparison of meat-containing and meatless meals. Because the reported meatless meals on average contained less food (by mass) than the meat-containing meals, the contents of these meals were scaled up in weight. As the focus of the present

[9] Where it is desired to understand the consumption of food categories by American adults at a greater level of specificity than that provided by NHANES, data on the disappearance of foods in the US has been used (USDA 2015a and NOAA 2014), as this is the best known data source for use as an approximation of consumption of these food types by human adults in the US, even though such consumption is not the only means by which food commodities recorded in these databases disappear. For example, consumption by children or animals are likely to also be responsible for some of the disappearance of these materials.

assessment is on *what* food people eat, this removes the confounding effect of *how* much food they eat[10]. Most importantly, it avoids the potential that if a benefit is to be identified for one meal type over another that it might be explained by the overall quantity of food eaten. Following this adjustment, the meatless meal averages represented here contain the same weight of food as the reported meat-containing meal averages, but the proportionate distribution of food types within the meal is based on the reported meatless meals. Food categories were scaled up consistently across both meals types to account for food waste.

The data on meals used here includes fluid milk and juices, but does not include other beverages, such as water, soda and other sweetened beverages. These other beverages are excluded partly because when represented by weight, they are a large majority of the weight of food and beverage consumed. Additionally, we assumed that the beverage consumption would not vary if one switched from a meat-containing to a meatless meal.

NHANES, USDA, NMFS data has been selected as the best available source of data to provide basis for this assessment due to the belief that they provide that best available basis for evaluating the question of to what extent “meatless”, “plant-based,” or “veggie” are useful selection criteria for attempting to reduce the environmental impact of food consumption, which is the goal of this analysis. However, NHANES, USDA and NMFS are not perfect sources of data for such a comparison and in particular the following necessary assumptions should be noted:

1. It is assumed this intake data, scaled to account for food waste, is sufficiently accurate and representative of actual behavior.
2. It is assumed that the combination of food types and amounts represented in NHANES/USDA/NMFS meal constructs is appropriate for a population-based comparison.
3. It is assumed that the population from whom the information is drawn represents well the population or people to whom the results would be applied.
4. It is assumed that beverage consumption is the same in meat-containing and meatless meals.

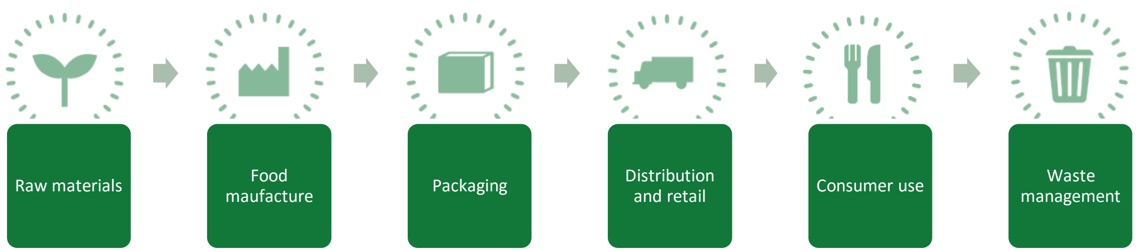
[10] Although the data used here do show that meals containing no meat weigh less than those containing meat, it is not clear that this is a causal relationship or simply correlational and due to other factors. For example, 60% of American vegetarians are female and women eat less than men do. In addition, there may be other factors that correlate with both vegetarianism and smaller meals beside gender, but that are not causal relationships. It is believed that applying the raw data from NHANES without adjusting for weight would create a greater risk of biasing the analysis in favor of meatless meals than any bias that applying this adjustment creates in favor of meat-containing meals.

5. It is assumed that the location at which meals are eaten (e.g., at home versus out of home) does not have an effect on the comparison of meat-containing and meatless meals, as location is not distinguished here.
6. It is assumed that the quality and specificity of life cycle inventory (LCI) data selected are sufficient to represent the range of food types and their classification within the NHANES/USDA/NMFS meal constructs. See for example the representation for meat categories in Table 5.

Representation of meals life cycle

The scope of the meal systems includes all activities needed to provide a meal to an American adult, from "farm to fork." As detailed in Figure 1, this includes the growing or production of all the products, their harvesting, processing, transport, manufacturing processes, packaging, food preparation and disposal of all packaging and food wastes.

Figure 1: Stages of the life cycle of the meat-containing and meatless meals



Regarding the raw material stage, Table 8 provides a summary of how each of the food categories described in the above section are represented by pre-existing or adapted life cycle inventory (LCI) data to represent the production of food raw materials within these categories. All stages downstream of raw material production are represented in a similar way for the meat-containing and meatless meals. While the proportion of various food commodities within the two meal categories do in fact differ and in more complicated ways than simple substitution, the remaining stages of the meal life-cycle are assumed to be nearly identical between these meal types. Many aspects of these stages are proportional to the weight of food and so the activity in these stages for breakfasts, lunches and dinners differ primarily based on the differences in average weight for each meal type. As shown in Table 6, the weights of food in the meals reported by NHANES have been adjusted so that for each of breakfast, lunch and dinner, the meatless meals have the same total weight as the meat-containing meals. However, breakfasts, lunches and dinners have not been adjusted to achieve an equal weigh among these three meal types, each being assigned the weight of meat-containing meals for that meal occasion as reported by NHANES.

In the case of fish-containing meals, it is noted that the activities of catching wild-caught fish (e.g., boat operation) are included; however, the implications for sustainability of fisheries are not able to be addressed in this assessment.[11]

Alternative scenarios within meals assessment

Although the outcomes of this assessment are focused on comparisons of consumption of meat as a category, in substituting individual meals, it is likely the case that one particular meat type is primarily being replaced, as it is assumed that most meat-containing meals contain either only one type of meat, or at least one type of meat makes up the majority of the meat within the meal. Because of the potential that these outcomes might vary by meat type, a set of scenarios are explored in which in the meat-containing meal is solely beef, chicken, pork or fish, rather than a mixture of each based on the average within the reported meals. In these cases, the total mass of all meat within the meat-containing meal average is represented as all beef, all chicken, all pork or all fish. Results of these scenarios are presented in Appendix E.

In identifying the best source of data to represent meatless and meat-containing meals, other data sources were considered. In particular, the Dietary Guidelines for Americans (USDA 2010) were evaluated. However, these were determined not to be the right source of data for the purpose of this study because they do not help represent what Americans actually eat or report to eat, but rather what Americans would eat if they followed dietary guidelines, and it has been reported that most Americans do not meet federal dietary recommendations (Krebs-Smith 2010). In addition, the meal composition in this source is a less specific categorization, which limits our ability to associate the food intake with production of specific types of food.

Product systems

MorningStar Farms® veggie products

MorningStar Farms® makes a wide range of foods, many of which fall into the category of meat substitutes, implying that these products are intended to be able to be included in recipes and meals as direct substitutes for a meat food product such as a hamburger patty, pork or chicken sausage patties, or other

[11] Although fish and shellfish are included throughout this assessment, the assessment does not consider the impact of fish consumption on the viability of the world's fisheries, which is an important concern regarding the impact of catching and consuming wild-caught fish. This additional issue should be considered when evaluating the environmental impact of fish consumption and that the LCA-based methods used here do not consider it.

primarily meat-based products. These products are made primarily of various grains, legumes and vegetables and include smaller amounts of other ingredients intended to season the products, provide texture or serve other purposes.

These products are manufactured by MorningStar Farms® in their US locations, where the products are also packaged and prepared for shipment to the market. These foods are kept frozen from the stage of manufacture through the distribution and retail network and are intended to be stored frozen in the consumer's home. The products may be cooked in a variety of ways. Most of the products resemble a meat patty and would most likely be heated in a pan on the stove or heated in the microwave. One of the foods resembles ground meat and is likely to be prepared in a wider variety of ways. Although the above describes the most typical use patterns, there is a wide range of ways in which any of the products might be prepared. After product use, the packaging is typically disposed of in the municipal waste system.

As detailed below and shown in Figure 2, the product system includes all aspects of production of the raw material ingredients, manufacturing and packaging of the food product, use of the product food consumption and disposal of packaging, as well as the intervening transportation, storage and handling of the raw material ingredients and food product between these activities. Note that in comparison to Figure 1, the waste disposal stage is omitted. Because it has been assumed that all the product that is purchased is consumed, the only waste materials at the product end-of-life is the packaging materials and the end-of-life management of these materials has been grouped into the packaging stage.

The six *MorningStar Farms® veggie products* being assessed are listed in Table 3 below, which also illustrates which of the *MorningStar Farms® veggie products* are compared to which meat alternative product. All products are compared on the basis of a 60-gram portion.

Figure 2: Represented stages of the life cycle of MorningStar Farms® veggie products

Table 3: The MorningStar Farms® and meat products compared in the assessment (all are compared on 60g basis[12])

MorningStar Farms® products (all frozen)	Meat products for comparison
Grillers® Crumbles™	Ground beef (fresh)
Grillers® Original Burgers	Beef burgers (frozen)
Spicy Black Bean (SBB) *Burgers*	
Roasted Garlic & Quinoa (RGQ) *Burgers*	
Original Sausage Patties	Pork sausage patties (frozen)
Original Chik Patties®	Breaded chicken patties (frozen)

Meat products

The meat products considered here include beef burger patty, pork sausage patty and chicken sausage patty. Although meat products may be distributed and sold to consumers in a wide range of forms, to reflect the most common distribution method in the US, as well as to maintain as similar of a comparative function with the *MorningStar Farms® veggie products* (which are sold frozen), the meat products are assumed to be sold in frozen format, divided into individual serving portions that can be cooked from frozen. The only exception to this is the ground beef, for which marketing data suggests fresh distribution is the most common distribution type in the US and so this product is represented as being kept at refrigerated temperatures from the stage of manufacture through the time of preparation (Nielsen 2015).

Details of the representation and underlying data sources for the representation of the beef, pork and chicken products is provided in Appendices I, J and K. The production of the meat products begins with the production of animal feed, which is in most cases grown elsewhere and transported to the animal raising operation, usually by truck. Note that some meat farms may grow some portion of their feed on-site. Table 13 contains assumptions about transportation stages throughout the life cycle and shows the assumptions about average feed transport.

[12] All products are compared on a basis of 60 grams, even if the actual size of a single packaged serving is not 60 grams. For example, the activities for cooking the products and cleaning of dishes are based on one packaged serving. Note that the weight of the meat products varies widely by manufacturer and so 60 grams has been used here as the packaged serving size of all meat products.

The meat products are derived from conventional animal raising operations, where the animals are kept and fed until the appropriate time is reached for them to be sent to slaughter, at which point they are slaughtered and divided into various meat products and in some cases other products (for example hides to be used for leather). The representation of beef in this study is not intended to reflect, 'natural and grass-fed only' beef, but rather the most typical beef production practices within the US. For all meats, in addition to being separated into various sections (i.e., butchering), the meats may also be further processed, such as grinding, at this stage. In all animal raising operations modeled here, the production up to the point of slaughter is allocated among various animal outputs through an economic allocation based on the value of each output type.

The meat products are represented as simply ground meat, with the addition of spices (pork and chicken) and breading (chicken), where appropriate based on the weight ratio of these same spices and breading in the *MorningStar Farms® veggie products recipes.*

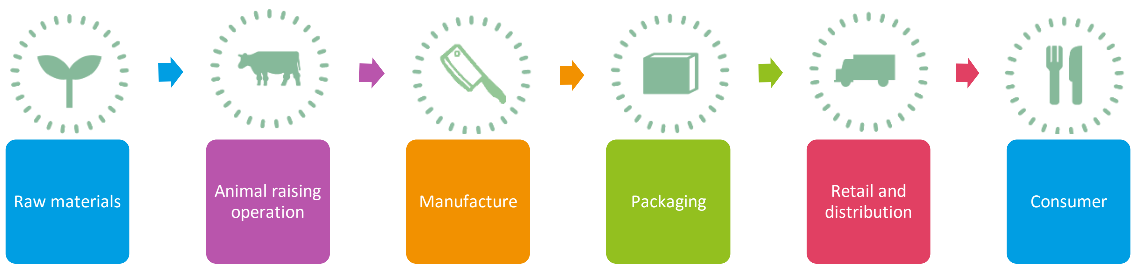
Meat products are then frozen or refrigerated and packaged, where they enter a similar distribution and retail network as for the *MorningStar Farms® veggie products*. Note that refrigerated meat products will typically move much more quickly through distribution, retail and the consumer's home than frozen products and so the assumed storage times for refrigerated meat products (ground beef in this case) is less than for frozen products.

As with the *MorningStar Farms® veggie products*, the meat products may be cooked at the consumers' homes in a variety of ways. We assume here the same set of cooking conditions for both the meat products and the *MorningStar Farms® veggie products*. Because there is no basis for assuming the cooking conditions would differ systematically for the meat products and *MorningStar Farms® veggie products*, we have used the same set of assumptions regarding cooking for both.

The primary packaging for meat products is represented as consisting of plastic film, which is packed for distribution within cardboard cases. Meat products in the categories represented are packaged in a wide variety of ways and a packaging system has been chosen here to be very similar to the *MorningStar Farms® veggie products*, as the assessment is not intended to be a comparison of packaging. After consumption, primary packaging materials (e.g., film and closures) are disposed of in the municipal waste system. The cardboard used in product distribution is assumed to be recycled. The other tertiary packaging materials (*e.g.*, plastic pallet wrap) are sent to municipal waste systems.

As detailed below and shown in Figure 3, the product system includes all aspects of production of the raw material ingredients, manufacture and packaging of the product, use of the product and disposal of packaging, as well as the intervening transportation, storage and handling of the raw materials and product between these activities. The consumer stage includes the storage and cooking of the products and the cleaning of cooking and eating utensils. Note that impacts of disposal of packaging are included in the packaging stage in the meals comparison. In addition to each of the meat products mentioned above, we also assess an "average" meat product. This averaging is done by weighting each of the beef, pork and chicken product results by the relative proportion of these meats in the disappearance data supplied by USDA (2015c). The proportions used are 26.9% beef, 23.1% pork and 50.0% chicken. Each percentage is calculated as the amount of the disappearance of that meat type divided by the sum of these three meat types. Beef is represented as frozen beef burger.

Figure 3: Stages represented in the life cycle of meat products



3.2 Comparative basis: Functions and functional unit

Life cycle assessment relies on a "functional unit" as a reference for evaluating the components within a single system or among multiple systems on a common basis. It is therefore critical that this parameter is clearly defined and measurable.

It is acknowledged that there is not a single clear and agreed upon measurement on which to set a functional basis for food consumed, due to the multiple reasons people eat (nutrition, alleviate hunger, support social interactions, and other psychological reasons), as well as the difficulty of quantifying how many of these needs are met. As noted below, both the meals and product are compared here on a per-weight basis. To explore the dependence of results on the functional unit, comparisons for the products have also been made on the bases of equal energy (calories) and equal protein content to allow evaluation of the importance of this selection of the functional unit basis. The results of these comparisons are shown in Appendix C.

The functional unit for the comparison of meals is *providing a US consumer with a meal at their home*.

In particular, the meals to be compared are considered to be comparable or interchangeable based on the total weight of food they contain. The size of the meals to be compared is based on the composition of meat-containing meals reported by American adults surveyed in NHANES (2011 – 2012). These meals contain 366 grams of food in the case of a breakfast, 412 grams in the case of a lunch and 496 grams in the case of a dinner. The composition of the meals to be compared is based on the combination of NHANES, USDA and NMFS data.

The functional unit for the comparison of *MorningStar Farms*® products and meat products is *providing a US consumer with 60 grams of meat patty or alternative at their home*.

The alternatives are considered to be functionally equivalent on the basis of equal mass and a serving size of 60 grams is used here. Note that this 60 gram amount may differ from the serving size in which products or sold or which the product's packaging defines as a serving of that product. For example, the energy used in cooking and washing dishes is assigned to each product on the basis of one packaged portion. Note also that the equivalence is set at the amount of product to-be-cooked ("in the recipe") rather than its weight after cooking. Some products may lose weight, especially from water loss, in cooking as steam or water droplets escape. This amount of weight loss will likely vary by product and by cooking method.

Note also that the function of the products or meals is not intended to provide an "optimal" set of nutrients. Consideration of the nutritional benefits of food choices is highly complex and is highly dependent on the individual and their lifestyle choices. Functional unit comparisons based on nutrition are outside the context of this LCA. Beyond nourishment, any other functions of the products are not considered here. For example, taste, enjoyment, relief of psychological stress, providing a basis for social interactions and others may all be reasons that people consume food in certain contexts. No attempt is made here to compare these products or meals to alternative ways of meeting these needs and each of the options compared is considered to be able to equally meet such functions.

Scenarios are conducted in Appendix C to consider a comparison of products on the alternative basis of calories or protein.

3.3 System characterization and data sources

To fulfill the functional unit, different quantities and types of materials and other processes are required for each product or meal. These lists of inputs that provide the functional unit are identified as "reference flows" and define the total demand from different economic activities that are required for each system. The following sections provide details of the information used to define these reference flows for the meals and products assessed here.

Animal feed production and animal raising

The processes of raising the animals are assumed to include amounts of energy and water on the farm site. The following table shows an example of the amounts used in the beef production model, which has been based on the "*Beef cattle for slaughter, at beef farm*" model from the Agri-footprint database (Blonk 2014), one of several data sources used as a reference for the modeling of the meat products. See Appendices I through K for more information on the modeling of the animal raising operations.

Table 4: Energy and Water Used on the cattle farm (For 11,700 kg of cattle, Blonk 2014))

Input	Value	Process LCI data used (from the Ecoinvent 3.1 database)
Transportation of feed to animal farm	37280 tkm	Transport, truck>20t, EUOR4, 80%, default/GLO Economic
Energy use from machinery	68043.7 MJ	Energy, from diesel burned in machinery/RER Economic
Drinking water for animals	1609.8 m3	Water, unspecified natural origin, US

In addition, the animal raising processes are assumed to require the inputs of feed materials. The feed materials included are listed in the Appendix I. Lacking a source on average distances for transport of grains to farms, it is assumed here that these feed materials are sourced locally and transported an average of 100 km from their point of production to reach the animal raising operation.[13]

The transportation of the animals from the farm to the processing plants is included within the animal raising stage and is based on the assumption that the animals will be transported by truck from farm to the point of slaughter and processing, which is assumed to occur at the same location. Lacking average statistics on this transportation stage, a value of 100 km has been assumed.

Animal slaughter and processing

The primary inputs for the slaughtering and processing are assumed to include the energy and water used at the processing operation (based on SCLCI 2015) and the emissions from these operations (based on

[13] The distance feed typically travels from feed production to animal raising operations in the US is not a well-documented value. In reviewing a few others' attempts to identify this value in similar studies we find that Castellini et al (2012) in their assessment of US pork use an assumption of 30 miles. Battagliese et al. (2013), assessing US beef use and assumption of 500 miles. Neither cites a source for their assumption beyond the rationale that there is usually a close proximity between feed production an animal raising. The 100 km value used here is based solely on judgement and taking a balance between the values used in these other studies.

Verheijen 1996). The underlying data for the processing of each of beef, pork and chicken are shown in Appendices I, J and K.

Raw material production and delivery for meat-containing meals and meatless meals

The raw materials stage is defined here as the processes necessary to produce agricultural and other raw material ingredients as supplies for food product manufacture and/or other processes to prepare food to be distributed to the market. The composition of the meat-containing meals and the meatless meals is based on meals developed using NHANES, USDA and NMFS data, with considerations made for waste. See section 3.1 for more information about NHANES, USDA, NMFS and associated dietary data.

Table 6 shows the resulting composition of meatless and meat-containing meal averages. Note that the contents of the meatless meals have been scaled upward to achieve the same overall mass of food as is present in the reported meat-containing meals. All food categories shown are represented in the environmental assessment of the meals.

To arrive at the final calculation of the environmental impact of producing the food raw materials within the meals being compared, the present LCA combines data from several sources to characterize the amounts of various food types within the meal averages and the environmental impact of producing each food type. In doing so, the availability and match of life cycle inventory (LCI) data to represent the food types as they are categorized based on the reported amounts consumed are in several cases imperfect and some assumptions and approximations are made. Rather than omitting food categories where matches are not perfect, the best effort is made with available data to provide a complete and accurate assessment. Table 5 illustrates the types of data used and steps made in making this calculation, using types of meat products as an example food category. Details of how all food categories have been represented are shown in Table 8.

Table 5: Calculations and data used to represent the environmental impact of producing raw materials for the meals, example using the meat category.

	Amount of raw materials produced to provide meal	x	Environmental impact per amount of raw material	=	Environmental impact to provide raw materials for meal
Primary data sources	The NHANES USDA (2015c) and NOAA (2014) are used to represent the amounts of food categories consumed, scaled up to estimate the amount produced by considering waste based on Buzby et al. 2014		Environmental impacts are based on Life cycle inventory (LCI) data sources are summarized in Table 8. These are primarily the Ecoinvent database (v31., SCLCI 2015) and Agri-footprint (Blonk 2014).		
How beef is represented	All food categorized as "beef" is grouped together		Environmental impacts are represented by the beef LCI dataset, as summarized in Appendix I		
How pork is represented	All food categorized as "pork" is grouped together		Environmental impacts are represented by the pork LCI dataset, as summarized in Appendix J		
How chicken / poultry is represented	All food categorized as chicken, turkey or other poultry is grouped together		Environmental impacts are represented by the chicken LCI dataset, as summarized in Appendix K		
How fish / seafood is represented	All food categorized as fish, shellfish or other seafood is grouped together		Environmental impacts are represented by the fish LCI, which is a mixture (50%/50%) of farmed and wild-caught fish, as summarized in Appendix L		
How other meats are represented	All other meat products or unspecified meat products are grouped together		Environmental impact of all other or unspecific meats are represented by a mixture of LCI data for beef, pork, chicken and fish, based on a weighted average of these meats according to their relative consumption in the US as reported by USDA (2015c) and NOAA (2014).		
How mixtures with meats are represented	Three sub-classifications of meat under NHANES are mixtures of meat with non-meat products. These are represented as mixtures of meat with vegetables and grains (see Table 8).		See Table 8 for a description of the representation of each category.		

Table 6: Composition (grams) of the original NHANES meal data and the weight-adjusted[14] and waste-adjusted meatless and meat-containing meals[15] (based on NHANES 2011-12, USDA 2015b, Buzby et al. 2014)

	Meat-containing meals						Meatless meals								
	Data from NHANES			Adjusted for waste			Data from NHANES			Scaled to equal meal weight			Adjusted for waste		
Commodity	Breakfast (g)	Lunch (g)	Dinner (g)	Breakfast (g)	Lunch (g)	Dinner (g)	Breakfast (g)	Lunch (g)	Dinner (g)	Breakfast (g)	Lunch (g)	Dinner (g)	Breakfast (g)	Lunch (g)	Dinner (g)
Milks and milk drinks	41.63	15.92	21.12	61.21	23.42	31.05	88.13	34.02	37.72	119.13	41.05	43.32	175.19	60.37	63.71
Cream and cream substitutes	3.47	0.63	0.77	4.89	0.88	1.08	4.35	0.76	1.42	5.88	0.92	1.63	8.28	1.30	2.30
Milk desserts, sauces, gravies	0.49	3.68	5.79	0.69	5.18	8.16	0.50	4.18	6.19	0.68	5.04	7.11	0.96	7.10	10.02
Cheeses	4.57	6.39	5.34	6.44	9.00	7.52	1.52	3.99	6.25	2.05	4.81	7.17	2.89	6.77	10.10
Meat, not specified	0.00	0.02	0.17	0.00	0.03	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beef	4.05	11.07	20.43	5.54	15.17	27.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pork	8.31	5.88	8.56	11.39	8.05	11.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lamb, veal, game, other carcass meat	0.22	0.36	1.34	0.30	0.49	1.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Poultry	6.76	25.97	31.21	8.67	33.30	40.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Organ, sausages, lunchmeats, spreads	21.63	15.72	7.61	29.64	21.54	10.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fish and shellfish	3.36	8.65	19.36	5.51	14.18	31.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Meat, poultry, fish with nonmeat items	25.49	74.93	78.46	34.91	102.64	107.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

[14] The meal-filtered data taken from NHANES shows a weight of 270.5, 341.1 and 342.1 grams for meatless breakfasts lunches and dinners in comparison to 365.6, 411.6, and 496.2 grams for meat-containing meals. The meatless meals have been adjusted to have equal weight to the meat-containing meals by increasing all meal components proportionately.

	Meat-containing meals						Meatless meals								
	Data from NHANES			Adjusted for waste			Data from NHANES			Scaled to equal meal weight			Adjusted for waste		
Commodity	Breakfast (g)	Lunch (g)	Dinner (g)	Breakfast (g)	Lunch (g)	Dinner (g)	Breakfast (g)	Lunch (g)	Dinner (g)	Breakfast (g)	Lunch (g)	Dinner (g)	Breakfast (g)	Lunch (g)	Dinner (g)
Frozen, shelf-stable plate meals, w/ meat	10.74	19.20	22.54	14.72	26.30	30.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vegetables with meat, poultry, fish	0.00	0.95	0.35	0.00	1.36	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eggs	13.56	1.43	1.00	18.83	1.98	1.39	3.95	2.29	1.63	5.34	2.76	1.87	7.41	3.84	2.60
Egg mixtures	29.57	2.38	1.62	41.07	3.31	2.24	11.65	7.94	5.81	15.75	9.58	6.67	21.88	13.31	9.27
Egg substitutes	0.45	0.10	0.00	0.63	0.14	0.00	0.19	0.07	0.00	0.25	0.08	0.00	0.35	0.11	0.00
Legumes[16]	4.29	8.49	12.32	1.83	3.62	5.25	1.75	15.88	19.40	2.36	19.17	22.28	1.01	8.16	9.49
Nuts, nut butters, and nut mixtures (with carob)	0.31	0.95	0.63	0.36	1.12	0.74	1.83	3.11	1.71	2.47	3.75	1.97	2.91	4.42	2.32
Seeds and seed mixtures	0.06	0.04	0.10	0.07	0.05	0.12	0.09	0.07	0.14	0.12	0.09	0.16	0.14	0.10	0.19
Yeast breads, rolls	25.19	22.65	16.34	36.51	32.83	23.68	16.42	13.56	12.60	22.20	16.37	14.47	32.17	23.72	20.97
Quick breads	8.54	4.00	7.29	12.37	5.79	10.56	2.97	2.82	4.16	4.01	3.40	4.78	5.81	4.93	6.93
Cakes, cookies, pies, pastries	3.91	7.16	9.26	5.66	10.38	13.42	6.63	6.01	6.30	8.97	7.25	7.23	13.00	10.51	10.48
Crackers and salty snacks from grain	0.27	2.08	1.67	0.39	3.01	2.43	0.77	3.84	3.06	1.04	4.63	3.52	1.51	6.71	5.10
Pancakes, waffles, French toast, other	9.30	0.78	0.57	13.48	1.13	0.83	3.78	1.26	1.11	5.11	1.52	1.27	7.41	2.20	1.84

[16] The weight of legumes shown here is cooked weight. These value were divided by 2.76 to arrive at the dry weight of beans consumed, based on the ratio of calories of cooked and dry beans from the USDA's nutrient database (2015b).

	Meat-containing meals						Meatless meals								
	Data from NHANES			Adjusted for waste			Data from NHANES			Scaled to equal meal weight			Adjusted for waste		
Commodity	Breakfast (g)	Lunch (g)	Dinner (g)	Breakfast (g)	Lunch (g)	Dinner (g)	Breakfast (g)	Lunch (g)	Dinner (g)	Breakfast (g)	Lunch (g)	Dinner (g)	Breakfast (g)	Lunch (g)	Dinner (g)
Pasta, cooked cereals, rice[17]	30.64	24.03	30.30	18.91	14.83	18.70	26.68	14.17	17.01	36.06	17.10	19.53	22.26	10.56	12.05
Cereals, not cooked or not specified[18]	1.09	0.06	0.14	0.56	0.03	0.07	11.40	1.83	1.82	15.41	2.21	2.09	7.95	1.14	1.08
Grain mixtures, frozen plate meals, soup	9.60	35.29	43.99	13.91	51.14	63.75	14.43	125.40	194.72	19.51	151.33	223.62	28.27	219.32	324.09
Meat substitutes, mainly cereal protein	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.00	0.03	0.05	0.00	0.04	0.07	0.00
Citrus fruits, juices	36.40	7.68	8.96	51.27	10.82	12.63	25.05	9.02	7.10	33.87	10.89	8.15	47.70	15.34	11.48
Dried fruits[19]	0.09	0.11	0.09	0.58	0.71	0.58	0.72	0.21	0.27	0.97	0.25	0.31	6.08	1.56	1.97
Other fruits	11.63	13.65	11.28	16.37	19.23	15.89	22.02	20.64	20.13	29.76	24.91	23.12	41.92	35.08	32.56
Fruit juices and nectars excl. citrus	8.94	7.80	8.92	12.60	10.99	12.56	8.04	10.13	6.80	10.87	12.22	7.81	15.31	17.21	11.00
White potatoes, starch veg.	16.95	23.15	33.51	24.22	33.07	47.87	3.15	7.62	9.84	4.25	9.20	11.30	6.07	13.14	16.15
Dark-green vegetables	0.49	5.85	10.84	0.70	8.36	15.49	0.36	3.29	5.48	0.49	3.97	6.30	0.70	5.67	9.00
Deep-yellow vegetables	0.17	2.72	5.03	0.24	3.88	7.19	0.84	2.52	2.67	1.14	3.04	3.07	1.63	4.34	4.38
Tomatoes and tomato mixtures	6.53	12.39	13.07	9.33	17.70	18.66	2.35	10.55	13.82	3.18	12.73	15.87	4.54	18.19	22.67

[17] The weight of pasta shown here is cooked weight. These value were divided by 2.35 to arrive at the dry weight of pasta consumed, based on the ratio of calories of cooked and dry pasta from the USDA's nutrient database (2015b).

[18] The weight of grains shown here is cooked weight. These value were divided by 2.81 to arrive at the dry weight of grains consumed, based on the ratio of calories of cooked and dry rice (white) from the USDA's nutrient database (2015b).

[19] The weight of dried fruit shown here is dried. These value were multiplied by 4.46 to arrive at the wet weight of fruits consumed, based on the ratio of calories of raisins and grapes from the USDA's nutrient database (2015b).

	Meat-containing meals						Meatless meals								
	Data from NHANES			Adjusted for waste			Data from NHANES			Scaled to equal meal weight			Adjusted for waste		
Commodity	Breakfast (g)	Lunch (g)	Dinner (g)	Breakfast (g)	Lunch (g)	Dinner (g)	Breakfast (g)	Lunch (g)	Dinner (g)	Breakfast (g)	Lunch (g)	Dinner (g)	Breakfast (g)	Lunch (g)	Dinner (g)
Other vegetables	4.93	31.68	46.91	7.04	45.25	67.01	3.80	29.37	38.21	5.14	35.44	43.88	7.34	50.63	62.68
Mixtures mostly vegetables w/o meat	0.19	0.05	0.00	0.28	0.07	0.00	0.48	0.66	0.00	0.66	0.80	0.00	0.94	1.14	0.00
Fats	1.73	0.60	1.28	2.79	0.96	2.07	1.04	0.58	0.63	1.41	0.69	0.72	2.27	1.12	1.17
Oils	0.00	0.05	0.07	0.00	0.08	0.12	0.03	0.12	0.10	0.05	0.14	0.11	0.08	0.22	0.18
Salad dressings	1.10	4.61	4.75	1.77	7.44	7.66	0.13	1.67	1.93	0.18	2.02	2.21	0.28	3.25	3.57
Sugars and sweets	8.94	2.45	3.19	15.15	4.16	5.41	5.37	3.49	4.05	7.26	4.21	4.65	12.30	7.13	7.88
Total of all categories	366	412	496	491	554	667	270	341	432	366	412	496	487	559	677

Note: Meat refers here to any item categorized by the NHANES as a meat, which includes the flesh of any animal, including fish. Meat does not include eggs or dairy.

To represent the amount of the raw materials produced, these material weights are scaled up to account for food waste, based on data from Buzby et al. (2014), which are shown in Table 7

Table 7: Loss of foods at the retail operations and consumer (Based on Buzby et al. 2014)

Food commodity group	Loss at retail level (%)	Loss at consumer level (%)	Total loss, retail and consumer (%)
Grain products	12	19	28.7
Fruit	9	19	26.3
Vegetables	8	22	28.2
Fluid milk	12	20	29.6
Other diary	10	19	27.1
Red meat, pork and other meats[20]	4	23	26.1
Poultry	4	18	21.3
Fish and seafood	8	31	36.5
Eggs	7	21	26.5
Nuts, legumes	6	9	14.5
Sugars, sweeteners	11	30	37.7
Fats, oils	21	17	34.4

The raw material production and delivery stage also includes the transportation of these commodities from their point of production (*e.g.*, a farm) to the relevant processing or manufacture location. The distribution of each of the commodities will vary widely throughout the food system. Lacking a specific source of data on the average distance of products from production to processing, a general assumption is applied here that all food commodities are transported 500 miles by truck to arrive at their next point of processing. Note also that some products will not undergo additional processing and will be transported fresh to the marketplace. It can be considered that this lack of additional transport is accounted for in arriving at the average distance mentioned above.

Representation of food raw materials within meals

Table 6 presents the weights of food raw material categories present within each of the meal types represented. Table 8 summarizes how each food group from Table 6 has been represented by life cycle inventory data characterizing the set of environmental emissions and uses of resources as part of the raw material production stage of the meal life cycle. For some categories, such as legumes and nuts, adequate

[20] The Buzby et al. 2014 report uses the term "meat" to apply to all meat products except for fish and poultry. It has been renamed to "red meat, pork and other meats" here to make it clearer to the reader to which food categories we have applied this waste value in the present assessment

detail on sub-categorization and/or adequate differentiation within life cycle inventory (LCI) data do not allow for finer differentiation, one or a few components of a category have been used to represent the production of all products in that category on a per-weight basis. Where it is feasible to do so and where the available life cycle inventory (LCI) data allow it to be utilized, additional specificity within the category has been added where possible to allow for a more detailed representation of what is consumed within each category. Where this is done, data from the USDA's Economic Research Service (ERS) is used (USDA 2015). These data characterize the proportional consumption of various food commodity categories within the United States. Legumes, pasta, grains, and dried fruit are scaled from wet weight to dry weight to account in differences in how these commodities are represented in the NHANES data in comparison to the LCI data sources. This scaling is done based on the relative caloric content of wet and dry versions of these commodities in the USDA ARS National Nutrition Database (USDA 2015b)

Because of the central role of meat in the comparison of meals, it is worth taking note that all meats that cannot be classified as specifically beef, pork, poultry or fish/shellfish have been represented as a mixture of these four categories, based on the assumptions that much of the meat in the underspecified categories is one of these four common categories and that for the amount that is other meats, the production of these four categories is the best available approximation of the production of these additional meat types. Of note, approximately 7% of total meat consumption in the US is turkey (UDSA 2015c and NOAA 2014) and all poultry has been represented here based on the production model for chicken. According to the USDA's Economic Research Service (2015c), supplemented with the data on seafood from NOAA (2014), the combination of beef, pork, poultry and seafood comprise 99.5% of total meat consumption in the US. As described above, this other 0.5% is included in the volume of meats consumed, but represented as a mixture of these other types of meat due to the lack of available LCI data to characterize the many less common meats.

As with the meats, many other food groups have been represented based on the USDA ERS disappearance data (USDA 2015a). The need to add greater specificity arises due to the need to match the food consumption categories from NHANES with the data on environmental impact data from the life cycle inventory databases used, Ecoinvent (SLCLI 2015) and Agri-footprint (Blonk 2014). Whereas the NHANES represents food consumption within relatively broad categories (e.g., "dark green vegetables", "citrus fruits"), the data from the LCI databases are typically for a specific food commodity (e.g, "spinach", "naval oranges"). Where greater specificity is needed, the percentages of food disappearance within a given commodity category were used to apportion the NHANES category amounts to these more specific commodities. LCI data are not available for all food commodities, and so the availability of representative data was also taken into account in assigning the categorizations. Where LCI data are missing, as similar a commodity as is possible is chosen for the representation. For example, grapefruit production may be represented as orange production. Where it is desired to understand the consumption of food categories by American adults at a greater level of specificity than that provided by NHANES, data on the disappearance of foods in the US has been used, as this is the best known data source for use as an approximation of consumption of these food types by human adults in the US, even though such consumption is not the only means by which food commodities recorded in these databases disappear.

Table 8: Representation of each food category by life cycle inventory data characterizing the environmental emissions and resources used during the raw material production stage

Category as defined in NHANES	Grouped as	Represented by
Milk and Milk Products		
Milks and milk drinks	Fluid dairy	All items in this category are represented as whole fluid milk, based on the following dataset from Ecoinvent v3.1[21], which represents whole fluid milk: "Cow milk {GLO}"
Cream and cream substitutes	Fluid dairy	
Milk desserts, sauces, gravies	Fluid dairy	
Cheeses	Cheese	Based on dataset from Ecoinvent v3.1: "Cheese, from cow milk, fresh, unripened {GLO}"
Meat, Poultry, Fish and Mixtures		
Meat, NS as to type	Meat mixture	Represented as 25.1% beef (See Appendix I), 21.5% Pork (see Appendix J), 46.6% Poultry (see Appendix K) and 6.8% Fish (See appendix L)[22]. Percentages are based on USDA (2015c) and NOAA (2014) and representing 2014 consumption. All poultry is represented here as chicken[23]. The following are the annual consumption statistics used for this calculation (all units are in pounds per capita): beef = 54.1, Pork = 46.4, Poultry = 100.3, Fish = 14.6. All meats which are not beef, pork, poultry or fish are included in the assessment and are represented as a mixture of these 4 meats based on their proportion of consumption in the US diet. This is due to not having applicable data available for raising of other types of meats and that the level of specificity here
Lamb, veal, game, other carcass meat	Meat mixture	
Organ, sausages, lunchmeats, spreads	Meat mixture	

[21] References throughout the report to the Ecoinvent v3.1 refer to the "cut-off system model" version of this database.

[22] Numbers used to calculate these percentages are (all in units of pounds annually per capita): beef 54.1, pork 46.4, poultry (100.3), and fish (14.6).

[23] Given the lack of life cycle inventory data on poultry production, the data for chicken production has been used as the best available representation for turkey production. This is based on the similarity of the animals (both birds) in comparison to other available meat production data (e.g., cows, pigs). Among the most important parameters in determining the impact of animal raising is the feed requirements and composition per amount of meat produced and it is expected that birds will be reasonably similar to each other in this regard in comparison to, for example, a mammal.

Category as defined in NHANES	Grouped as	Represented by
		does not allow their differentiation in many cases from these four common meat categories.
Beef	Beef	See Appendix I
Pork	Pork	See Appendix J
Poultry	Chicken	See Appendix K; note poultry is represented as chicken for environmental impact calculations.
Fish and shellfish	Fish	See Appendix L
Meat, poultry, fish with nonmeat items	Mixture of meat and vegetables	Based on the description of this category, it is not clear how much of the food represented is meat or vegetables. Lacking any other basis, it has been represented here as an even split, half each of the category of meat mixture as described above, vegetable mixture as described below. This 50/50 split is chosen as the point of minimal potential error or bias in the absence of any better information.
Vegetables with meat, poultry, fish	Mixture of meat and vegetables	
Frozen, shelf-stable plate meals, w/meat	Mixture of meat, vegetables and grains	Based on the description of this category, it is not clear how much of the food represented is meat or vegetables. Making an assumption of even distribution of this weight among the major categories that are expected to be included, it has been represented here as an even split, equal parts (1/3 each) of the category of meat mixture as described above, vegetable mixture as described below, and grains as described below. This 33/33/33 split is chosen as the point of minimal potential error or bias in the absence of any better information.
Vegetables		
White potatoes, Puerto Rican starch veg.	Starchy vegetables	Represented based on the dataset "Potato, US" from Ecoinvent v3.1 (SCLCI 2015)
Dark-green vegetables	Dark green vegetables	Represented based on the dataset "Spinach, GLO" from Ecoinvent v3.1 (SCLCI 2015)
Deep-yellow vegetables	orange/yellow vegetables	Represented based on the dataset "Carrot, GLO" from Ecoinvent v3.1 (SCLCI 2015)
Tomatoes and tomato mixtures	Vegetable mixture	Represented by the following datasets from Ecoinvent v3.1 (SCLCI 2015): 4% cruciferous vegetables ("cauliflower, white, GLO"), 3% broccoli ("Broccoli, GLO"), 2% carrots ("Carrots, GLO"), 1% celery ("celery, GLO"), 5% corn ("maize grain, US"), 1% cucumber ("cucumber, GLO"), 5% leafy vegetables ("spinach, GLO"), 4% lettuce ("lettuce, GLO"), 3% onions ("onions, GLO"), 2% peas ("protein peas"), 2% peppers ("green bell pepper, GLO"), 23% root vegetable ("sugar beet, CH"), 22% potatoes ("potato, US"), 1% string beans ("zucchini") and 22% tomatoes ("tomato, GLO"). The breakdown is from USDA's Economic Research Service (USDA 2015h).
Other vegetables	Vegetable mixture	
Mixtures mostly vegetables w/o meat	Vegetable mixture	
Eggs		

Category as defined in NHANES	Grouped as	Represented by
Eggs	Eggs	Represented by the following dataset from the Agri-footprint database (Blonk 2014): “Consumption eggs, laying hens > 17 weeks, at farm”
Egg mixtures	Eggs	
Egg substitutes	Eggs	
Legumes, Nuts, and Seeds		
Legumes	Legumes	All legumes are represented by the following dataset from the Ecoinvent database (v3.1, SCLCI 2015) “Fava bean, integrated production”
Nuts, nut butters, and nut mixtures (with carob)	Nuts	All nuts are represented as almonds, based on the following dataset from the AusLCI database (AusLCI 2011) “Almond kernels, at huller and sheller”
Seeds and seed mixtures	Nuts	
Grain Products		
Yeast breads, rolls	Grains	Represented as wheat flour, 74% (Ecoinvent v3.1 “Flour, wheat, from dry milling, at plant”); corn flour/meal, 11% (Ecoinvent v3.1 “Maize flour, from dry milling, at plant”), rice, 11% (Ecoinvent v3.1 “Rice, US”) and oats, 4% (Ecoinvent v3.1 “Oat grain, dried, at farm). The breakdown is from USDA’s Economic Research Service (USDA 2015h, 2015i).
Crackers and salty snacks from grain	Grains	
Pasta, cooked cereals, rice	Grains	
Pasta, cooked cereals, rice	Grains	
Pasta, cooked cereals, rice	Grains	
Cereals, not cooked or NS as to cooked	Grains	
Grain mixtures, frozen plate meals, soup	Grains	
Quick breads	Cakes	Represented as one-third flour (based on “Wheat flour, from dry milling, at plant” from Agri-footprint, Blonk 2014), one third butter (based on “Butter, from cow milk” from Ecoinvent v3.1, SCLCI 2015) and one third sugar (based on “Sugar, from sugar beet” from Ecoinvent v3.1, SCLCI 2015)
Cakes, cookies, pies, pastries	Cakes	
Pancakes, waffles, French toast, other	Cakes	
Meat substitutes, mainly cereal protein	Veggie protein product	Represented based on the model of MorningStar Farms® Griller Original Burger from this assessment
Fruits		
Citrus fruits, juices	Fruit mixture	Represented as 17% apples (Ecoinvent 3.1 “Apples, GLO”), 8% bananas (Ecoinvent 3.1 “Bananas, GLO”), 3% berries (Ecoinvent 3.1, “Strawberries, GLO”), 7% grapes (Ecoinvent 3.1 “Grape, GLO”), 8% melons (Ecoinvent 3.1 “Melon, GLO”), 49% citrus (Ecoinvent 3.1 “Citrus, GLO”), 3% stone fruit (Ecoinvent 3.1 “Peaches, GLO”), and 5% tropical fruit (Ecoinvent 3.1 “Pineapple, GLO”). The breakdown is from USDA’s Economic Research Service (USDA 2015d).[24]
Dried fruits	Fruit mixture	
Other fruits	Fruit mixture	
Fruit juices and nectars excl. citrus	Fruit mixture	

[24] Where it is desired to understand the consumption of food categories by American adults at a greater level of specificity than that provided by NHANES, data on the disappearance of foods in the US has been used (USDA 2015a and NOAA 2014), as this is the best known data source for use as an approximation of consumption of these food types by human adults in the US, even though such consumption is not the only means by which food commodities

Category as defined in NHANES	Grouped as	Represented by
Fats, Oils, and Salad Dressings		
Fats		
Oils		
Salad dressings	Fats and oils	Represented as 3% animal fats (Ecoinvent 3.1, "Tallow, unrefined"), 20% margarine (Ecoinvent 3.1, "Vegetable oil, refined"), 51% cooking oil (Ecoinvent v3, mixture of "cottonseed oil", "soybean oil" and "rape oil"), 20% shortening (Ecoinvent 3.1, mixture of "soybean oil" and "palm oil") and 6% other oils (Ecoinvent 3.1 "Refined coconut oil, at plant"). The breakdown is from USDA's Economic Research Service (USDA 2015e).
Sugars and Sweets		
Sugars and sweets	Sugar	Represented as the following break-down of sugar types, with the LCI datasets in parenthesis: Beet sugar, 30% (Ecoinvent 3.1, "Sugar, from beet"); Cane sugar, 22% (Ecoinvent v3.1, "Sugar, from cane"); High fructose corn syrup, 35%; Glucose syrup ,9%; Dextrose, 2%; and "Edible Syrup", 1% (all represented as Ecoinvent v3.1 "Glucose syrup". Honey (1%) is omitted. The breakdown is from USDA's Economic Research Service (USDA 2015g.

Food product manufacturing for meatless and meat-containing meals

As with the transport of the food commodities, the variety of circumstances of manufacturing and processing is very broad. There is not any information available to support an assumption that meat-containing meals have either more or less environmental impact associated with the manufacturing than meatless meals and so this stage is represented the same for both meal types.

This stage includes an approximation of the extent of energy used in food processing per meal for the US, which is derived based on the following set of information and assumptions.

- A 2012 poll by Gallup identified that the average American spends $151 per week on food expenses. Assuming 3 meals per day, this is $7.19 per meal (Gallop 2012).
- Carnegie Mellon University (CMU 2015) provides an environmentally-extended economic input-output database linking purchases and expenses for >400 economic sectors in the US to environmental activities, such as emissions and energy use. Their data indicates that each dollar

recorded in these databases disappear. For example, consumption by children or animals are likely to also be responsible for some of the disappearance of these materials.

spent in the food sector results in roughly 0.05 to 0.1 MJ of total energy use at the manufacturing stage, depending on the sub-sector.

- Combining the above, we conclude that the meal average will require approximately 0.7 MJ of total energy use in manufacture. We have represented this energy use here as being drawn from the US grid.

Packaging for meatless and meat-containing meals

The US Environmental Protection Agency (US EPA) reports the amount of packaging disposed of in the US to be 75 million tons (USEPA 2011), with differentiation of the amounts of paper, plastics and other materials contained within this. A 1990 study by Hunt et al. reported that 2/3 of packaging waste in the US was food related. With no more recent statistic available, we have assumed that this ratio is still reasonably correct, even if the total amount of packaging may have changed, such changes are assumed to be distributed equally among food packaging and packaging of other types of products. We therefore apply the 2/3 ratio to the EPA's total waste generation and divide by the total number of meals consumed by the US population (319 million people x 3 meals x 365 days = 349 billion meals) to derive an estimate of the amounts of materials used in packaging food. This total packaging also includes packaging for snacks and beverages, each of which are categories that are expected to contribute a relatively high amount of packaging in comparison to their weight. Approximately 25% of US caloric intake is through snacks and 20% through non-dairy beverages (Sebastien at al. 2011 and US Beverage Guidance Panel 2015). We have therefore divided the result described above by a factor of 2 to arrive at the amount of packaging, on average, per meal consumed.

Retail and distribution for meatless and meat-containing meals

Drawing on the Carnegie Mellon University EIOLCA.net database (CMU 2015), it is identified that each purchase of a $7.19 average meal cost from the retail sector will result in approximately 0.014 MJ of total energy use in the retail operation and in purchased transportation services, which we assume here is drawn from the US electrical grid. The environmental impact of retailing is based on the generation of these 0.014 MJ of energy as purchased electricity from the US electrical grid.

Food product use for meatless and meat-containing meals

Food is stored and prepared in a wide variety of ways with few statistics available or identified to characterize the average among meals. We have therefore used the energy use values from the product comparisons section of this report as a reasonable approximation of the energy used in storing, cooking and cleaning up for a meal. The energy, water and materials used in cooking and cleaning from the product comparison are applied here, scaled by the overall meal weight.

Waste management for meatless and meat-containing meals

Table 7 shows the amounts of food assumed to result in waste at the consumer's home (based on Buzby et al. 2014). We have assumed here that this food is sent to landfill and handled there as an organic waste. The above mentioned packaging is assumed to be disposed of by a combination of recycling and municipal waste disposal based on material-specific recovery percentages published by the USEPA. Throughout the study, all end-of-life processes are represented based on what is termed the "cut-off" approach, meaning that the impact of operating the recycling processes is included, but any benefits associated with recovery of recycled materials are not considered and are assumed to be a part of the next product system those materials enter. This issue is not expected to have a large enough impact on the study conclusions to warrant considering alternative approaches as scenarios.

Meat product packaging

The meat products are assumed to be frozen in individual serving portions and then packaged in a flexible plastic packaging, composed primarily of polyethylene (25% by weight) and paper dividers between patties (75% by weight). The following amounts of materials are assumed to be used for packaging each functional unit of the meat products:

Table 9: Amounts of packaging used for meat products (per 60g of meat product)

	Input	Mass (kg)	Process LCI data used (from the Ecoinvent 3.1 database)
Primary packaging	Low-density polyethylene foam	0.000721	Polyethylene, LLDPE, granulate, at plant/RER U
	Paper	0.00217	Kraft paper, bleached, at plant/RER U
Tertiary packaging	Cardboard case	0.00191	Packaging, corrugated board, mixed fibre, single wall, at plant /RER U
	Pallet	0.0000013	EUR-flat pallet/RER U
	Plastic wrap	0.0000213	Polyethylene, LLDPE, granulate, at plant/RER U Extrusion, plastic film/RER U

MorningStar Farms® raw material inputs and delivery

This section provides details of the materials, energy and processes that are identified as raw material inputs to the *MorningStar Farms® veggie products*. The six *MorningStar Farms® veggie products* being assessed are listed below, followed by a table identifying the list of ingredients within each product. Most of these ingredients arrive at the production facilities as part of a mixture of materials from the supplier. Appendix G shows the breakdown of the specific food ingredients within each product. Note that this appendix is shown in the external review version of this report but removed in the publicly available version due to the proprietary nature of *MorningStar Farms®* meal composition data. In conducting the assessment, a more specific list of ingredient composition, accurate to 1% for each ingredient, has been provided and used.

The transportation processes required to deliver these raw material commodities from their points of origin to the manufacturing plants are also included within this stage. For each material, the knowledge about the location of origin and mode of transport is identified in Table 10. This table covers those ingredients that contribute to the majority of the product by mass and that are therefore most important for characterizing the impact of the material delivery network. All other products are represented as originating from within the US and are shipped to manufacturing via truck. For all products originating from within the US a fixed transport distance of 930 miles has been assumed, which corresponds to approximately one-third the breadth of the continental United States, whereas for quinoa, produced in Bolivia, transport to the production site has been modelled through truck transport within South America, ocean transport to the US and truck transport for the shipping within the US to the point of manufacture.

Table 10: Countries of origin and transportation modes for key MorningStar Farms® ingredients

Ingredient	Sourcing Country	Mode of Transportation
Corn and corn derivatives	US	truck
Soy and soy derivatives	US	truck
Wheat and wheat derivatives	US or Canada	truck
Dairy and derivatives	US	truck
Egg	US	truck
Quinoa	Bolivia	truck, ship, truck
Canola oil	US	truck
Oats	US	truck
Barley	US	truck
Beans (black beans and lentils)	US	truck

Note that whereas the meals comparison considers waste at retail and the consumer, the products comparison does not. It is challenging to apply the waste data from Buzby (2014) data to the veggie products, as they do not fall squarely into one category (they contain legumes, grains, nuts, vegetables and oils). It has been decided to leave both types of products un-adjusted for waste to avoid biasing the comparison in the way this data is applied.

MorningStar Farms® manufacturing

The raw material ingredients are mixed and processed into the finished product at two US-based manufacturing facilities. These facilities produce primarily these products and similar products. It is assumed that all aspects of manufacture can best be allocated to each unit of product produced based on its mass. That is, that each equivalent mass of product leaving the facility has an equivalent responsibility for the overall use of electricity, fuels, water, emissions and waste generation at the facility. These aspects of production are therefore assigned to each product system based on the mass of the product and based on the data for these facilities provided by *MorningStar Farms®* and presented in Table 11.

Table 11: MorningStar Farms® manufacturing information (2014 data)

Metric	Facility A	Facility B
Production (pounds)	24,541,935	48,838,460
Electricity (kwh)	10,461,000	21,208,400
Electricity Source	grid	grid
Natural gas (MMBTU)	58,536	77,751
Water Use (gallons)	53,887,000	64,186,109
Wastewater discharge (gallons)	45,505,891	59,059,542
GHG emissions (metric tonnes CO2 eq.)	7,128	18,670
Waste to landfill (metric tonnes)	1,832	548
Waste recycled (metric tonnes)	435	1,383
Waste incinerated (metric tonnes)	125	0
Waste used as animal feed (metric tonnes)	661	386

Differences in the values between facility A and B on Table 11 are due to a combination of the production scale in each plant and their operating conditions and their scale. Overall manufacturing consumption data was used to calculate the average amount of electricity, heat, water and waste per kg of *MorningStar Farms® veggie products* made. These values, together with the ingredient lists, were then used for the modelling of the production of the different *MorningStar Farms® veggie products*.

MorningStar Farms® packaging

MorningStar Farms® veggie products are packaged, as of January 2016, in a flexible plastic primary packaging, suitable for use in frozen foods applications, and this primary packaging is transported within the retail supply chain in corrugated cardboard secondary packaging. The specific weights and materials used in these packaging systems for the six *MorningStar Farms® veggie products* are shown in Table 12. The plastic film consists of a combination of 48-gauge Matte PET heat sealable plastic with ink and adhesive with 2.5 mil WHDPE and 100g Matte OPP with ink and adhesive and 2.50 mil WHDPE.

Table 12: Specific materials for MorningStar Farms® packaging

MorningStar Farms® product description	# of packages/ case	Weight of closure (g)	Weight of film (g)	Weight of case (g)
Grillers® Crumbles™, 8 count, 12 oz.	6	1.977	10.53	276.7
Grillers® Original Burgers, 12 count, 9 oz.	8	2.183	7.72	167.8
Spicy Black Bean Burgers, 12 count, 9.5oz	8	2.183	7.72	167.8
Roasted Garlic & Quinoa Burgers, 8 count, 9.5 oz.	8	2.183	7.65	181.4
Original Sausage Patties, 12 count, 8 oz.	6	1.633	8.74	249.5
Original Chik Patties®, 8 count, 10 oz.	8	2.292	8.3	181.4

MorningStar Farms® and meat product distribution and retail

It is assumed that both the meat products and *MorningStar Farms®* veggie products follow equivalent paths from the point of production to reach the consumer's home. From the point of product manufacture, the packaged products travel by frozen transport to the retail outlets, usually with an intermediary stop at the retailer's regional distribution center. The distances of these trips will vary widely depending on the points of manufacture and the location of the retail stores and distribution center. The following distances have been used here, which are assumed to be a reasonable representation of such processes in the US.

The distance between production site and retailer distribution center is taken directly from an average distance provided by Kellogg and applied here to all products, both *MorningStar Farms® veggie products* and the meat products. The distance from distribution centers to retail stores is an assumption, since the average distance across all US retailers is not known.

Table 13: Transportation distances between stages of the life cycle

Transportation stage	Distance (miles)
Transport from farming to manufacturing	930
Transport from production site to distribution center	292
Transport from distribution center to retail store	450

The transportation of the product from the retailer to the consumer's home has been represented based on the shopping habits of Americans. The National Household Transportation Survey (latest data represents 2009) indicates that the average US household travels a total of 2980 miles each year over 470 shopping trips, or an average of 6.4 vehicle miles per trip. The Food Marketing Institute has reported that US households spent approximately $50 in total per grocery shopping trip between 2006 and 2012. The resulting 0.13 miles of vehicle travel has been assigned to both the product life cycle based on an assumption of $0.5 paid per 60 g serving for all products, or 0.065 vehicle miles travelled per functional unit. This trip is allocated to the products purchased based on their cost.

Similarly, the transport modes (e.g., road, rail, seaway, etc.) and distances of the products being transported from the retailer to the consumers will vary widely and the average situation is not known. The following assumptions have been used here, which are assumed to be a reasonable scenario: a consumer drives an average of seven miles roundtrip in a compact gasoline-powered car to purchase a total of 20 items, among which the package of *MorningStar Farms®* or meat products is one.

The storage of products throughout the food chain is based on an adaptation of the recommendations in Humbert and Guignard, 2015. The products are assumed to occupy 0.0002 m3 (2cm x 10cm x 10cm box and are stored with an overall ratio of product volume to storage volume of 1/3 for frozen products and ½ for refrigerated products. The meat products are assumed to be kept frozen at the distribution center (4 weeks) and at the retailer stores (and additional 4 weeks), except for the fresh ground beef, which is assumed to be at refrigerated temperature and only kept at the distribution center for 1 day and at retail for 2 weeks. Chilled storage at distribution centers is assumed to use 35 kWh/m3-year. Storage at retail assumed 1100 Kwh/m3-year for chilled and 1500 Kwh/m3-year for frozen. Note that retail refrigerators and freezers are highly inefficiency compared to a large distribution center, due both to scale and the frequent opening or permanent open state of these commercial coolers. The total energy consumption for storing the frozen products is therefore 0.00054 kWh at distribution and 0.023 kWh at retail, while the energy consumption for the refrigerated product (fresh ground beef is 0.000019 kWh at distribution and 0.0085 kWh at retail. Note that for all aspects described in this section, with the exception of the refrigeration of fresh ground beef, the processes taking place for both the meat and veggie products will be identical and so although several aspects of this stage are highly variable with uncertain average values, the extent to which the assumptions here differ from the true average will have no effect on the outcome of the comparative results. Note also that a scenario is conducted in which the transport and storage of the meat products is at refrigerated rather than frozen temperatures.

MorningStar Farms® veggie product and meat product use

As with the distribution and retail stage, the default set of assumptions in the product use stage are similar between the two sets of products being compared. However, because there could be reasons to assume some potential differences in food preparation between the products, some scenarios are explored at this stage to understand how significantly these potential differences may affect the overall environmental impact of the consumption of these products. The consumer use of the products includes the following set of activities: storage of the products (in a home freezer or refrigerator), cooking of the products (in an oven, in a microwave, or on a stovetop), and cleaning of the cooking and eating equipment.

Storage of the products is assumed to occur in an average home freezer. It is assumed here that the products are stored for one month in a freezer that uses 1.3 kWh per liter (volume) per year and that each serving of product requires around 0.02 liters of storage space in the freezer. Moreover, the burgers need to be thawed before cooking. Following the cooking indications which can be found on the *MorningStar Farms®* website, thawing through one-minute operation of a microwave oven at half power has been assumed. Each burger is thawed individually. Note that variation in any of these aspects would scale the overall impact of this aspect of product use upward or downward proportionately (e.g., doubling the storage time would double the impact of storage).

Cooking of all of the meat and *MorningStar Farms®* veggie products are represented here as occurring in one of two scenarios: stovetop preparation in a frying pan or griddle, or baking in the oven within a larger prepared dish, such as a casserole or meatloaf. The stovetop preparation is chosen as the default option, with the oven cooking examined as a sensitivity test. Lacking observational data on consumer cooking, in all cases it is assumed that four servings are prepared at once on the stovetop and eight servings in the oven. That is, in the stovetop preparation, it is assumed that four meat or non-meat patties are cooked simultaneously in the same pan. In the oven preparation, it is assumed that eight servings of food overall are contained in the recipe being baked, so that one-eighth of the baking is allocated to the meat product or *MorningStar Farms®* product representing the serving in question.

Thawing and cooking is assumed to occur based on the conditions and assumptions listed in Table 14.

Table 14: Assumptions regarding consumer cooking and clean-up conditions (applies to one burger or patty product)

Consumer use process	Characteristic	Data or assumption
Thawing of frozen products	Device used	1.1 kWh (max) microwave, weight 15 kg
	Life time of microwave	8 years
	Thawing time	1 min (50% power)
	Energy use:	0.00917kWh/serving
	Frequency of use	5 times/week
Cooking on skillet	Skillet weight	2.2 kg
	Life time	8 years
	Cooking time	0.13 hour
	Energy use	0.13 kWh/serving
	Times skillet used	500 times
Oven cooking	Skillet weight	2.2 kg
	Cooking time	0.3 hour
	Cooking temperature	180 ºC
	Energy use	0.72 kWh/serving
	Servings cooked in lifetime of oven	146,000
Dish washing	Washing method	Residential dishwasher
	Usage rate	Each serving occupies 1/10th of a dishwasher load

MorningStar Farms® and meat product loss in manufacture, retail and consumer storage

The loss of ingredients during manufacturing process is assumed conservatively to be 5% by weight for all products (BSR 2013). This is assumed to be a conservative assumption, as meat products may be subject to a higher rate of loss in the processing stage as compared to the grains and other ingredients used in the *MorningStar Farms®* veggie products due to the need to separate the meat from other parts of the animal (bones, hide, etc.), but no data is available to support using a different waste assumption at this stage for different food types. The spoilage of food at retailer and at the consumer level is therefore not considered for the product comparisons. This is due to the inability to ensure an accurate representation of the amount of waste of *MorningStar Farms®* veggie products at these stages (they do not fall easily within one category of the Buzby et al 2014 data and there are not other comparable data sources available to represent this food category) and because of the potential effect on the result of showing a difference among the product types in the amount wasted without having accurate data to support it.

MorningStar Farms® and meat product packaging end of life

Primary packaging materials (e.g., film and closures) are assumed to be disposed of in the municipal waste system. The cardboard (part of the tertiary packaging materials) is assumed to be recycled. The other tertiary packaging materials (e.g. plastic pallet wrap) are assumed to be sent to municipal waste systems.

3.4 Temporal and geographic boundaries

This assessment is intended to be representative of food production and consumption conditions in the US at the time the study is conducted (2015). 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, although data from the relevant geography is not always available and data for most aspects of the system are at minimum a year old and in many cases several years old. Main databases and key reports used in this study are all from 2010 or later, which is considered to represent current conditions in the industry.

It should be noted that some processes within the system boundaries might in fact take place anywhere in the world and over a much wider range of time than the current year. For example, the processes associated with producing food consumed in meals in the US take place both in the US as well as in a wide variety of other countries. The information to represent food production in this assessment has been selected with a preference for data representing US production. To the extent that such data is not available in all cases, it is hoped that the use of data from other geographies, when needed, balances in part the actual sourcing of products from both within and outside the US.

Regarding the temporal boundaries, certain processes may generate emissions over a longer period of time than the reference year. Regardless of such considerations, all data has been selected to as closely represent conditions in 2015 as is practical.

3.5 Cut-off criteria

Processes may be excluded if their contributions to the total system's environmental impact are expected to be less than 1%. Materials that are less than 1% by mass are assumed to also contribute less than 1% of the environmental impact, except in cases where there is a reason to expect otherwise, such as with hazardous substances. Despite this criterion for allowing components to be excluded, all product components and production processes are included when the necessary information is readily available or a reasonable estimate can be made. It should be noted in particular that the *MorningStar Farms® veggie products* contain many ingredients in the range of 1% by mass and all such ingredients have been included in the modeling.

It should be noted that the capital equipment and infrastructure available in the *Ecoinvent v3.1* database (SCLCI 2015) are included in the background data for this study in order to be as comprehensive as possible.

The following are just a few examples of items excluded from the study due to lack of reliable data and expected contribution lower than the cut-off criteria: seals and stickers on packaging or used in retail; production of eating utensils; shipping pallets.

4 Assessment methodology

4.1 Allocation methodology

A common methodological decision point in LCA occurs when the system being studied produces co-products. When systems are linked in this manner, the boundaries of the system of interest must be widened to include the system using all co-products, or the impacts of producing the linked product must be distributed—or allocated—across the systems. While there is no clear scientific consensus regarding an optimal method for handling this in all cases (Reap et al. 2008), many possible approaches have been developed, and each may have a greater level of appropriateness in certain circumstances.

ISO 14044 prioritizes the methodologies related to applying allocation. It is best to avoid allocation through system subdivision or expansion when possible. If that is not possible, then one should perform allocation using an underlying physical relationship. If allocation using a physical relationship is not possible or does not makes sense, then one can use another relationship.

Many of the processes in the Ecoinvent database (SCLCI 2015), which has been used as a primary source of data in this assessment, also provide multiple functions, and allocation is required to provide inventory data per function (or per process). This study accepts the allocation method used by this database for those processes.

Transport allocation

Transport vehicles have both a weight capacity and a volume capacity. These are important aspects to consider when allocating the impacts of an entire transportation journey to one product. Vehicles transporting products with a high density (high mass-per-volume ratio) will reach their weight capacity before reaching their volume capacity. Vehicles transporting products with a low density (low mass-per-volume ratio) will reach their volume capacity before reaching their weight capacity. Therefore, the density of the product is critical for determining whether to model transportation as volume-limited or weight-limited. In this study, all transport is assumed to be weight-limited and the transportation of the cargo within the vehicle is therefore allocated based on its weight.

4.2 Impact Assessment

Impact assessment method and indicators

Impact assessment classifies and combines the flows of materials, energy, and emissions into and out of each product system by the type of impact their use or release has on the environment. The method used here to evaluate environmental impact is the peer-reviewed and internationally-recognized life cycle impact assessment (LCIA) method IMPACT 2002+ vQ2.2 (Humbert et al. 2012). This method assesses seventeen different potential impact categories (midpoints)[25] and then aggregates them into endpoint categories.

The main body of this report will consider most heavily the five indicators shown and described in Figure 4. The endpoint indicators for Health Impact of Pollution, Ecosystem Quality and Resource Consumption are each comprised of several midpoint indicators. Appendix F includes the contribution of each of these midpoint indicators, as illustrated in Figure 5, in determining the overall result for these endpoint indicators for the meat products. This set of five indicators allows an overview of the results, while maintaining a simple enough list of indicators to identify and understand the main trends.

Figure 4 provides a summary of these five environmental impact categories given primary focus. Carbon Footprint and Water Use are given additional focus in addition to the endpoint indicators because of the

[25] The Human Toxicity midpoint category is divided between carcinogenic and non-carcinogenic effects, hence a total of 17 midpoint indicators (Humbert et al. 2012).

strong interest in these issues, as well as the important role food systems are known to play in these issue areas.

Figure 4: Description of the five environmental impact indicators given primary focus in this assessment

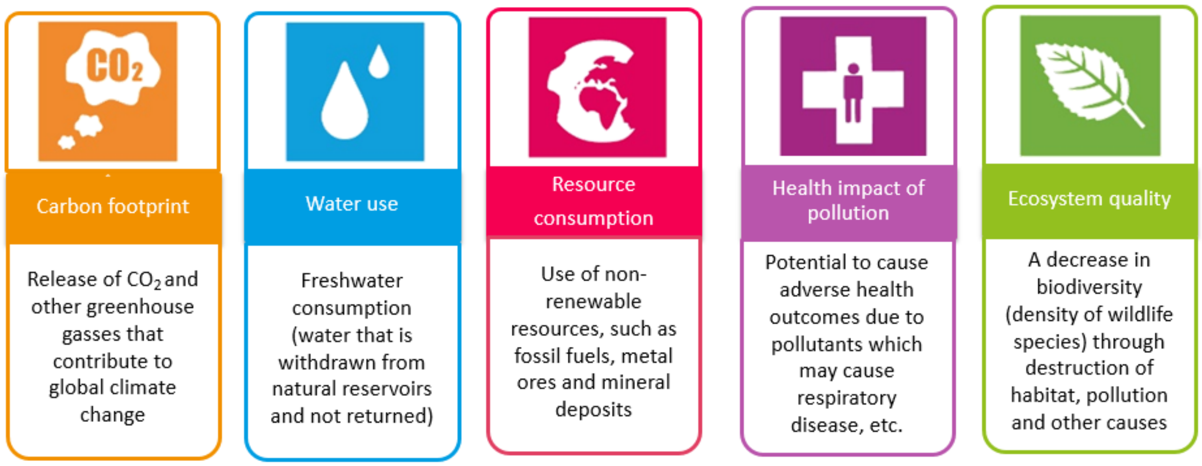
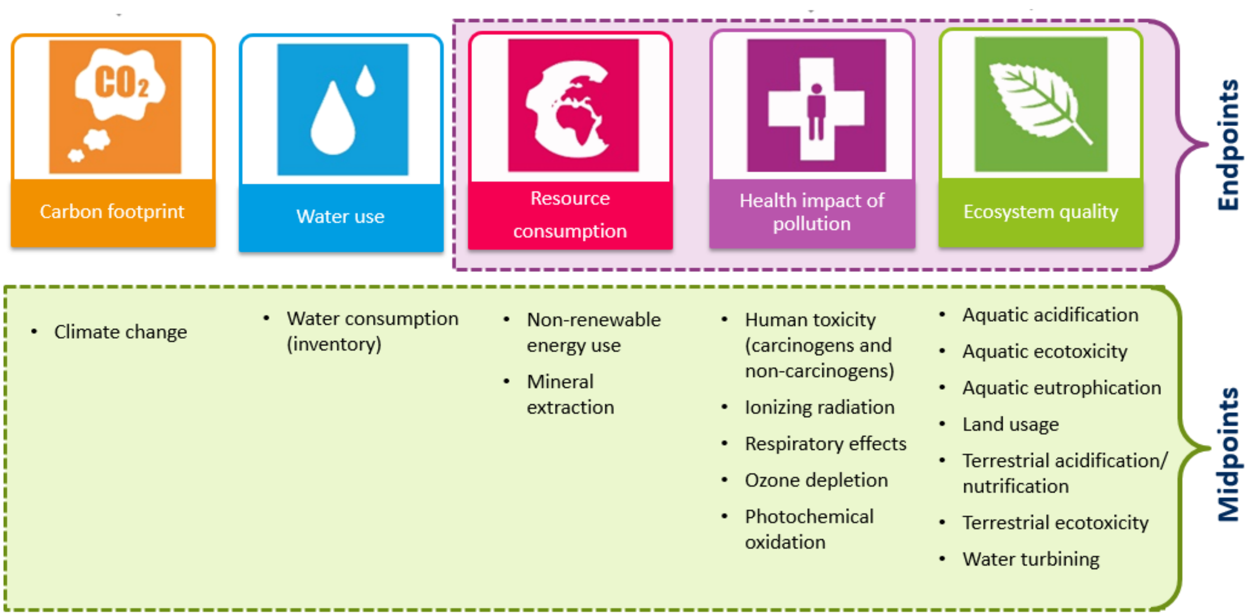


Figure 5: IMPACT 2002+ midpoint and endpoint categories



A more detailed description of the impact categories than what is shown in Figure 4 is provided in Appendix A.

No normalization of the results is carried out with the exception of results presented on a relative basis (%) compared to the reference for each system. No weighting of the endpoint categories is done; they are presented individually and not as a single score, as there is no objective method by which to achieve this.

LCA results estimate the potential that environmental impacts will occur and does not represent a measurement of actual environmental impacts that have occurred. They are relative expressions, which are not intended to predict the final impact or risk or whether standards or safety margins are exceeded. Additionally, these categories do not cover all the environmental impacts associated with human activities. For example, impacts such as noise, odors, and electromagnetic fields are not included in the present assessment, as the methodological developments regarding such impacts are not sufficient to allow for their consideration within life cycle assessment.

4.3 Calculation tool

SimaPro 8.0.3 software, developed by PRé Consultants (2015) was used to assist the LCA modeling, link the reference flows with the life cycle inventory database, and compute the complete inventory of the systems. The final result was calculated combining foreground data (intermediate products and elementary flows) with generic datasets providing cradle-to-gate background elementary flows to create a complete inventory of the two systems. Microsoft Excel was used to help with processing the results from the LCA.

4.4 Uncertainty analysis

We identify and discuss below two types of uncertainty related to the LCA modes developed here: uncertainty in inventory data; and uncertainty in the impact characterization models, which translate inventory into environmental impacts. With assessment of comparative results, it is important to note the difference between the uncertainty in the impact of a given product and the uncertainty in the direction of difference in impact between two products. It is very possible for the uncertainty in the absolute impact of two given products to each be relatively high and yet the uncertainty of how they compare to be very low. In particular, the more similar two products are in terms of the processes and materials that comprise them, the more the factors that contribute to the uncertainty in the absolute impact of each will cancel each other out when comparing them.

Inventory data uncertainty analysis

An analysis of the uncertainty due to the variability of inventory data has been performed. SimaPro 8.0.3 software (PRé 2015) includes a module for Monte Carlo simulation, which allows assessment of the uncertainty and variability embedded in inventory data. The great majority of the data here is drawn from the *Ecoinvent* database, which has a thorough characterization of the uncertainty for most of the flows of energy and material within the life cycle inventory data that it provides.

Monte Carlo analysis was used here to understand the uncertainty within the product systems assessed here, using 100 iterations for each product system to understand the range in outcomes when the data within the product model is represented as probabilistic rather than as fixed values. For the assessment of meals, a separate Monte Carlo simulation has not been performed due to the added variability of the types of food present within specific meals, which adds a further degree of uncertainty/variability. It is believed that the uncertainty assessment for the product systems provides some context for the size of the uncertainty regarding specific food items within the meals assessment, even if these are not assessed specifically.

Monte Carlo simulation has been applied to the product models but not to the meal models. This is due to an expectation that the Monte Carlo results for meals would give a significant underestimation of the uncertainty among individual comparative meal choices. There are a very wide range of possible meals within both the meatless and meat-containing categories. It is certain that among these meals exist some that are much more extreme than the average result shown here in both directions, including both comparisons that would show the opposite directional results and some that would show a much more extreme result in a consistent direction. It is expected that showing results for a Monte Carlo on the LCI data representing the meal average without accounting for this meals' variability would give a falsely high sense of confidence that all or nearly all possible meal comparisons would find a consistent direction as the results shown here, when this may not be the case.

Characterization models uncertainty analysis

In addition to the inventory data uncertainty described above, there are two types of uncertainty related to the LCIA method. The first is about the characterization of the LCI results into mid-point indicators, and the second is about the subsequent characterization of those midpoint scores into end-point indicators. The uncertainty ranges associated with characterization factors at both levels vary from one mid-point or end-point indicator to another. The accuracy of characterization factors depends on the ongoing research in the many scientific fields behind life cycle impact modeling, as well as on the integration of current findings within operational LCIA methods. There are presently no systematic methods available for quantifying or evaluating the influence of the uncertainty in these characterization models within the comparative assessments made here. Without consideration of the uncertainty in LCIA characterization factors, the uncertainty assessment results derived here should be seen as something like a lower bound on the level of uncertainty in the systems and the uncertainty would be higher if considering also the uncertainty in these characterization factors.

4.5 Critical Review

A critical review has been conducted by an independent panel. This panel was chaired by Michael Hauschild, PhD, of Technical University of Denmark and included as panelists Greg Thoma, PhD, of University of Arkansas and Joan Sabaté, PhD of Loma Linda University. This review process was intended to validate that the study follows the stipulations set forth in the ISO 14040 and 14044 standards (ISO 2006a, 2006b). The external critical review report, as well as Quantis' comments and responses to the review report, are presented in Section 9.

5 Results

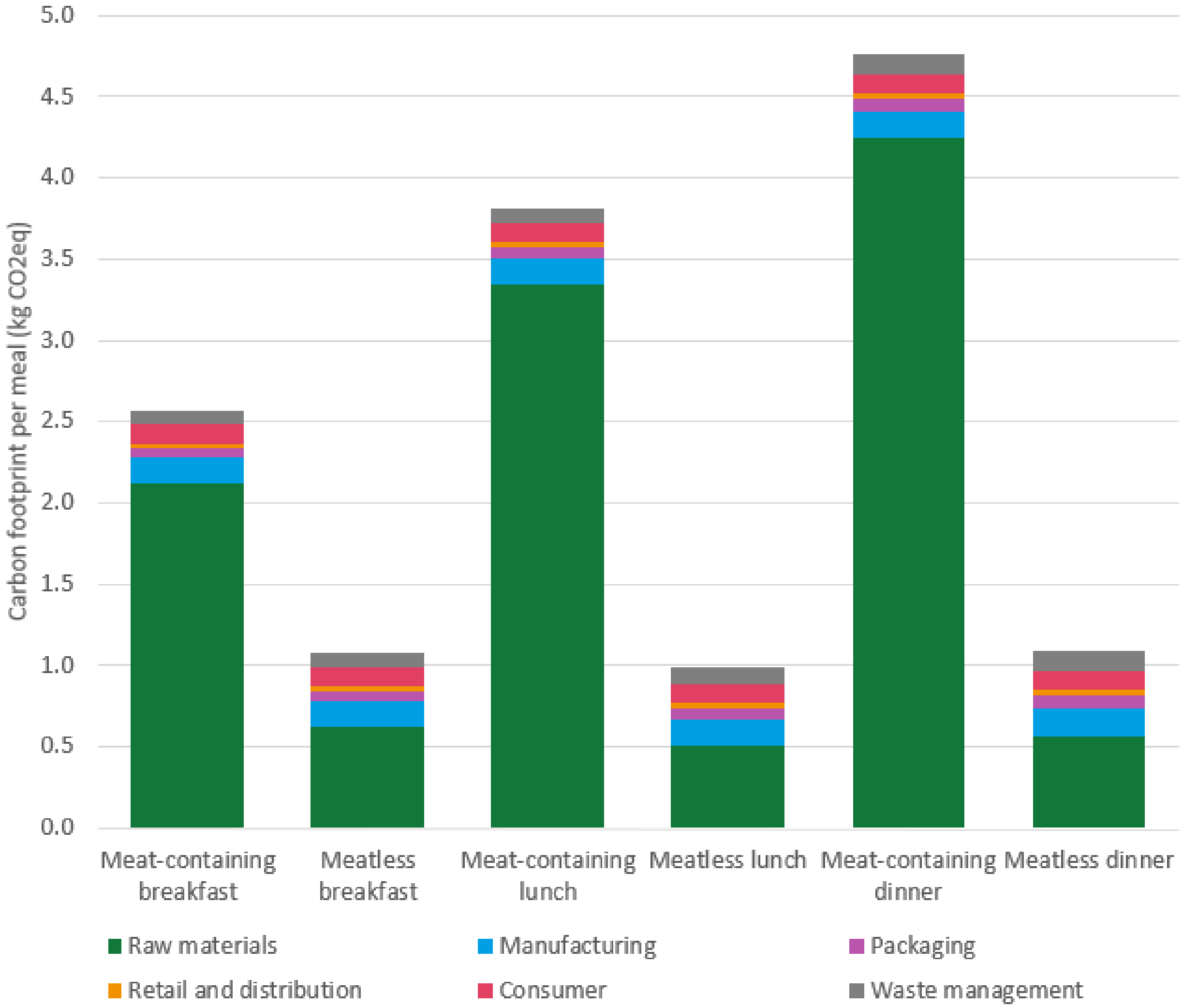
The following sections present study results of the assessment, first focusing on the comparison of meatless and meat-containing meals and then focusing on the comparisons of products.

5.1 Environmental impact of meatless and meat-containing meals

Figure 6 shows Carbon Footprint result for meat-containing and meatless meals. The results for both meal types for the Carbon Footprint, Water Use, Resource Consumption, Health Impact of Pollution, and Ecosystem Quality indicators are shown in Table 15.

For both meat-containing and meatless meals, lunches show a larger environmental impact than breakfasts, and dinners show a larger environmental impact than lunches, following the directional trend in overall weight of food among the meals. The relatively high impact of the meatless breakfast in proportion to its ratio of weight is primarily due to the high proportional intake of dairy products within the meatless breakfasts, as is evident in the detailed results shown further below.

Figure 6: Carbon Footprint of meat-containing and meatless meals



Note: Meat is represented here as beef, chicken, pork and fish. Meat does not include eggs or dairy.

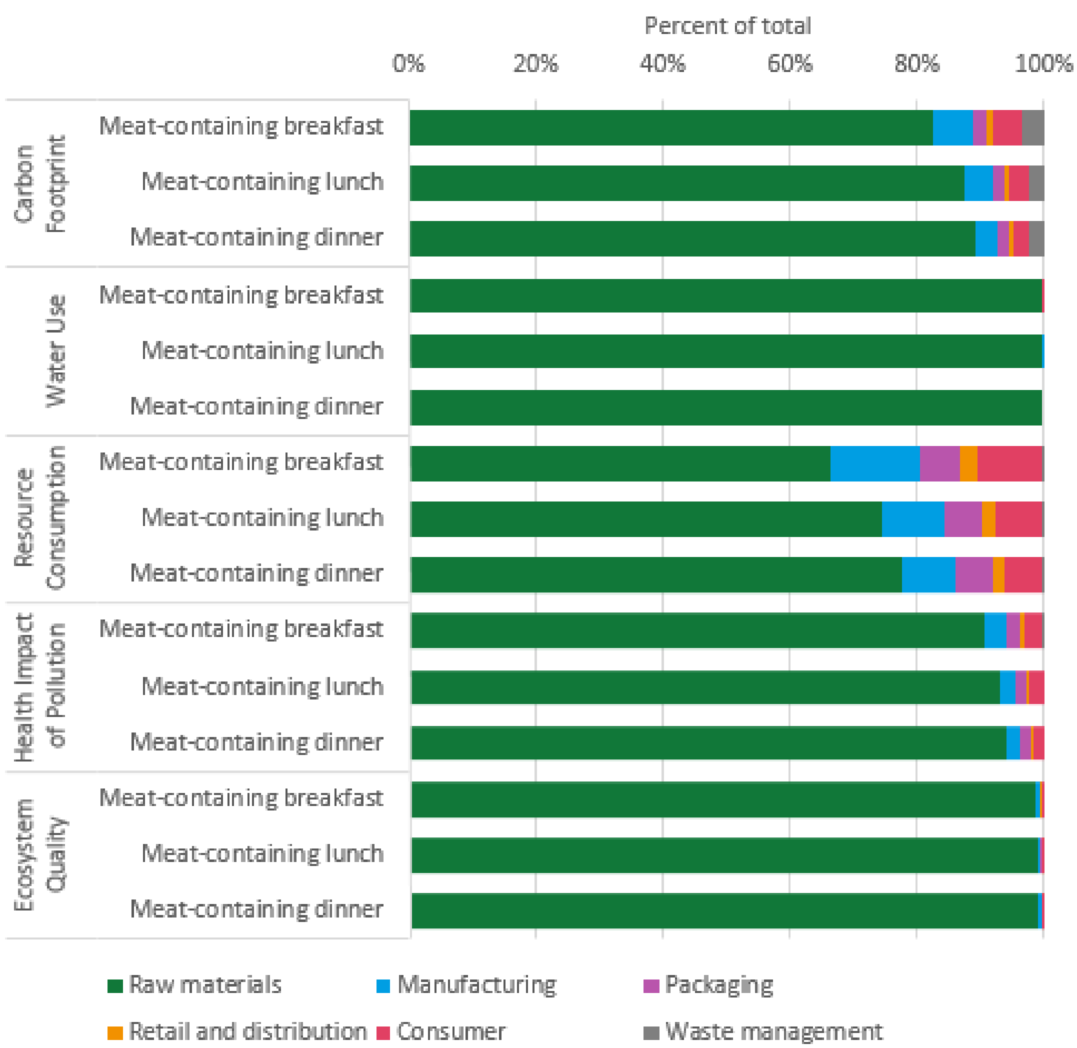
Table 15: Environmental impacts of meatless and meat-containing[26] meals by life cycle stage (per type of meal)

Impact category	Meal	Raw materials	Manufacture	Packaging	Retail and distribution	Consumer use	Waste management	Total
Carbon Footprint (kg CO2 eq)	Breakfast with meat	2.118	0.164	0.051	0.033	0.117	0.087	2.569
	Meatless breakfast	0.624	0.164	0.051	0.033	0.117	0.091	1.080
	Lunch with meat	3.344	0.164	0.067	0.033	0.117	0.094	3.819
	Meatless lunch	0.503	0.164	0.067	0.033	0.117	0.099	0.983
	Dinner with meat	4.245	0.164	0.084	0.033	0.117	0.115	4.757
	Meatless dinner	0.570	0.164	0.084	0.033	0.117	0.121	1.088
Water Use (m3)	Breakfast with meat	0.409	0.000575	0.000020	0.000115	0.000469	0.000069	0.410
	Meatless breakfast	0.145	0.000575	0.000020	0.000115	0.000469	0.000072	0.146
	Lunch with meat	0.685	0.000575	0.000026	0.000115	0.000469	0.000075	0.686
	Meatless lunch	0.129	0.000575	0.000026	0.000115	0.000469	0.000079	0.130
	Dinner with meat	0.952	0.000575	0.000032	0.000115	0.000469	0.000091	0.953
	Meatless dinner	0.151	0.000575	0.000032	0.000115	0.000469	0.000096	0.152
Resource Consumption (MJ)	Breakfast with meat	12.58	2.63	1.18	0.527	1.923	0.063	18.91
	Meatless breakfast	4.28	2.63	1.18	0.527	1.923	0.066	10.62
	Lunch with meat	19.38	2.63	1.55	0.527	1.923	0.068	26.09
	Meatless lunch	3.89	2.63	1.55	0.527	1.923	0.072	10.60
	Dinner with meat	24.82	2.63	1.94	0.527	1.923	0.083	31.92
	Meatless dinner	4.46	2.63	1.94	0.527	1.923	0.087	11.57
Health Impact of Pollution (DALY)	Breakfast with meat	0.00000246	0.000000099	0.000000050	0.000000020	0.000000084	0.000000004	0.00000272
	Meatless breakfast	0.00000077	0.000000099	0.000000050	0.000000020	0.000000084	0.000000004	0.00000103
	Lunch with meat	0.00000366	0.000000099	0.000000065	0.000000020	0.000000084	0.000000004	0.00000393
	Meatless lunch	0.00000058	0.000000099	0.000000065	0.000000020	0.000000084	0.000000004	0.00000085
	Dinner with meat	0.00000463	0.000000099	0.000000081	0.000000020	0.000000084	0.000000005	0.00000492
	Meatless dinner	0.00000063	0.000000099	0.000000081	0.000000020	0.000000084	0.000000005	0.00000092
Ecosystem Quality (PDF-m2-yr)	Breakfast with meat	6.911	0.052	0.011	0.010	0.031	0.001	7.017
	Meatless breakfast	1.996	0.052	0.011	0.010	0.031	0.001	2.101
	Lunch with meat	10.444	0.052	0.014	0.010	0.031	0.002	10.553
	Meatless lunch	1.476	0.052	0.014	0.010	0.031	0.002	1.585
	Dinner with meat	12.988	0.052	0.018	0.010	0.031	0.002	13.101
	Meatless dinner	1.417	0.052	0.018	0.010	0.031	0.002	1.530

Note: Meat is represented here as beef, chicken, pork and fish. Meat does not include eggs or dairy.

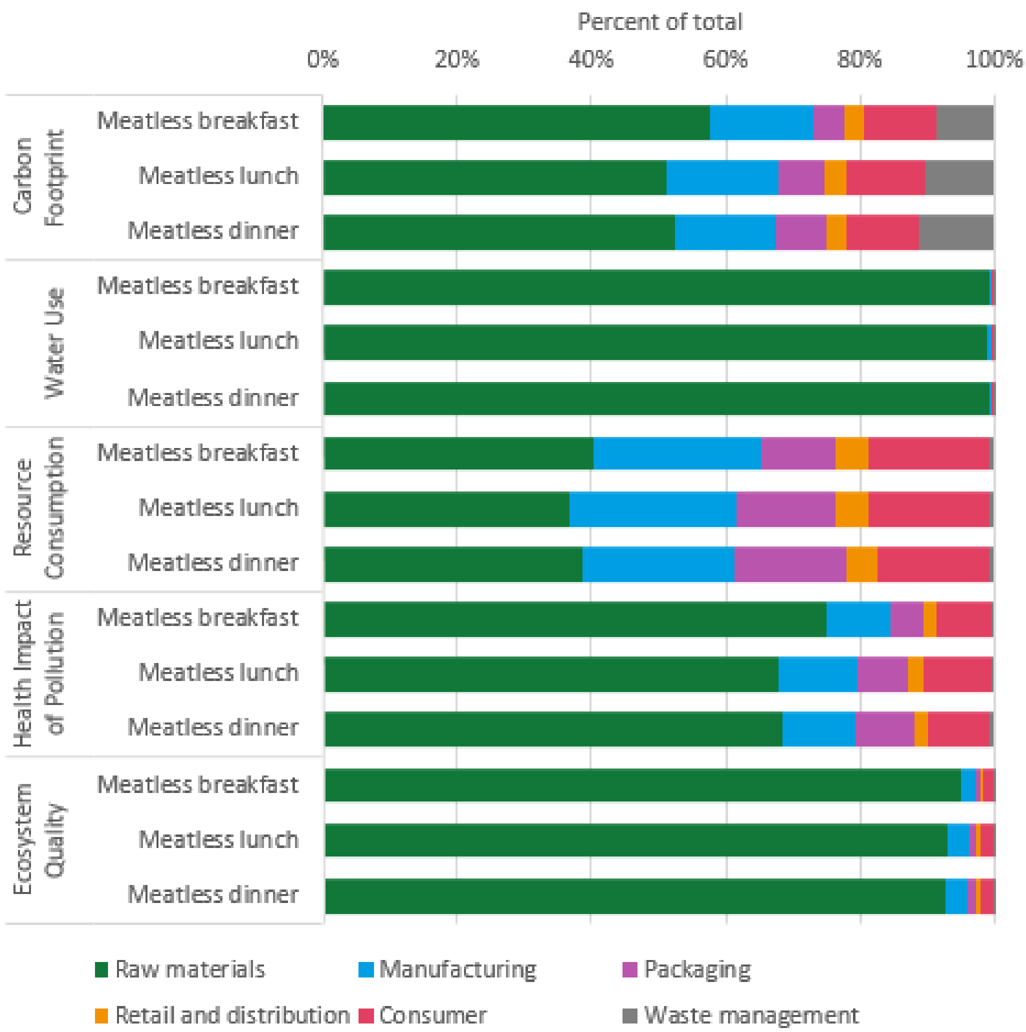
Figure 7 and Figure 8 show the percent of impact for each impact category that results from each stage of the meal life cycle for each of the meals examined. For all impact categories, for both meat-containing and meatless meals, the raw materials stage is the most significant contributor to environmental impact across the life cycle. This dominance of the raw materials stage is seen more forcefully for the meat-containing meals compared to the meatless meals. For Water Use and Ecosystem Quality, the stages other than raw materials contribute only a very small percentage of the total impact, 1% or less in all cases for Water Use and 10% or less in all cases for Ecosystem Quality. Among the other stages of the life cycle, all stages other than waste management contribute in a moderate proportion to the impact categories of Carbon Footprint, Resource Consumption and Health Impact of Pollution.

Figure 7: Environmental impact of meat-containing meals by stage of life cycle



Note: Meat is represented here as beef, chicken, pork and fish. Meat does not include eggs or dairy.

Figure 8: Environmental impact of meatless meals by stage of life cycle

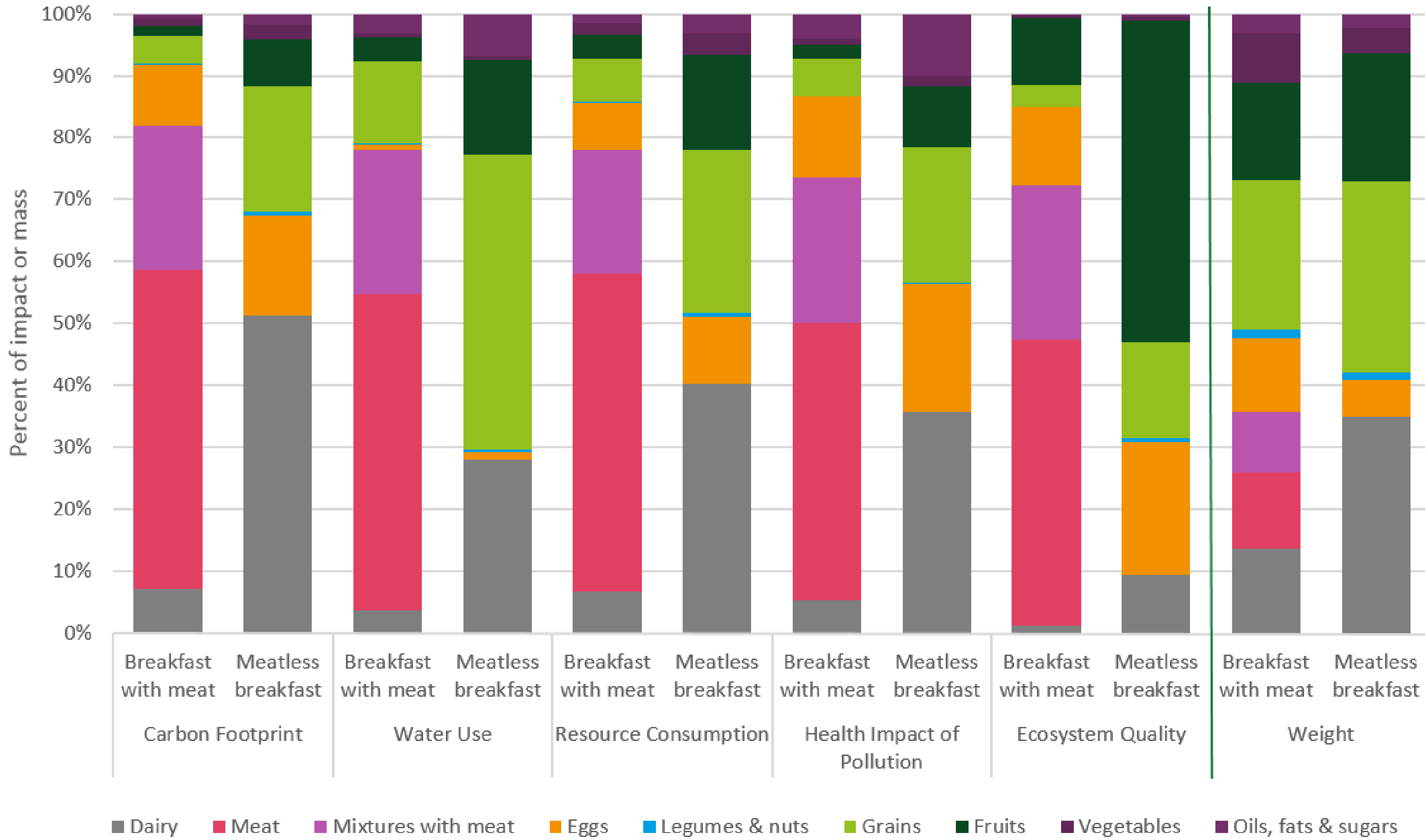


Note: Meatless refers to a meal that does not contain meat, but may contain eggs or dairy.

To understand further the contribution within this stage of the meal life cycle, the following figures provide a closer look at the contributions of various categories of food materials to each meal type. The percent of each meal by mass is also shown in each figure for comparison. Note that these figures show the proportionate result for food groups within a given meal and comparisons of the overall impact between meals should not be drawn from these figures.

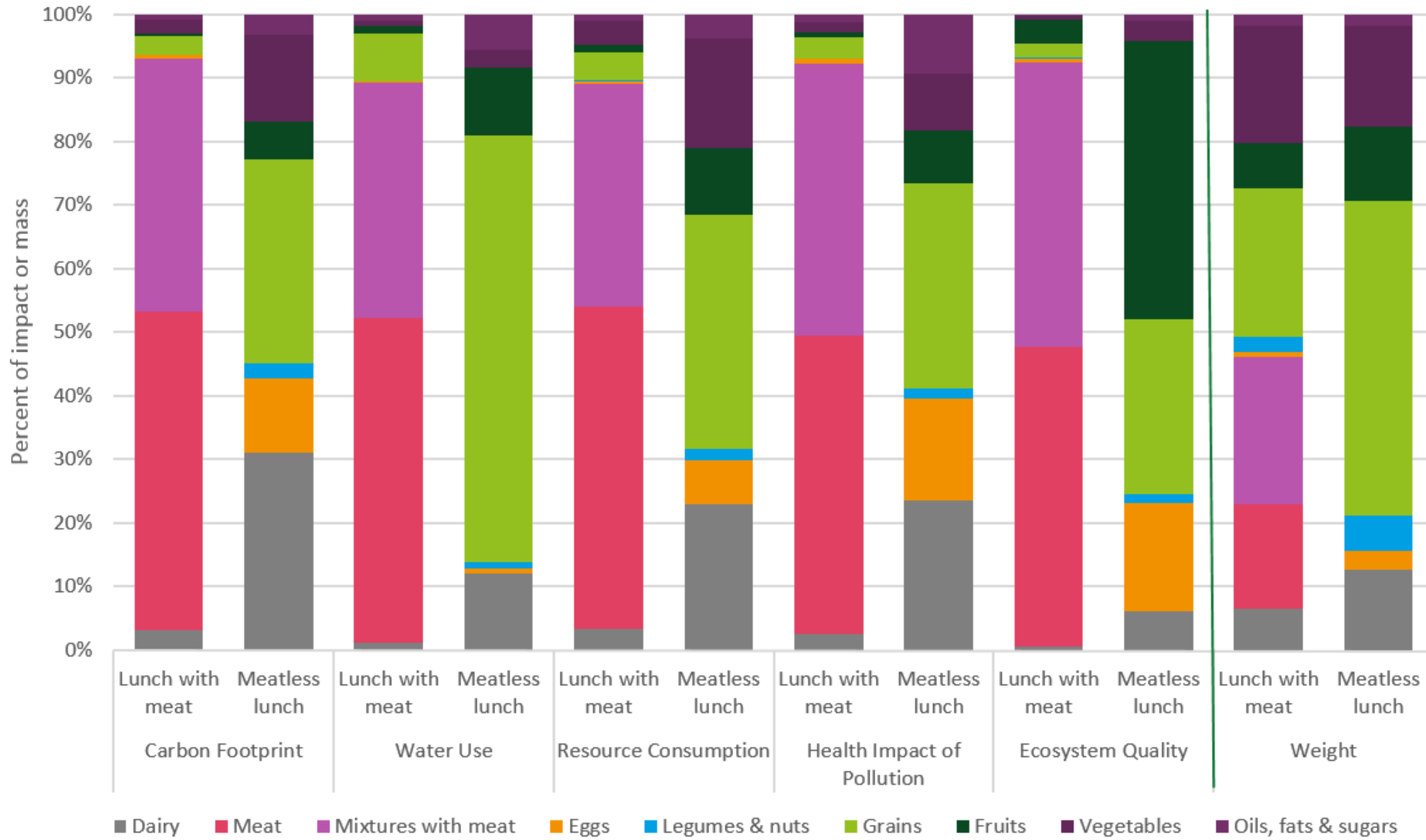
For meat containing meals, the high proportion of impact contributed by the meat products is strongly evident. Dairy and grains are high contributors to the environmental impact of the meatless meals, with dairy being more substantial for meatless breakfasts in comparison to other meals.

Figure 9: Contribution of food categories to the environmental impact of breakfasts



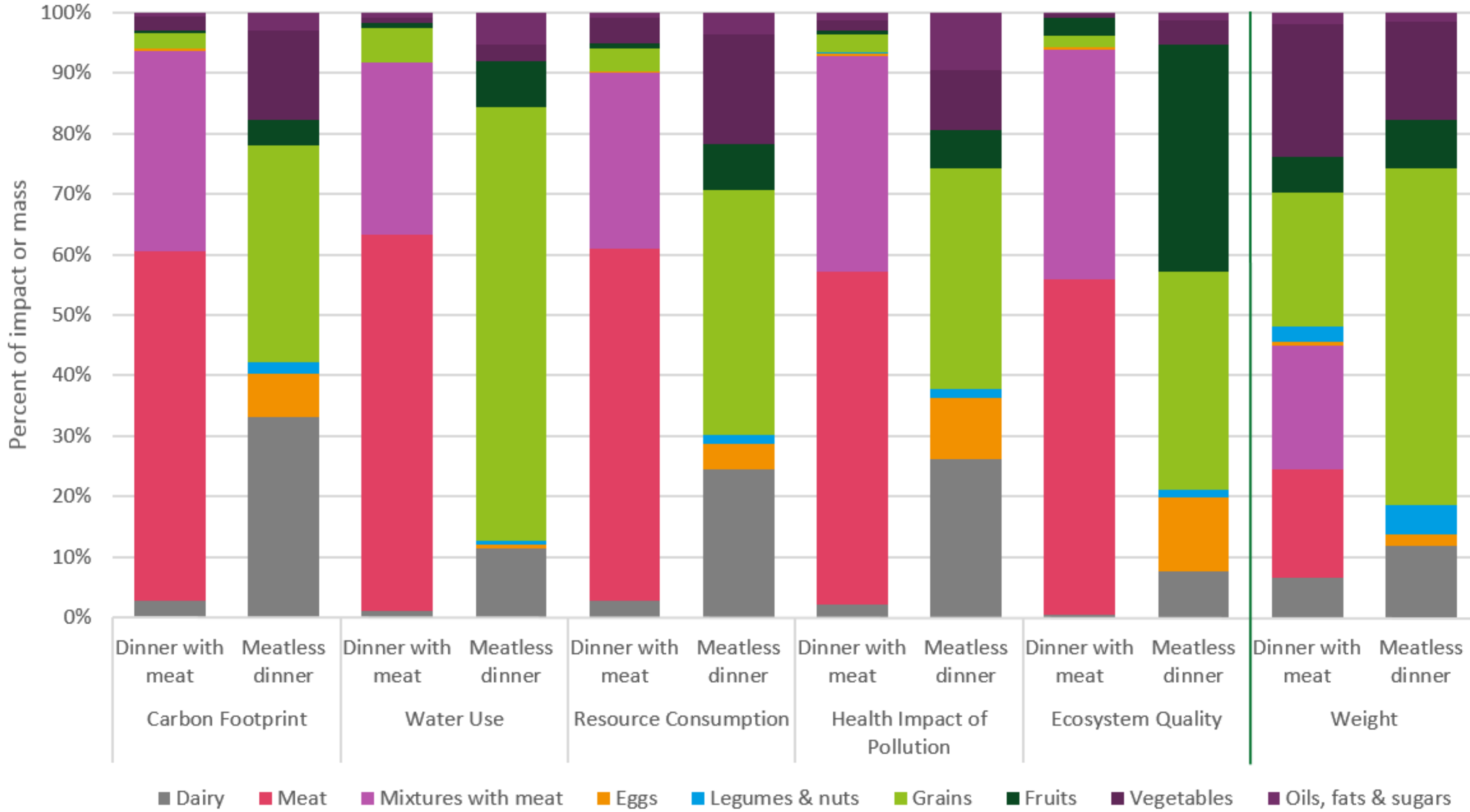
Note: Meat refers here to beef, chicken, pork, and fish. Meat does not include eggs or dairy. "Mixtures with Meat" describes categories from NHANES that are classified within meats, but whose description indicates that they are likely not entirely meat. As described in Section 3.1 and Table 8, these are represented as a mixture of meat, vegetables and grains, depending on their description

Figure 10: Contribution of food categories to the environmental impact of lunches



Note: Meat refers here to any item categorized by the NHANES as a meat, which includes the flesh of any animal, including fish. Meat does not include eggs or dairy. "Mixtures with Meat" describes categories from NHANES that are classified within meats, but whose description indicates that they are likely not entirely meat. As described in Section 3.1 and Table 8, these are represented as a mixture of meat, vegetables and grains, depending on their description.

Figure 11: Contribution of food categories to the environmental impact of dinners



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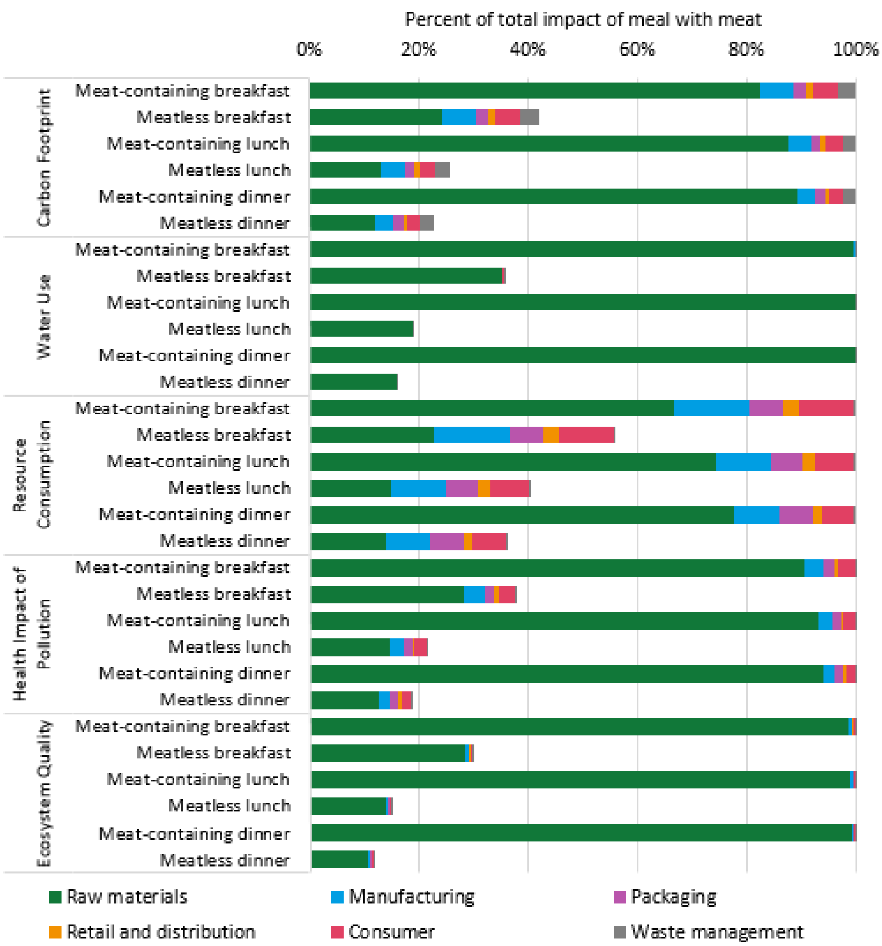
5.2 Comparison of meatless and meat-containing meals

The following figure shows the comparison of environmental impact in each category between the meatless meal and the meat-containing meals. The meatless meals show a lesser impact, ranging from roughly 40% to nearly 90% less, for all impact categories and all meal types. With the exception of the Resource Consumption indicator, the estimated reduction in impact of a meatless meal relative to a meat containing meal is more than 50% and in most cases more than 70%.

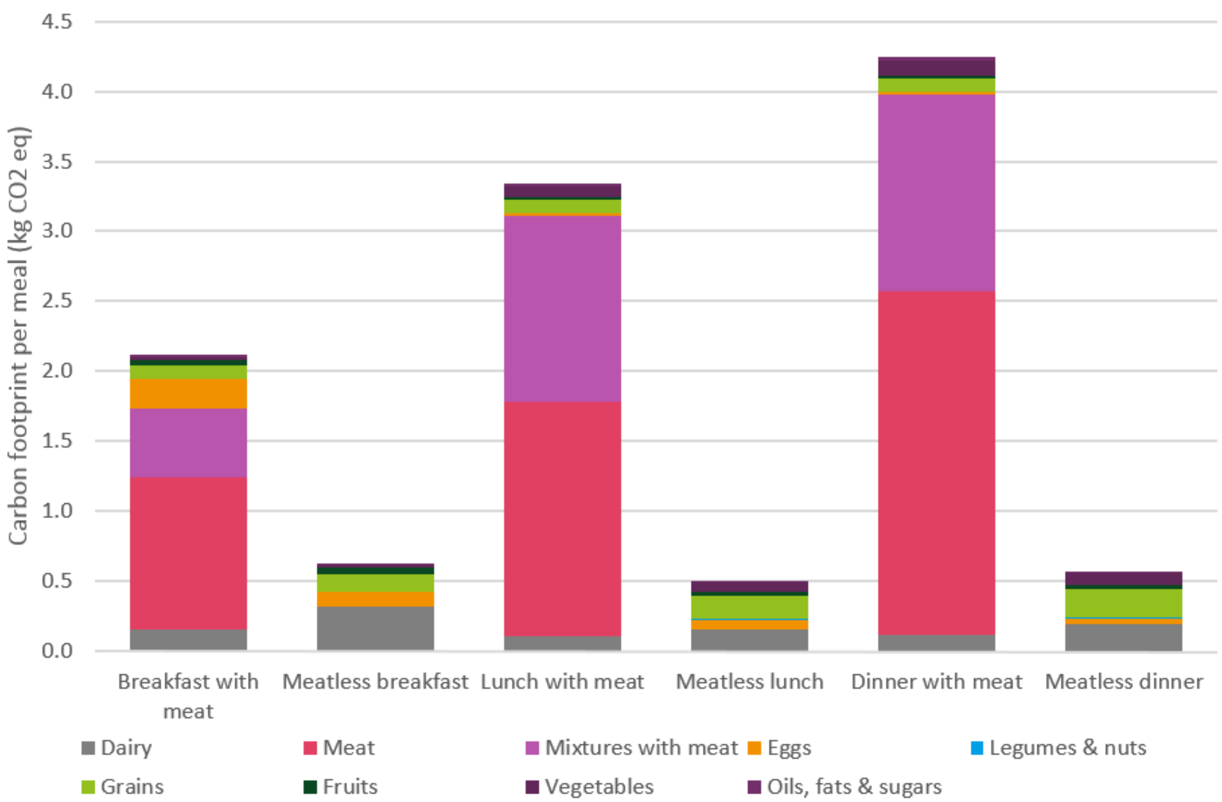
Figure 12: Comparison of the environmental impact of meatless and meat-containing meals



Note: Meat refers here to any item categorized by the NHANES as a meat, which includes the flesh of any animal, including fish. Meat does not include eggs or dairy.

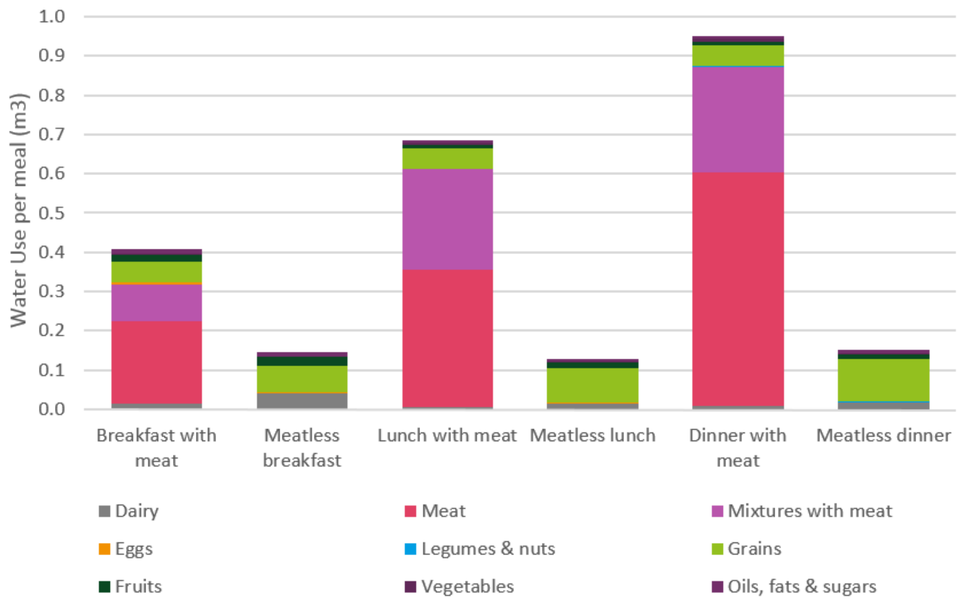
As most of the difference in environmental impact between the meatless and meat-containing meals occurs in the raw materials stage, the following several figures illustrate in more detail the environmental impact associated with this stage by category of food product consumed. It is very clear from these figures that the meat consumption associated with the meat-containing meals is the cause of the much higher impact of these meals. It can also be seen that although the overall impact associated with some other food groups increases when moving from a meat-containing meal to a meatless meal, this is more than offset by the reduction of removing the meat.

Figure 13: Comparison of the Carbon Footprint of raw materials for meatless and meat-containing meals



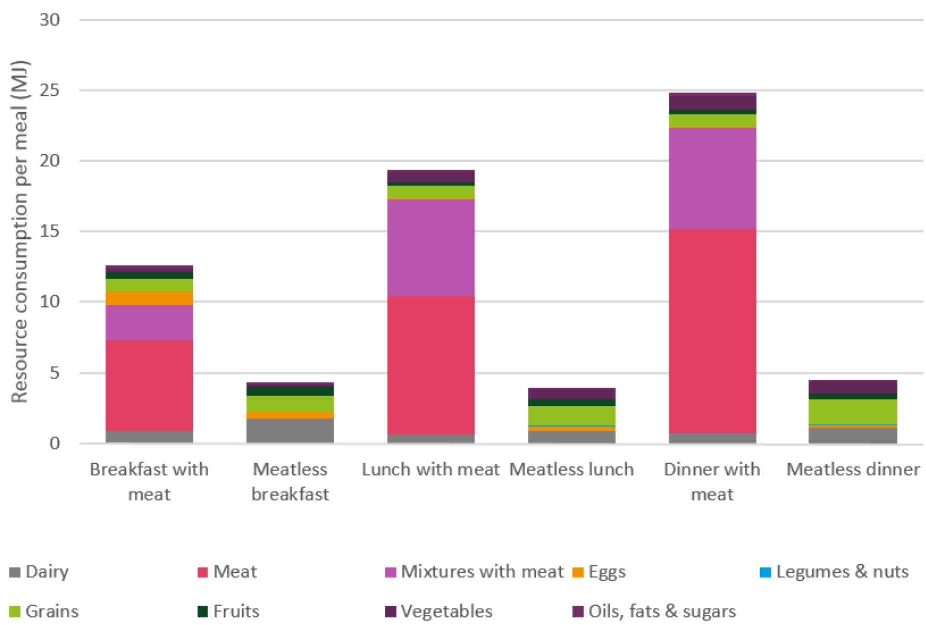
Note: Meat refers here to any item categorized by the NHANES as a meat, which includes the flesh of any animal, including fish. Meat does not include eggs or dairy. "Mixtures with Meat" describes categories from NHANES that are classified within meats, but whose description indicates that they are likely not entirely meat. As described in Section 3.1 and Table 8, these are represented as a mixture of meat, vegetables and grains, depending on their description.

Figure 14: Comparison of the Water Use impact of raw materials for meatless and meat-containing meals



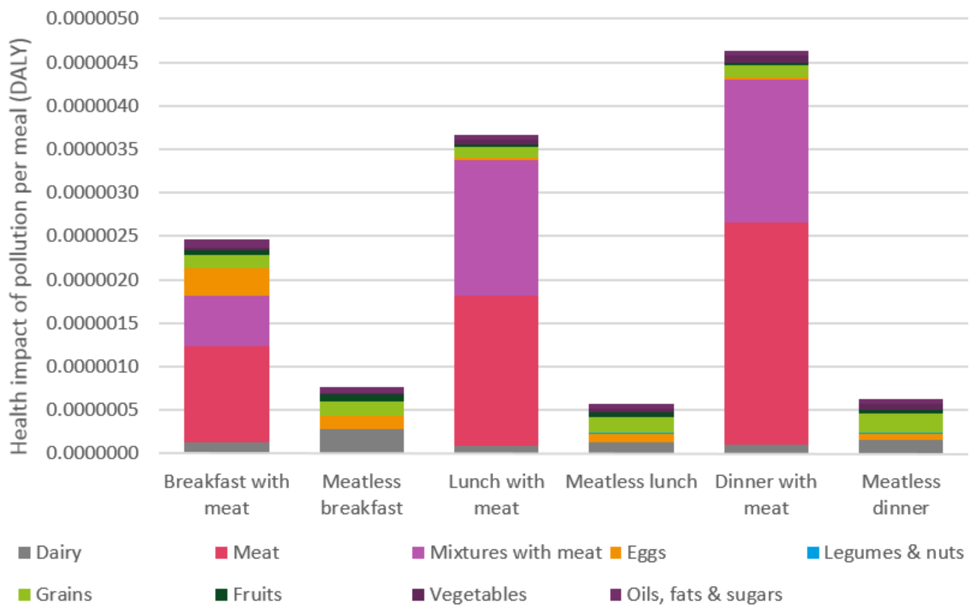
Note: Meat refers here to any item categorized by the NHANES as a meat, which includes the flesh of any animal, including fish. Meat does not include eggs or dairy. "Mixtures with Meat" describes categories from NHANES that are classified within meats, but whose description indicates that they are likely not entirely meat. As described in Section 3.1 and Table 8, these are represented as a mixture of meat, vegetables and grains, depending on their description.

Figure 15: Comparison of the Resource Consumption of raw materials for meatless and meat-containing meals



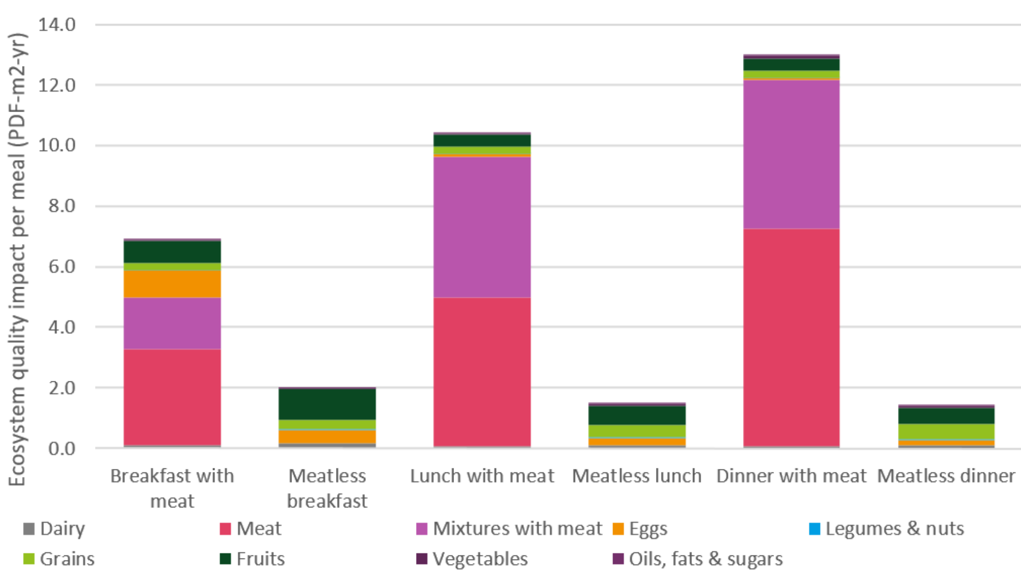
Note: Meat refers here to any item categorized by the NHANES as a meat, which includes the flesh of any animal, including fish. Meat does not include eggs or dairy. "Mixtures with Meat" describes categories from NHANES that are classified within meats, but whose description indicates that they are likely not entirely meat. As described in Section 3.1 and Table 8, these are represented as a mixture of meat, vegetables and grains, depending on their description.

Figure 16: Comparison of the Health Impact of Pollution of raw materials for meatless and meat-containing meals



Note: Meat refers here to any item categorized by the NHANES as a meat, which includes the flesh of any animal, including fish. Meat does not include eggs or dairy. "Mixtures with Meat" describes categories from NHANES that are classified within meats, but whose description indicates that they are likely not entirely meat. As described in Section 3.1 and Table 17, these are represented as a mixture of meat, vegetables and grains, depending on their description.

Figure 17: Comparison of the Ecosystem Quality impact of raw materials for meatless and meat-containing meals



Note: Meat refers here to any item categorized by the NHANES as a meat, which includes the flesh of any animal, including fish. Meat does not include eggs or dairy. "Mixtures with Meat" describes categories from NHANES that are classified within meats, but whose description indicates that they are likely not entirely meat. As described in Section 3.1 and Table 17, these are represented as a mixture of meat, vegetables and grains, depending on their description.

Table 16 summarizes the amount of the environmental improvement estimated for the change of one meal from meat-containing to meatless, depending on the type of meal (breakfast, lunch or dinner).

Table 16: Amount of lesser environmental impact of a meat-containing compared to a meatless meal by meal occasion (impact of meat containing meal minus impact of meatless meal)

	Carbon Footprint (kg CO2 eq.)		Water Use (m3)		Resource Consumption (MJ)		Health Impact of Pollution (DALY)		Ecosystem Quality (PDF-m2-y)	
Meal	Amt.	%	Amt.	%	Amt.	%	Amt.	%	Amt.	%
Breakfast	1.489	58%	0.264	64%	8.30	44%	0.00000169	62%	4.92	70%
Lunch	2.836	74%	0.556	81%	15.49	59%	0.00000309	78%	8.97	85%
Dinner	3.670	77%	0.801	84%	20.35	64%	0.00000401	81%	11.57	88%

To better understand the dependence of the results on the type of meat in the meat-containing meal, a set of scenarios examining switches from meals with specific types of meats has been conducted and the outcomes are shown in Appendix E.

5.3 Additional scenarios of meal comparisons

Appendix E contains the results of the scenarios examining the influence of meat type within meals. The mixture of meat contents present in the meal averages has been represented as all either beef, chicken, pork or fish in these scenarios. The outcome of these scenarios show that although a benefit is seen for choosing a meatless meal in comparison to any of the meat types, a much larger benefit is seen for removal of beef in comparison to the other meat types.

5.4 Footprint profile of meat products

Table 17 and Figure 18 provide an overview of the LCA results for the five primary indicators examined here. It is clear that the feed crop production is the most important source of impact for all three meat products used for the product comparison of the LCA. The animal raising stage is also a very high contributor in the case of beef due to emissions of methane directly from cattle as well as from managing their manure. The other stages of the life cycle, although similar for the various meat products, are proportionately more important in the case of chicken and pork due to the lower impact at the feed and farm level for these meat products.

Figure 18: LCA results by life cycle stage for the meat products assessed in the product-to-product comparison

Table 17: LCA results of meat products[27]

Impact category (units)	Product	Total per 60 grams
Carbon Footprint (kg CO2 eq)	Fresh ground beef	3.69
	Beef burger	3.70
	Pork sausage patty	0.96
	Chicken meat patty	0.538
	Meat (avg.)	1.49
Water Use (m3)	Fresh ground beef	0.0466
	Beef burger	0.0467
	Pork sausage patty	0.0142
	Chicken meat patty	0.00754
	Meat (avg.)	0.0196
Resource Consumption (MJ)	Fresh ground beef	14.0
	Beef burger	16.3
	Pork sausage patty	11.7
	Chicken meat patty	7.26
	Meat (avg.)	10.7
Health Impact of Pollution (DALY)	Fresh ground beef	0.00000397
	Beef burger	0.00000401
	Pork sausage patty	0.000000827
	Chicken meat patty	0.000000543
	Meat (avg.)	0.00000154
Ecosystem Quality (PDF-m2-yr)	Fresh ground beef	15.1
	Beef burger	15.1
	Pork sausage patty	1.08
	Chicken meat patty	0.670
	Meat (avg.)	4.66

5.5 Footprint profile of *MorningStar Farms® veggie products*

Figure 19 and Table 18 show the relative contribution of the various stages of the product life cycle to the total environmental impact of these six MorningStar Farms® products for the five primary indicators

[27] The meat average shown here is derived by weighting each of the three meat types (beef, port, and chicken) shown by their portion in the US diet based on USDA (2015c). Chicken (poultry) represents 50.0%, beef represents 27.0% and pork represents 23.0%.

assessed here. For each of the products, similar to the meat products, raw material production is a highly significant contributor to each of the indicators examined. However, the manufacturing and consumer use stages are also significant contributors and are generally more significant on a proportional basis for the *MorningStar Farms® veggie products* than is seen above for the meat products.

Figure 19: Environmental impact by stage for the six MorningStar Farms® veggie products evaluated

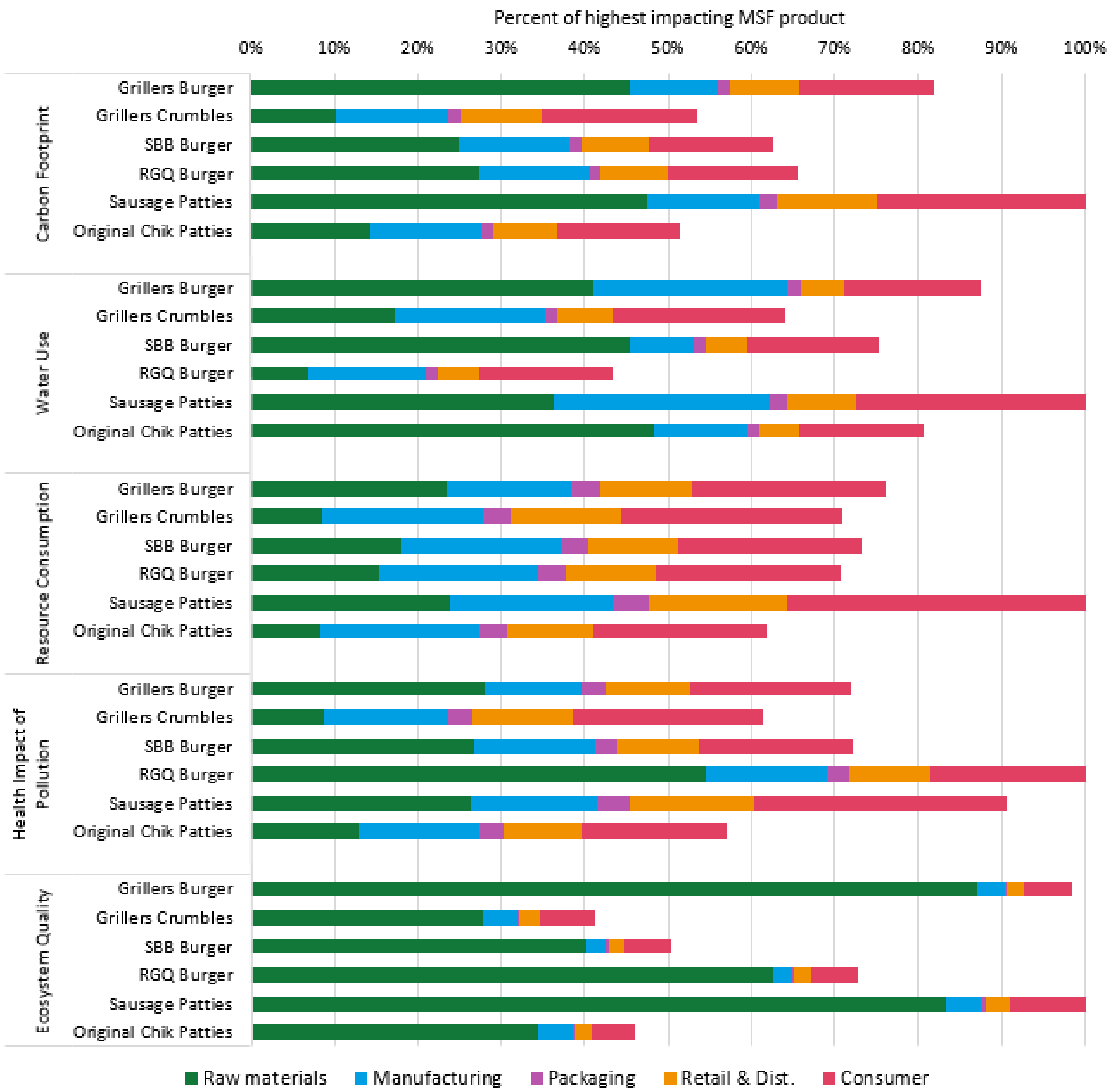


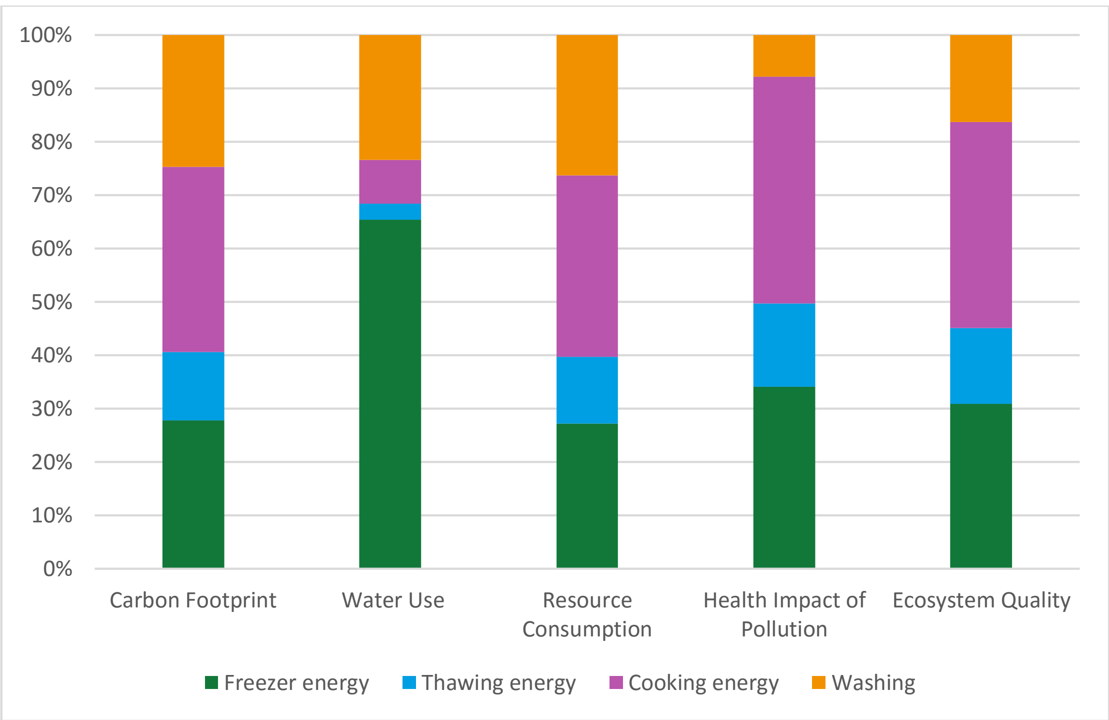
Table 18: Total life cycle environmental impact of the six MorningStar Farms® veggie products assessed

Impact category (units)	Product	Total per 60 gram serving
Carbon Footprint (kg CO2 eq)	*Grillers® Crumbles™*	0.362
	Grillers® Original Burger	0.554
	Spicy Black Bean Burgers Burger	0.4124
	Roasted Garlic & Quinoa Burger	0.443
	Original Sausage Patties	0.676
	Original Chik Patties®	0.347
Water Use (m3)	*Grillers® Crumbles™*	0.00169
	Grillers® Original Burger	0.00231
	Spicy Black Bean Burger	0.00199
	Roasted Garlic & Quinoa Burger	0.00114
	Original Sausage Patties	0.00264
	Original Chik Patties®	0.00213
Resource Consumption (MJ)	*Grillers® Crumbles™*	5.53
	Grillers® Original Burger	5.93
	Spicy Black Bean Burger	5.70
	Roasted Garlic & Quinoa Burger	5.49
	Original Sausage Patties	7.79
	Original Chik Patties®	4.82
Health Impact of Pollution (DALY)	*Grillers® Crumbles™*	0.000000249
	Grillers® Original Burger	0.000000293
	Spicy Black Bean Burger	0.000000293
	Roasted Garlic & Quinoa Burger	0.000000407
	Original Sausage Patties	0.000000369
	Original Chik Patties®	0.000000232
Ecosystem Quality (PDF-m2-yr)	*Grillers® Crumbles™*	0.211
	Grillers® Original Burger	0.501
	Spicy Black Bean Burger	0.256
	Roasted Garlic & Quinoa Burger	0.370
	Original Sausage Patties	0.509
	Original Chik Patties®	0.234

Consumer use consists of several components, including storage, cooking and cleaning of dishes. Figure 20 shows the relative contributions of these activities. Because these activities are assumed to be similar between all products, the detailed view of this stage is shown only using the *Grillers® Original Burger* product.

There is a large amount of variability among consumers in how they will use these products. Figure 20 shows the contribution to the environmental impact of the components of the product use stage. Again, because the use stage of each of the products is not systematically different, the results here are shown using only the *Grillers® Original Burger* product for simplicity. Note that the *Grillers® Crumbles™*, due to its form, may be more likely than other products to be included in meals baked in the oven, but any of the products could potentially be prepared in either manner.

Figure 20: Contribution of the components of consumer use to the environmental impact categories (Grillers® Original Burger)



5.6 Comparison of *MorningStar Farms®* veggie products and meat products

The following figures present an overview of the total life cycle impact of the four types of meat products and the relevant selection of comparison among the six *MorningStar Farms® veggie products* that have been assessed. All products are compared on the basis of the 60-gram functional unit.

Figure 21: Environmental impact of <u>fresh ground beef</u> and an alternative Morningstar Farms® veggie product

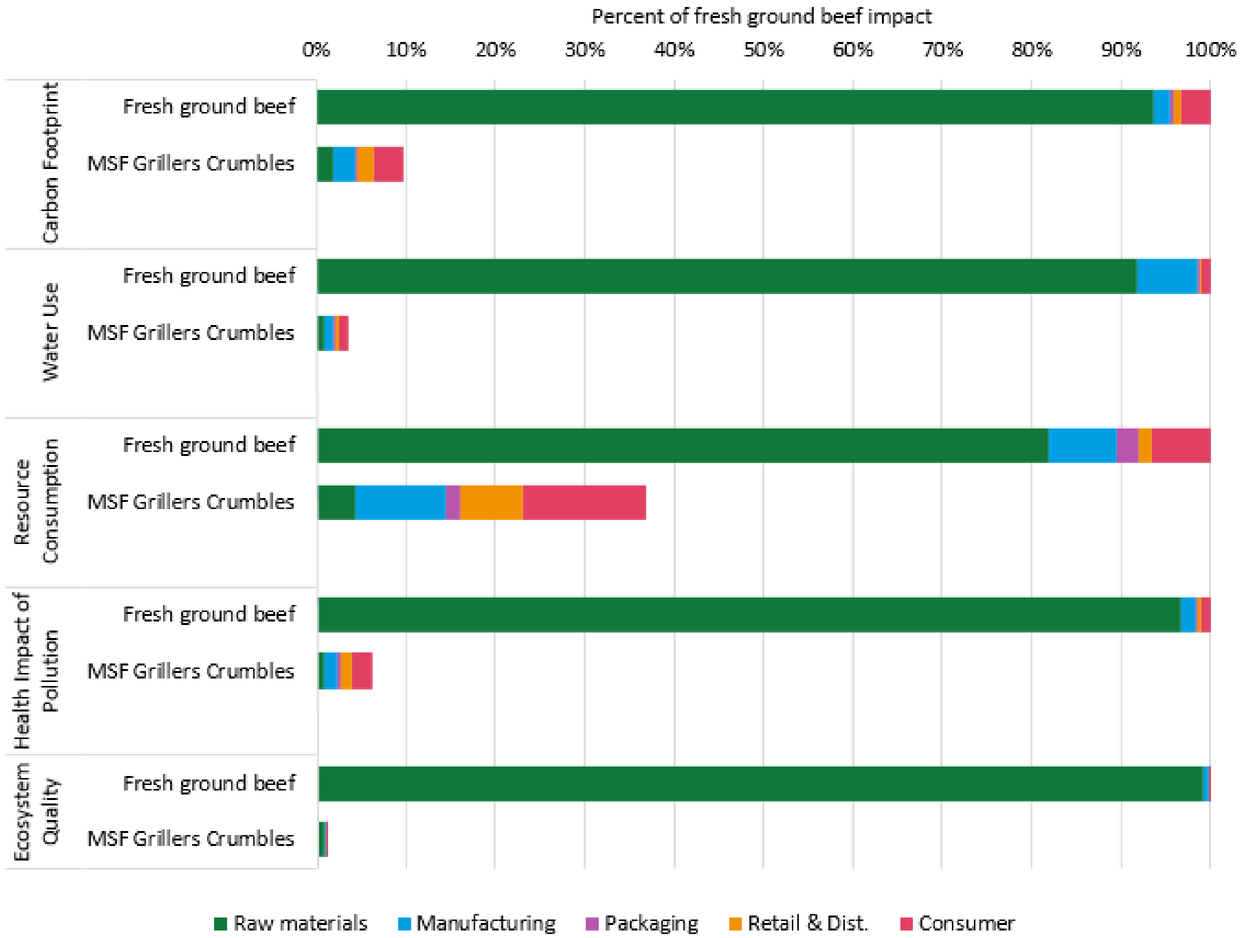


Figure 22: Environmental impact of <u>frozen beef burgers</u> and MorningStar Farms® alternative veggie products

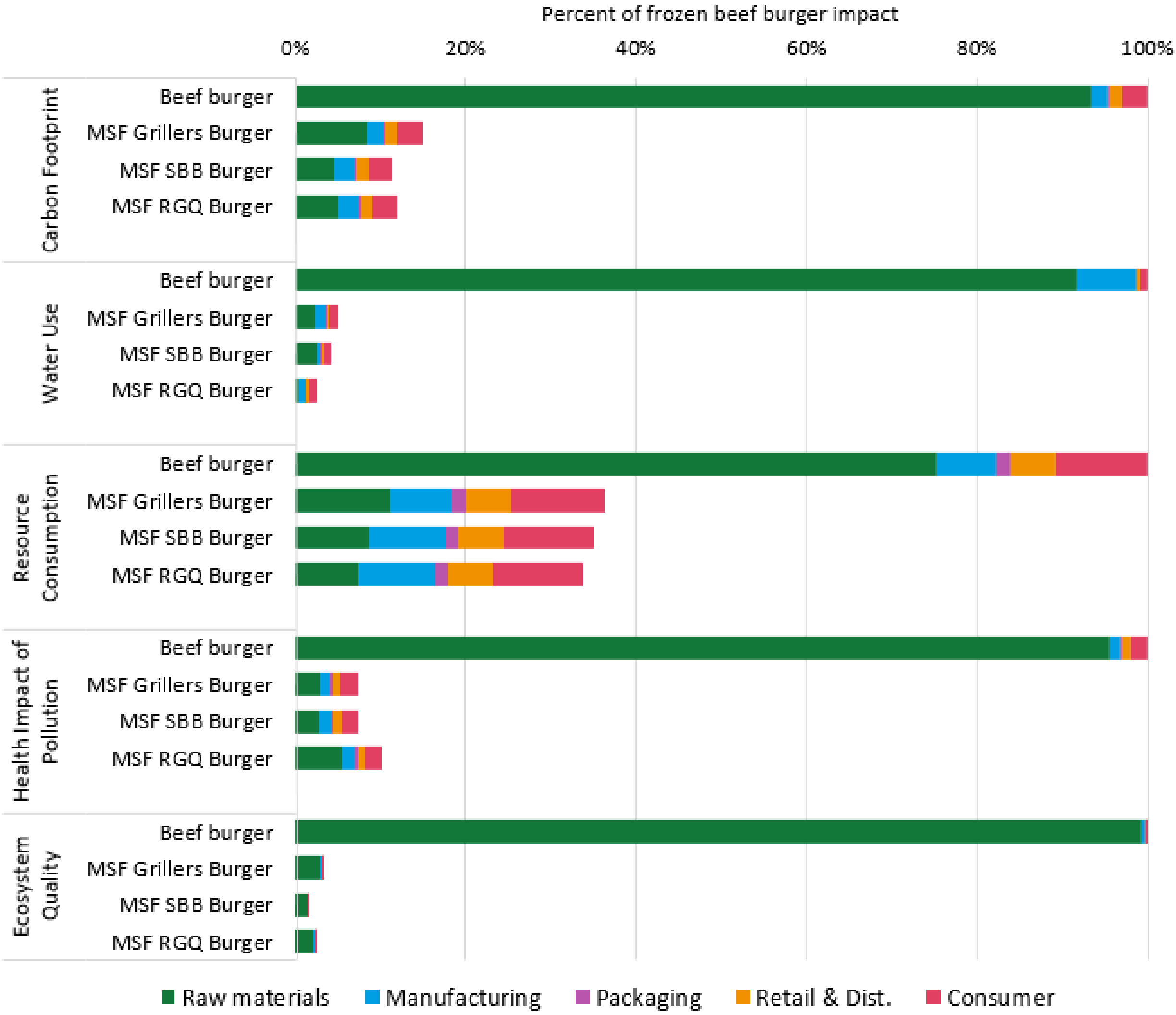


Figure 23: Environmental impact of pork sausage patty and the alternative Morningstar Farms® veggie product

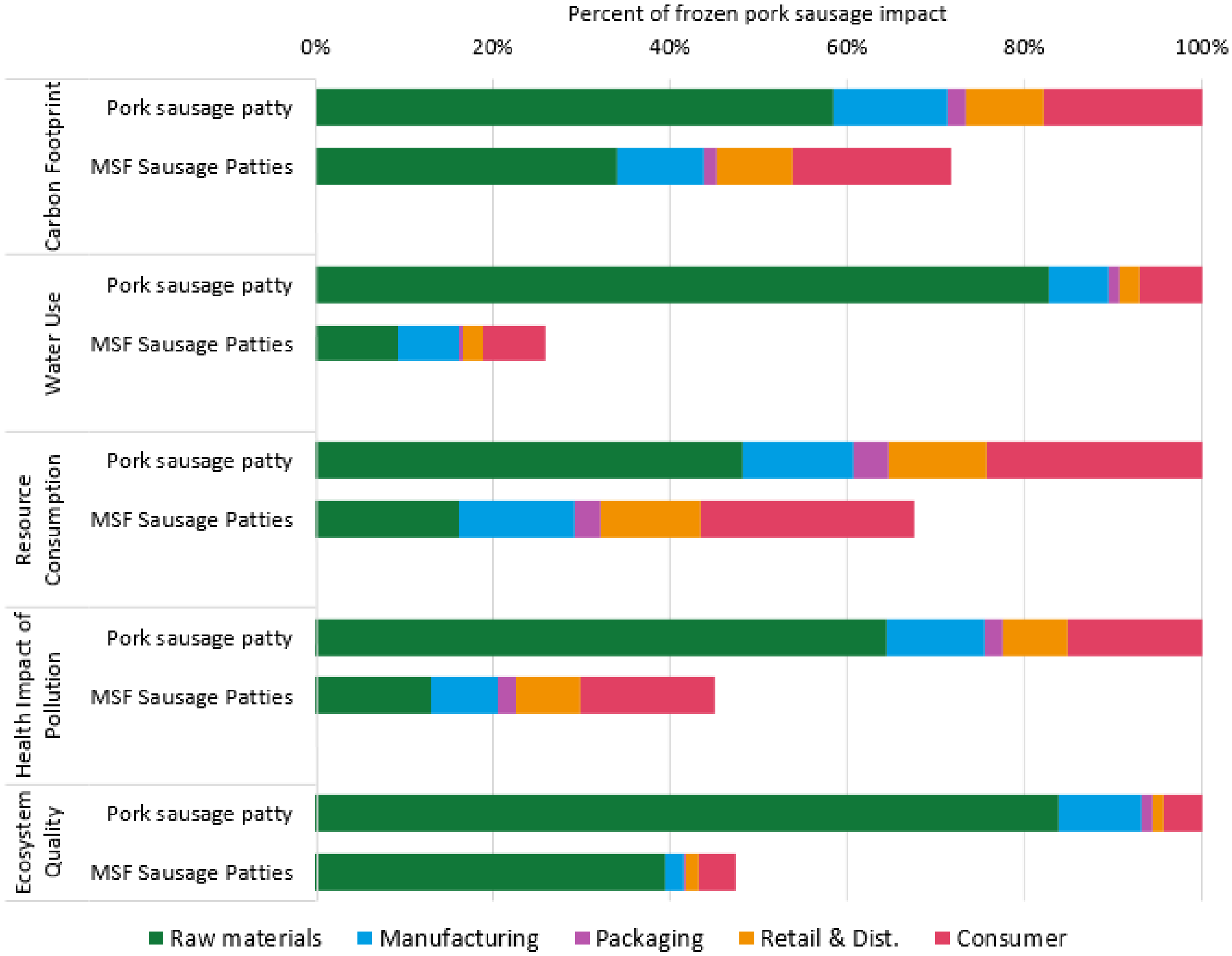
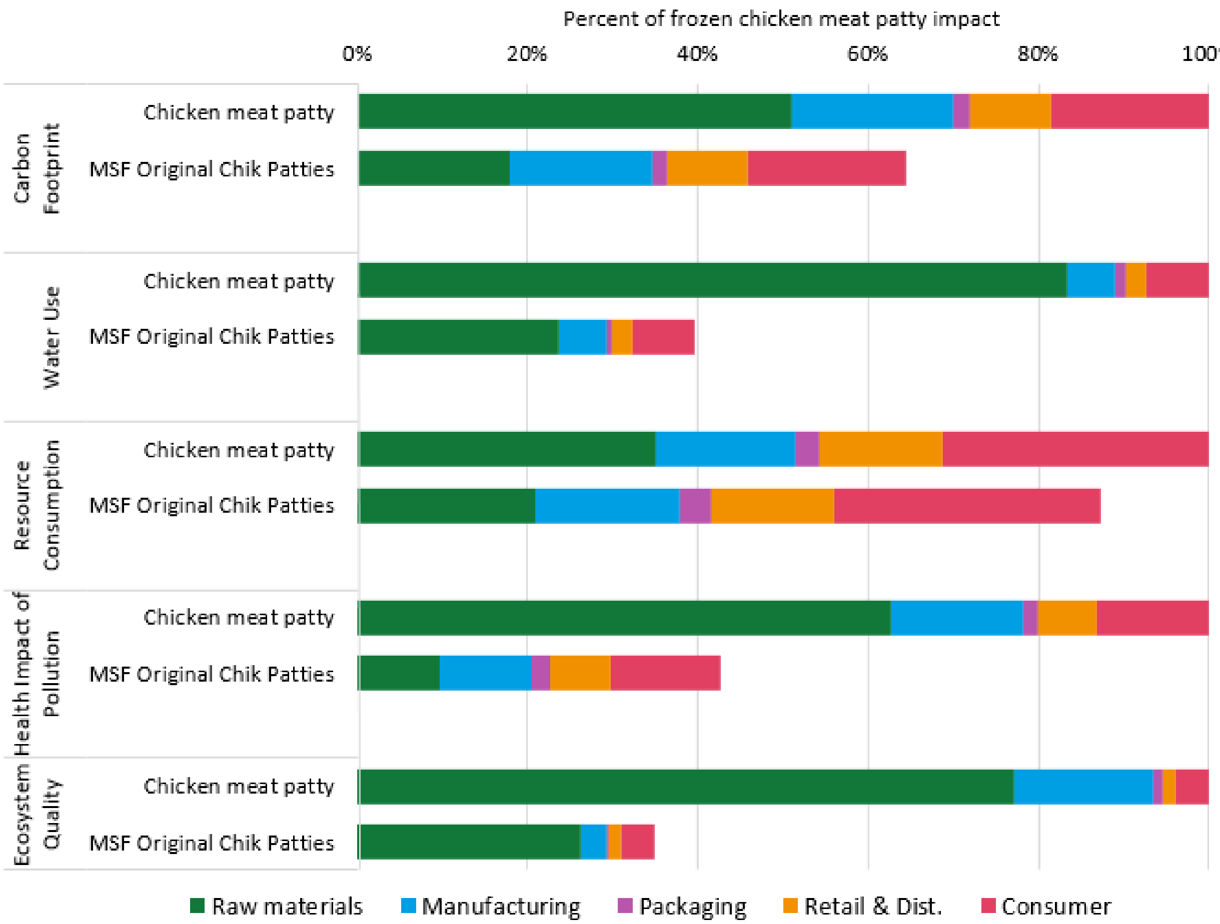


Figure 24: Environmental impact of chicken meat patty and an alternative Morningstar Farms® veggie product



As can be seen in each comparison, the meat products have for the most part a substantially higher overall impact compared to the veggie products. This is most pronounced in the case of the beef products where, with the exception of the Resource Consumption indicator, all other indicators show a reduction of at least 80% for each of the *MorningStar Farms® veggie products* compared. The Resource Consumption improvement is less in this case due to the greater contribution of the life cycle stages from manufacturing to the consumer, which are nearly identical between the meat products and veggie products. In the cases of the pork and chicken veggie alternatives, the benefit when substituting the *MorningStar Farms®* veggie product ranges from a very small difference to in some cases to a reduction of as much as 75% in the case of Water Use.

The differences between products are the result primarily of differences in the raw materials production. With the exception of the Carbon Footprint impact of beef, most of the raw materials production impact for the meat products happens at the farms producing feed rather than in the animal raising operations. The overall results therefore reflect the fact that the animal systems require a much larger amount of plant-based farm production to support the production of the eventual products the consumer receives. The results portrayed here compare the products on a functional basis of their mass only and do not account for other bases of comparison, such as nutritional aspects.

6 Conclusions

6.1 Key findings

This assessment has compared meat-containing meals with meatless meals, as well as made a set of specific product comparisons of meat products with example veggie products that would substitute for a serving of meat. The goal has been to understand whether (and how much) environmental benefit might be obtained by Americans shifting their food consumption toward plant-based options on a meal-by-meal and product-by-product basis. The following are the key findings from this work, focused on the assessments made here of both meals and specific products.

When an American chooses to consume a meatless breakfast, lunch or dinner rather than one that contains meat[28], the decreased environmental impact of the meatless meals is a reduction on average of at least 40% compared to the meat-containing meals over the entire cycle of producing the raw materials and consuming that meal. This applies to each of the impact metrics evaluated here and the directional trend indicating an environmental savings is very consistent and in most cases indicates an improvement greater than the 40% mentioned above.

With regard to Carbon Footprint, a meatless meal is shown to result in a 58%, 74% and 77% reduction compared to a meat-containing meal for breakfast, lunch and dinner, respectively. For Water Use, the reductions are 64%, 81% and 84% for breakfast, lunch and dinner. Meatless lunches and dinners show a higher amount of environmental savings among all the impact categories than breakfasts, primarily because meat-containing lunches and dinners contain more meat than breakfast occasions, as well as the fact that meatless breakfasts were reported to contain a high proportion of dairy. Note that beverages have been excluded from the meals based on the assumption that beverage consumption would not vary

[28] Meat refers here to the flesh of any animal, including fish. Meat does not include eggs or dairy.

between meat-containing and meatless meals; hence the percentages referred to above could be altered if beverages were included.

In both the meal and product comparisons we find that the main driver for environmental impacts takes place in the production of raw materials. For all meal types, the production of food raw materials is the most important source of environmental impact in providing the meal, with raw materials being responsible for >50% of the Carbon Footprint of meatless meals, >80% of the Carbon Footprint of meat-containing meals, and >99% of the Water Use of all meal types. With the addition of a high level of Carbon Footprint impact at beef raising operations, the majority of the difference between meat and non-meat products happens in producing the feed that the animals consume.

Put simply, raising animals to feed humans requires the growing of a much larger amount of primary vegetable material than if humans consume the vegetable material directly rather than raising and consuming the meat. Because the differences seen in the meals comparison can be associated with the occurrence of a much lesser amount of very similar types of processes (farming of grains and other plants), it is believed that the direction of the comparison is quite certain, even if there is much uncertainty in variation in the specific quantitative improvements.

In comparing specific products, it is found that consuming the *MorningStar Farms®* veggie products, in comparison to the equivalent meat products, results in reductions in environmental impact ranging from indeterminate to as much as a 90% reduction across the full product life cycle, depending on the products compared and the environmental indicator in question. The results for pork and chicken products range from being of a similar impact to the *MorningStar Farms®* veggie products, to showing a benefit of as much as 75% for substitution of meat products by their comparable *MorningStar Farms®* veggie products in the case of Water Use.[29]

As with the meals discussion, the great majority of the difference in the impact of these products is linked to the production of the raw ingredients for the products and, in particular, the higher impact of meat relative to the materials for which it substitutes. Much of this meat-related impact is associated animal feed production, of which much more is required than the weight of grains and other vegetable matter

[29] The key findings explained here are based on comparing products by equal weight. When exploring the basis of comparison (calories, weight or protein content), it is found that in some cases one basis favors the meatless products more or less than another, but without a clear pattern.

that might be substituted for the meat. As a result, the meatless products result in a lesser amount of very similar production processes being required, adding a high level of confidence in the certainty of the directional results.

Across the set of comparisons made here, it is found that choosing to substitute meat products for veggie products in meals is likely to lead American adults, on average, to achieve a lesser environmental impact of that selected meal. The extent of the improvement will vary widely, with substitutions for beef likely to result in a larger benefit than substitutions for pork or chicken.

In considering the results of this study, it should again be noted that nutritional content, an important feature of food, has not been considered directly. The intention here is to portray an environmental comparison 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 Americans make their food choices.

6.2 Discussion

Although there are frequently suggestions or assertions made that plant-based dietary choices carry an environmental benefit, this assertion at the meal level appears to have been rarely, if at all, thoroughly studied through the type of Life Cycle Assessment approach applied here. Much of the scientific information used to suggest the environmental impacts of meat-based diets is based on assessing the overall extent of the environmental impact of the meat raising industry, but does not consider the alternatives. The conclusions from such work are generally that the impacts of meat production on a global scale are large, rather than that environmental improvements that can be made by considering alternative meatless meals. This study shows clear evidence that, on average, the selection of plant-based options, on a product-by-product and meal-by-meal basis are very likely to result in significant environmental improvements. As is acknowledged throughout, this outcome will vary widely in the case of specific meals being compared and is intended only to assess an average outcome that can be applied across a population.

It should be noted that the uncertainty within the products and meals examined here is high and becomes higher when extending the implications of these results to the range of food choices Americans encounter in their daily lives. Appendix D provides a quantitative assessment of the uncertainty within the product comparisons and finds that despite high uncertainty in these food product systems, the directional comparative results are quite firm. Regarding comparison of meals, even if one were to find a similar level of confidence in the comparison, such an uncertainty assessment regarding the average meals assessed here does not encompass the variability within meals, which is equally or more important when considering the application of these results to meal choices. Although the results shown here apply to meal averages among American adults, certainly there could be cases where the individual meatless meal choices could be more impacting than some meat-containing meals depending on the choices within that meal. Similarly, there will be some meatless to meat-containing meal changes that result in a much greater benefit than that shown here. The possible variability for individual meals indicates that the results shown here are more likely to be representative of the average of many meal choices by either an individual or a population (dozens, hundreds, thousands, etc.) than for a single meal choice, as the outcomes for this larger selection of meals are likely to revert to the mean as their number grows.

Although the food system is large and complex, resulting in a large number of uncertain and variable aspects that lie behind such an assessment, the overall conclusions here can be associated with a simple and necessary trend, which is that feeding plant matter to animals in order to consume the animals requires a larger amount of plant matter production than consuming the plant matter directly. Despite the complexity of all the operations that happen in moving the food throughout our modern food system, from "farm to fork," the effect of this requirement for more primary plant production is sufficiently strong that the other aspects of the system are of relatively little importance in influencing the result. Although many varied results could likely be found in specific meal choice comparisons, the average result explored here is reasonably certain in its direction and in the general magnitude shown here.

In recent years, a number of efforts have been made to call attention to the size of the magnitude of environmental impact of global meat production. See for example, reports from the Food and Agriculture Organization (2006), United Nations Environmental Program (2012) and the World Watch Institute (2009), among many others. What many of these reports lack is a clear comparison of these products with alternative options. The present report provides this component and can be complementary to such efforts by supporting the potential benefit of choices that individual citizens make in their daily lives. By taking a narrower view of meal averages in different occasions of the day, this report does not attempt to identify what a complete dietary pattern change would look like within the global food chain, but simply highlights the extent of the influence of meal or product choices. As suggested by Joyce et al. (2012), influencing the meal choice behavior of the population toward more environmentally-friendly choices may be challenging with environmental messaging alone is likely to be much more successful if such messaging is complemented with nutritional and/or ethical messaging. The evidence provided here should be seen as supporting just one facet of a complicated set of choices made daily by a population with diverse needs, interests and circumstances. In addition to providing important information that can be used by the public in their attempts to reduce the environmental impact of their food consumption choices, the outcomes of this assessment also have important implications for those in the food production industry, governments and others.

For those developing and manufacturing food products, the evidence that meatless options are on average less environmentally impacting than meat-containing options offers a simple and important product development criterion that can be used, along with more detailed environmental assessments, to develop less impacting food products to bring to the market. The results of this assessment also highlight to food manufacturers the importance of raw material sourcing in the overall environmental impact of their products. As a broad assessment of a large system, the many details of the food sourcing system have not been able to be explored here but there is a clear indicator to manufacturers that this portion of their overall value chain needs to be closely understood and addressed to make meaningful improvements in their environmental impact. In comparison, aspects such as energy use at food production facilities or the importance of food packaging are shown to be relatively small in comparison. This is not intended to suggest that these are not also topics worthy of focus, but rather that perspective on relative importance can help to target the level of improvement efforts in the appropriate proportion.

A further observation for companies producing plant-based food products is that the environmental benefits of such products are relatively clear and so the more they are able to gain people's interest to incorporate veggie products into their diets in lieu of meat products, the greater the benefit to the environment. In addition, there is a growing number of American consumers considering environment and sustainability when making purchasing decisions and so efforts to make information available about the benefits of plant-based foods has the potential to raise greater awareness and increase the amount of people incorporating meatless meals into their diets.

Food manufacturers, governments and the public, are also becoming more concerned with food waste and the overall environmental impact of the food system. Due to the high importance of the raw material production stage and the high rates of food waste at various steps downstream of raw material production, there are large opportunities for industry and government players to work together to improve the overall environmental performance of the food system through the reduction of food waste, which in turn reduces the demand for food raw materials. Assessments such as this that highlight the differences in environmental impact and waste among food categories can also be used to target waste reduction efforts at those categories where the most impact occurs in raw material production.

Our aim was to determine whether a simple selection criterion, with meat or without meat, is useful in indicating to American adults a way of achieving a lower environmental impact. The results here indicate that this rule is indeed a useful decision criteria and although there will certainly be exceptions that can be found to this rule, on average, this selection criterion would lead to environmental benefits and in many cases, reasonably large benefits, reducing overall environmental impact of the meal by half or more.

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8. Appendices

Appendix A: Description of impact categories

CARBON FOOTPRINT

Alterations in the statistical distribution of weather patterns of the planet over time that last for decades or longer; Carbon Footprint is represented based on the International Panel on Climate Change's 100-year weightings of the global warming potential of various substances (IPCC 2007). Substances known to contribute to global warming are weighted based on an identified global warming potential expressed in grams of CO_2 equivalents. This indicator covers all greenhouse gas emissions.

Because the uptake and emission of CO_2 from biological sources can often lead to misinterpretations of results, it is not unusual to omit this biogenic CO_2 from consideration when evaluating global warming potentials. Here, the recommendation of the PAS 2050 product Carbon Footprinting guidance is followed in not considering either the uptake or emission of CO_2 from biological systems and correcting biogenic emissions of other gases accordingly by subtracting the equivalent value for CO_2 based on the carbon content of the gas (BSI 2008).

WATER USE

Sum of all volumes of fresh Water Used in the life cycle of the product, with the exception of Water Used in turbines (for hydropower production), less the amount of water returned to the freshwater systems. This includes the volume of water taken from freshwater reservoirs (lakes, rivers, aquifers, etc.) that is evaporated during industrial or agricultural processes, embedded in products or otherwise consumed. Drinking water, irrigation water and water for and in industrialized processes (including cooling water) are all taken into account. Use of seawater is not considered. Neither is the use of rainwater, which has not yet reached a lake, river or aquifer.

RESOURCE CONSUMPTION

Depletion caused when nonrenewable resources are used or when renewable resources are used at a rate greater than they can be renewed; various materials can be weighted more heavily based on their abundance and difficulty to obtain. An evaluation of the overall impact of a system on resource depletion has been made following the resources end-point in the IMPACT 2002+ methodology, which combines nonrenewable energy use with an estimate of the increased amount of energy that will be required to obtain an additional incremental amount of that substance from the earth based on the Ecoindicator 99 method (Goedkoop and Spriensma 2000).

HEALTH IMPACT OF POLLUTION

Impact that can be caused by the release of substances that affect humans through acute toxicity, cancer-based toxicity, respiratory effects, increases in UV radiation, and other causes; an evaluation of the overall impact of a system on human health has been made following the human health end-point in the IMPACT 2002+ methodology, in which substances are weighted based on their abilities to cause each of a variety of damages to human health. These impacts are measured in units of disability-adjusted life years (DALY), which combine estimations of morbidity and mortality from a variety of causes.

ECOSYSTEM QUALITY

Impairment from the release of substances that cause acidification, eutrophication, toxicity to wildlife, land use, and a variety of other types of impact; an evaluation of the overall impact of a system on Ecosystem Quality has been made following the Ecosystem Quality endpoint IMPACT 2002+ methodology, in which substances are weighted based on their ability to cause each of a variety of damages to wildlife species. These impacts are measured in units of potentially disappearing fractions (PDF), which relate to the likelihood of species loss. Land use is included within the Ecosystem Quality impact. Land Use is defined as use of land for any purpose within the scope of the assessment, including such uses as farms, roads, factories and retail stores.

Appendix B: Glossary

The primary source for the definitions in this glossary is the latest version of the ISO 14044 standard (ISO 2006b). Other sources are referenced where relevant.

Allocation	Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems (ISO 2006b).
Background processes	Modeled processes influenced by measures taken in the foreground system; system or process for which secondary data are used. Processes that are incidental to the production of the evaluated product and not included in those used to determine foreground (primary operations/processes) attributes. In this study this includes, for instance, the production of electricity, fuels and chemicals used in the production of the pulp and paper. Forest and printing operations are also included in the background processes.
Co-product	Any of two or more products coming from the same unit process or product system (ISO 2006b).
Primary data	Data specific to the activities taking place directly within the processes studied.
Product system	Collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product (ISO 2006b).
Reference flow	Measure of the outputs from processes in a given product system required to fulfill the function expressed by the functional unit.
Secondary data	Data from databases or literature or estimated data.
Unit process	Smallest element considered in the life cycle inventory analysis for which input and output data are quantified (ISO 2006b).

Appendix C: Sensitivity analysis of functional unit

A per-weight basis has been used to compare the meals and products assessed here. Although there are other potential bases on which to compare these systems, weight has been chosen as the basis for comparison because it is expected to be the best approximation of how much of a given product or meal a person chooses to eat in a given sitting. The food's weight and volume are the inputs one often uses when judging what portion of food to choose for a given meal. To test the importance of this basis for comparison, we have evaluated the comparative product results on a comparative basis of per-weight (the baseline), per-energy (calories), and also per-protein content. We have not done a similar test for meals partly due to an assumption that the test on products will be somewhat indicative of the results for meals and due to the effort needed to convert all the underlying food mass data within the meals to both calories and protein content.

The following nutritional data is used in conducting those comparisons.

Table 19: Calorie and protein profile of meat products (USDA 2015b)

Meat	Calories (kcal per 100g meat)	Protein (g per 100 g meat)	Reference material from USDA 2015b
Beef products	228	17.37	"USDA Commodity, beef, ground, bulk/coarse ground, frozen, raw" (NDB No. 23508)
Pork products	221	15.41	"USDA Commodity, pork, ground, fine/coarse, frozen, raw" (NDB No. 10805)
Chicken products	143	17.44	"Chicken, ground, raw" (NDB No. 05332)

Table 20: Calorie and protein profile of MorningStar Farms products

Product	Calories (kcal per serving)	Protein (g per serving)	Serving size (g)
Grillers® Original Burgers	213	23.9	64
Grillers® Crumbles™	135	18.5	50
Spicy Black Bean (SBB) Burgers	168	14.6	67
Roasted Garlic & Quinoa (RGQ) Burgers	192	10.7	67
Original Sausage Patties	210	25.8	38
Original Chik Patties®	197	11.2	71

This does not cover all potential functional units for products, but provides a broader view of the importance of the selection of the functional unit on the results seen here. These results are presented in the following figures for the five main indicators evaluated.

Figure 25: Sensitivity test of the use of calories, weight or protein as a basis for comparison for the fresh ground beef and MorningStar Farms® product

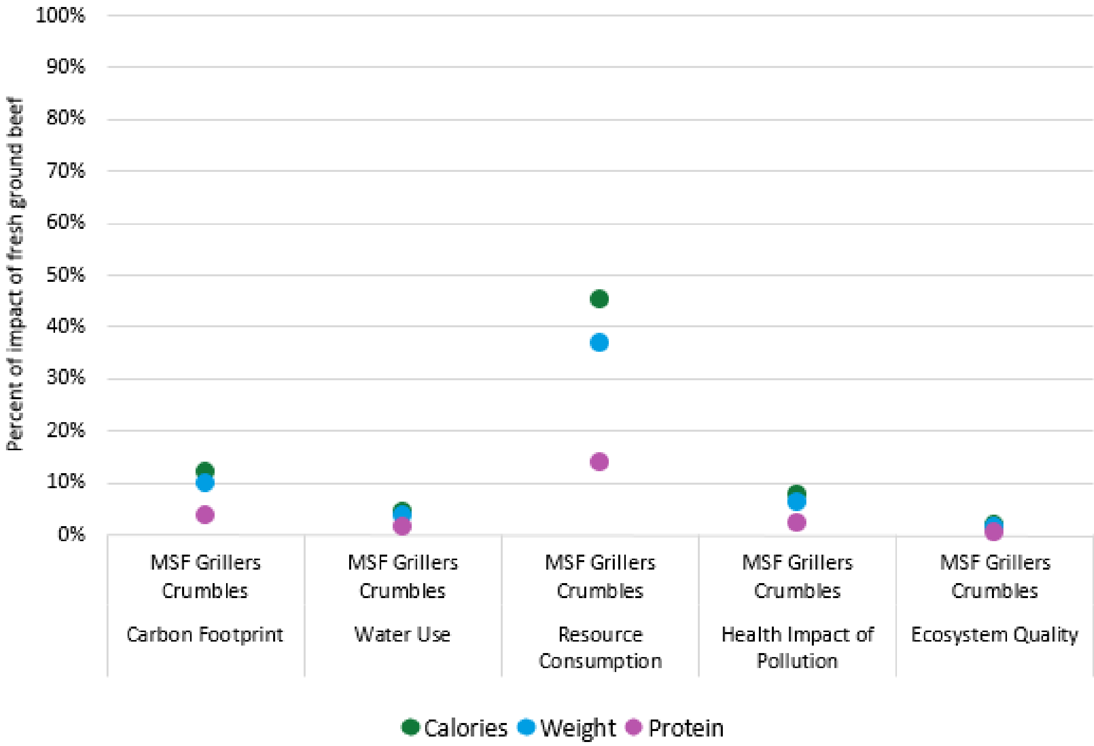


Figure 26: Sensitivity test of the use of calories, weight or protein as a basis for comparison for the frozen beef patties and MorningStar Farms® veggie products

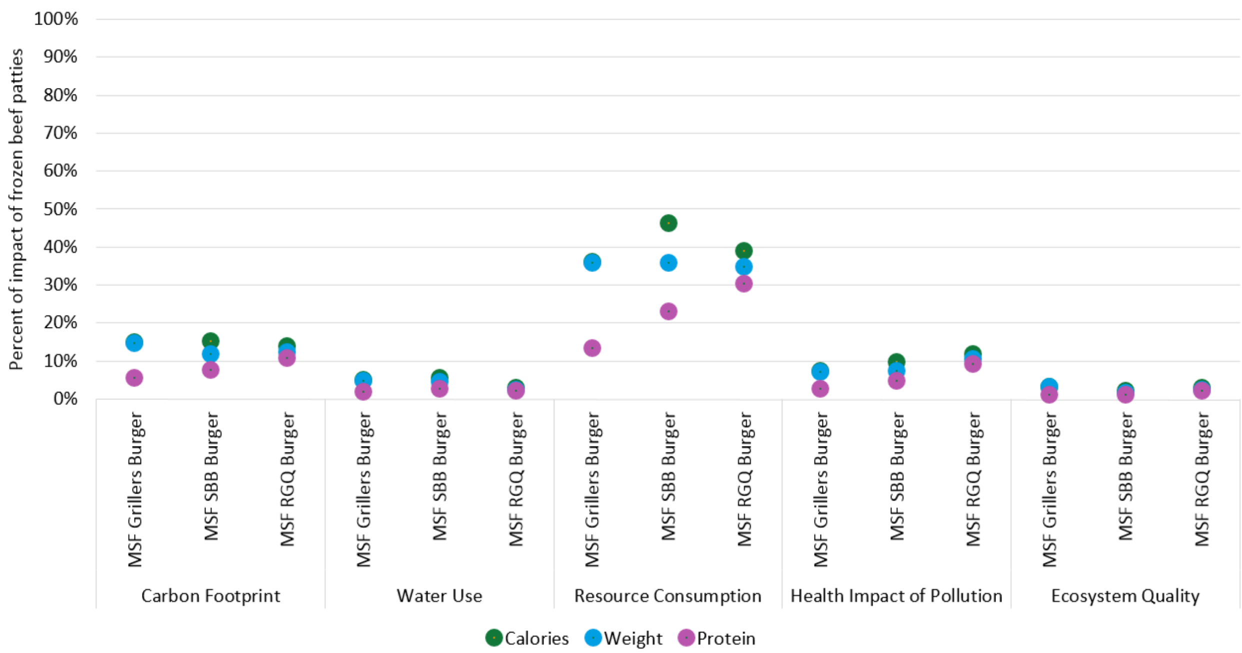


Figure 27: Sensitivity test of the use of calories, weight or protein as a basis for comparison for the pork sausage patties and MorningStar Farms® product

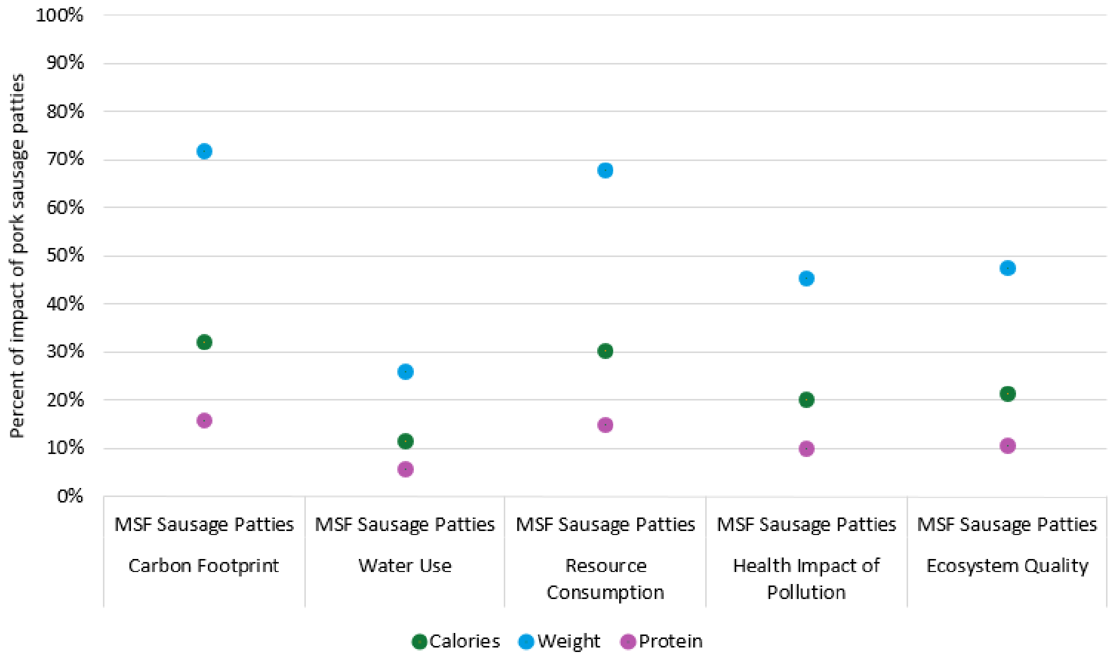
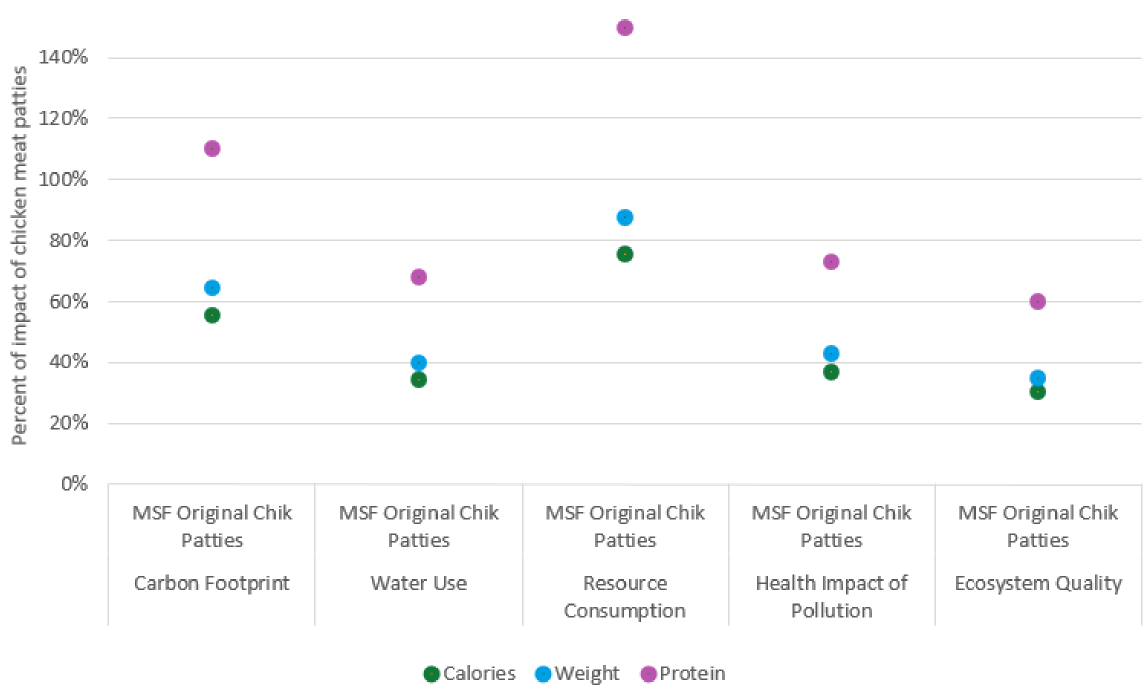


Figure 28: Sensitivity test of the use of calories, weight or protein as a basis for comparison for the chicken meat patties and MorningStar Farms® product



As is seen in the above scenarios, the choice of weight (as opposed to calories or protein content) as a basis for comparison is sometimes more favorable and sometimes less favorable to the *MorningStar Farms®* veggie products in comparison with the meat products. Interestingly, for comparison with each meat type, it is a different basis of comparison that most favors the meat product in the comparison, with the magnitude of comparison with beef being smallest when comparing based on calories, the gap with pork products being smallest when comparing on weight and the gap with chicken products being smallest when comparing based on protein. The results for pork and chicken show the potential for variation in results based on the functional unit, as the comparison based on protein is the most favorable option for the *MorningStar Farms®* product in the comparison with pork and the least favorable in the comparison with chicken. This is a reflection that the *MorningStar Farms®* Original Sausage Patties are relatively dense in their calorie and protein content per weight as compared with pork sausages, whereas the *MorningStar Farms® Chik Patties®* have a relatively low protein content per weight in comparison to chicken meat patties.

In the case of the beef product comparisons, the *MorningStar Farms®* veggie products maintain an advantage of nearly twofold or more in all cases. For both the pork and chicken products, the *MorningStar Farms®* veggie products are favorable for the majority of the functional unit options explored for each indicator, but in some individual cases, the advantage is less clear, with some products being closer in impact, the extreme case being a nearly 50% advantage in Resource Consumption for the meat food product when the chicken products are compared on a protein basis.

With this exception, the results of each comparison are sufficiently strong for the *MorningStar Farms®* veggie products to conclude that these products appear to be a better environmental choice than meat regardless of the basis of comparison used. In the case of comparison of *MorningStar Farms® Original Chik Patties®* with chicken meat patties on a per-protein basis, the results here are mixed among the environmental indicators, suggesting one option is not definitively better than the other from an overall environmental perspective.

Because of the variation in the reasons that people eat food and the causation of why they choose to eat what they eat in a given instance, it is not possible to say one of the functional units explored above is more sensible than others in all cases. While many people make their food choices based on their perception of food amounts, others are on strict diets in which they monitor the amounts of calories, protein or other nutritional content. The appropriate basis of comparison may therefore be an individual choice based on one’s intended diet pattern, as well as depending on what other food is making up the remaining intake of that person on that day.

In examining these alternative options for the basis of comparison (functional unit), we gain a better understanding of the importance of this choice and can conclude that with very few exceptions, the overall conclusions reached here are not highly sensitive to the choice of functional unit. This assessment therefore further reinforces the main findings of the assessment that meatless content is a useful selection criterion for consumers who intend to reduce the environmental impact of their food consumption and such choices will, on average, lead to a reduction in environmental impact.

Appendix D: Uncertainty analysis

When evaluating a system as diverse as the overall food production system, there is a high degree of variability, as well as uncertainty with regard to how accurate each point of measure within the system is. While it is not possible to rigorously assess the exact magnitude of the uncertainty in such a model, the tools and methods developed around LCA provide some options for providing reasonable estimates of the amount of uncertainty which can help us understand which results may be highly effected by uncertainty within the models and which seem quite firm in spite of the uncertainties. Here we have made use of features in the main databases and software used in this assessment to provide a quantitative assessment of uncertainty in the food product comparisons.

Of the thousands of individual elementary flows inventoried in the elementary processes of the scenarios studied, the vast majority come from the Ecoinvent database (v3.1, SCLCI 2015), while others have been adapted from sources such as the Agri-Footprint database (Blonk 2014), with use of Ecoinvent database to represent many of the processes in the background. Ecoinvent contains information associated with most processes that allows the characterization of the uncertainty distribution within most of its datasets. The variability of most of these data sets are represented by a lognormal distribution around the central value specified (and used for the deterministic calculations), characterized by its standard deviation. In most cases, this variability is not statistically determined using real measurement, but estimated by applying a pedigree matrix describing the data quality by its origin, its collection method and its geographical, temporal and technological representativeness (Weidema and Wesnæs 1996).

The Monte Carlo simulation conducted here is on the difference of two compared systems (i.e., result of subtraction between the two), where the distance of this difference from zero indicates the probability that one option generates more impact than the other. The calculated uncertainty is based on 100 iterations using the Monte Carlo feature in the SimaPro software, tracking results for each of the endpoint and midpoint indicators.

Table 21 shows the number out of the hundred iterations from the Monte Carlo assessment in which the MorningStar Farms® product has a lesser environmental impact than the meat product. **Note that the**

information that is being displayed in Table 21 is in regard to the certainty that the results point in one direction or another and not the magnitude of the difference. Differences that are proportionately small may be very certain and those that are large may be uncertain.

For most outcomes, the results of the uncertainty assessment show a very high likelihood (>95%) that the MorningStar Farms® product has a lesser impact of the indicator in question than the meat product to which it is compared. In the case of those few midpoint indicators in the comparisons with chicken meat patties and pork breakfast patties where the outcomes suggest a higher likelihood than not that the meat products are less impacting on these indicators, the corresponding endpoint indicator- to which that midpoint is associated- shows a high likelihood that the MorningStar Farms® product has a lesser impact than its meat equivalent.

Table 21: Uncertainty assessment to determine the likelihood that the meat products have a higher impact than MorningStar Farms™ products, shown as the number of iterations out of 100

Impact category	Number of iterations out of 100 in which breaded chicken patty is more impacting than MSF Chik Patty	Number of iterations out of 100 in which pork breakfast patty is more impacting than MSF Original Breakfast Patty	Number of iterations out of 100 in which fresh ground beef is more impacting than MSF Grillers Crumbles	Number of iterations out of 100 in which frozen beef patty is more impacting than MSF SBB Burger	Number of iterations out of 100 in which frozen beef patty is more impacting than MSF Grillers Original Burger	Number of iterations out of 100 in which frozen beef patty is more impacting than MSF RGQ Burger
Carbon Footprint	100	98	100	100	100	100
Water Use	82	55	100	100	100	100
Resource Consumption	98	86	61	93	91	88
Health Impact of Pollution	100	100	100	100	100	100
Ecosystem Quality	100	100	100	100	100	100
Aquatic acidification	100	100	100	100	100	100
Aquatic ecotoxicity	65	33	100	100	100	100
Aquatic eutrophication	100	100	100	100	100	100
Human toxicity, carcinogens	100	99	98	100	100	100
Human toxicity, non-carcinogens	55	13	100	100	100	100
Ionizing radiation	100	100	96	100	100	100
Land use	100	99	100	100	100	100
Mineral extraction	100	100	100	100	100	100
Non-renewable energy	100	100	100	100	100	100
Ozone layer depletion	100	100	100	100	100	100
Respiratory inorganics	100	100	100	100	100	100
Respiratory organics	100	2	100	100	99	100
Terrestrial acid/nutri	100	100	100	100	100	100
Terrestrial ecotoxicity	44	9	100	100	100	100

Similar Monte Carlo results have not been produced for the meals due to a concern that they may give a false (and too low) impression of the uncertainty in applying the results of the assessment to an individual mean choice. The meals are represented as an average of actual meals that the sampled population reported eating and are intended to represent a very diverse set of actual meals that the population might choose. It is therefore believed that the variation in the actual outcome of the meals assessment is very broad and much broader than would be shown by conducting a Monte Carlo assessment of the type done here for products. Showing the result of a Monte Carlo assessment on this data may give an impression that the range of results to be found in comparing meals is much narrower than it is in actuality because it would not address the component of meal variability. We find it more informative to simply acknowledge that the range of outcomes for specific meals can vary. can vary.

Appendix E: Influence of meat type in meal comparison

The meal comparisons that have been made here are based on reported food intake by American adults for each meal type. The results therefore represent the comparison between a mixture food types grouped into meal averages. These meal averages are differentiated into those that contain any meat[30] and those that do not. As is seen in the products comparison made within this report, meat products themselves vary considerably in their impact and it is therefore useful to consider how the comparison of meals would vary for individual meat types as opposed to the mixture of meat types based on reported intake averages. To explore this question, we have conducted a set of scenarios where all of the meat product within the meat-based meals has been represented as either beef, pork, chicken or fish. This total amount of meat is 60.6 grams in the case of breakfasts, 112.5 for lunches and 135.8 for dinners. These amounts are determined by adding all the materials within the NHANES data representing these meals that are meat, including division of some categories which are mixtures containing meat, as described in Section 3 and Table 8. These meals have then been compared to the meatless meals to understand how the results for the meal comparisons are affected by the type of meat within the meal being compared. The results of these scenarios are shown in Table 22, while the underlying amount of meat and other products involved in the comparison are listed in Table 6.

[30] The meat-based meal averages are defined here as the arithmetic average contents of all meals reported which contained the flesh of any animal, including fish. Meat, as defined here does not include eggs or dairy. and is categorized as either beef, pork, chicken, or fish. Table 5 and Table 8 provide more detail on the content and representation of meat within the meals assessment. The meal averages are based on the relative disappearance of the four meat types listed based on USDA ERS (2015c) and as listed in Table 8.

Table 22: Difference in environmental impact of breakfast, lunches and dinners containing specific meat types versus meatless meals [31]

Meal types compared		Impact of A minus impact of B				
A	B	Carbon Footprint (kg CO2e)	Water Use (m3)	Resource Consumption (MJ)	Health Impact of Pollution (DALY)	Ecosystem Quality (PDF*m2*yr)
Beef-based breakfast	Meatless breakfast	4.663	0.214	13.88	0.0628890	17.14
Pork-based breakfast	Meatless breakfast	0.721	0.174	7.40	0.0628854	1.34
Chicken-based breakfast	Meatless breakfast	0.347	0.086	4.46	0.0628852	0.88
Fish-based breakfast	Meatless breakfast	0.878	1.171	14.82	0.0628862	0.58
Meat-based breakfast avg.	Meatless breakfast	1.490	0.264	8.30	0.0000017	4.92
Beef-based lunch	Meatless lunch	8.53	0.350	26.17	0.0683330	31.18
Pork-based lunch	Meatless lunch	1.220	0.275	14.16	0.0683262	1.87
Chicken-based lunch	Meatless lunch	0.529	0.112	8.71	0.0683258	1.02
Fish-based lunch	Meatless lunch	1.514	2.124	27.92	0.0683277	0.46
Meat-based lunch average	Meatless lunch	2.836	0.556	15.49	0.0000031	8.97
Beef-based dinner	Meatless dinner	10.25	0.395	31.57	0.0834016	37.83
Pork-based dinner	Meatless dinner	1.428	0.305	17.08	0.0833935	2.45
Chicken-based dinner	Meatless dinner	0.592	0.108	10.49	0.0833930	1.43
Fish-based dinner	Meatless dinner	1.781	2.537	33.69	0.0833952	0.75
Meat-based dinner average	Meatless dinner	3.669	0.801	20.36	0.0000040	11.57

[31] The meat-based meal averages are defined here as the arithmetic average contents of all meals reported which contained the flesh of any animal, including fish. Meat, as defined here does not include eggs or dairy. and is categorized as either beef, pork, chicken, or fish. Table 5 and Table 8 provide more detail on the content and representation of meat within the meals assessment. The meal averages are based on the relative disappearance of the four meat types listed based on USDA ERS (2015c) and as listed in Table 8.

Table 23: Difference in environmental impact of breakfast, lunches and dinners containing specific meat types versus meatless meals by midpoint impact category[32]

Meal types compared		Impact of A minus impact of B (negatives represent increased impact)						
A	B	Mineral extraction (MJ surplus)	Non-renewable energy (MJ primary)	Aquatic eutrophication (kg PO_4^{3-}-eq)	Aquatic acidification (kg SO2-eq)	Land use (m2-yr)	Terrestrial acidification and nutrification (kg SO2-eq)	Terrestrial ecotoxicity (kg TEG soil)
Beef-based breakfast	Meatless breakfast	0.000771	14.34	0.000372	0.0878	5.280	0.680	1638.6
Pork-based breakfast	Meatless breakfast	-0.00078	7.50	0.000292	0.0101	1.139	0.065	4.5
Chicken-based breakfast	Meatless breakfast	-0.00165	4.23	0.000143	0.0065	0.642	0.044	14.8
Fish-based breakfast	Meatless breakfast	0.004127	14.77	0.003376	0.0083	0.199	0.056	20.9
Meat-based breakfast avg.	Meatless breakfast	0.001253	9.93	0.013222	0.3288	1.894	29.325	649.5
Beef-based lunch	Meatless lunch	0.005071	25.63	0.000615	0.1596	9.357	1.236	2981.6
Pork-based lunch	Meatless lunch	0.002199	12.96	0.000466	0.0155	1.678	0.095	-48.8
Chicken-based lunch	Meatless lunch	0.000582	6.88	0.000191	0.0089	0.756	0.057	-29.6
Fish-based lunch	Meatless lunch	0.011294	26.43	0.006187	0.0122	-0.066	0.079	-18.4
Average meat-based lunch	Meatless lunch	0.004252	15.53	0.010359	0.2702	2.969	21.822	907.0
Beef-based dinner	Meatless dinner	0.005628	30.51	0.000644	0.1925	11.185	1.492	3624.2
Pork-based dinner	Meatless dinner	0.002161	15.21	0.000465	0.0185	1.915	0.115	-34.2
Chicken-based dinner	Meatless dinner	0.000209	7.87	0.000132	0.0106	0.802	0.069	-11.0
Fish-based dinner	Meatless dinner	0.01314	31.48	0.00737	0.0146	-0.191	0.095	2.5
Average meat-based dinner	Meatless dinner	0.004734	19.34	0.00685	0.1870	3.564	12.629	1069.1

[32] The meat-based meal averages are defined here as the arithmetic average contents of all meals reported which contained the flesh of any animal, including fish. Meat, as defined here does not include eggs or dairy. and is categorized as either beef, pork, chicken, or fish. Table 5 and Table 8 provide more detail on the content and representation of meat within the meals assessment. The meal averages are based on the relative disappearance of the four meat types listed based on USDA ERS (2015c) and as listed in Table 8.

Table 24: Difference in environmental impact of Breakfast, lunches and dinners containing specific meat types versus meatless meals by midpoint impact category, continued[33]

Meal types compared		Impact of A minus impact of B (negatives represent increased impact						
A	B	Aquatic ecotoxicity (kg TEG water)	Respiratory organics (kg C2H4-eq)	Ozone layer depletion (kg CFC-11-eq)	Ionizing radiation (Bq C-14-eq)	Respiratory inorganics (kg C2H4-eq)	Human toxicity, non-carcinogens (kg C2H3Cl-eq)	Human toxicity, carcinogens (kg C2H3Cl-eq)
Beef-based breakfast	Meatless breakfast	2792	0.000322	4.31E-08	11.04	0.0063	0.0226	0.4000
Pork-based breakfast	Meatless breakfast	-113	0.000139	3.70E-08	9.35	0.0010	0.0215	0.0220
Chicken-based breakfast	Meatless breakfast	-143	8.29E-05	1.94E-08	5.26	0.0006	0.0118	0.0232
Fish-based breakfast	Meatless breakfast	-41	0.000857	9.98E-08	18.27	0.0020	0.0077	0.0322
Meat-based breakfast avg.	Meatless breakfast	561	0.000211	3.02E+01	8.38	0.0273	0.0162	0.1244
Beef-based lunch	Meatless lunch	5395	0.000596	7.77E-08	20.22	0.0115	0.0372	0.6929
Pork-based lunch	Meatless lunch	8	0.000257	6.64E-08	17.09	0.0015	0.0352	-0.0080
Chicken-based lunch	Meatless lunch	-47	0.000153	3.37E-08	9.51	0.0009	0.0173	-0.0058
Fish-based lunch	Meatless lunch	140	0.001589	1.83E-07	33.62	0.0035	0.0096	0.0109
Average meat-based lunch	Meatless lunch	1329	0.00043	2.22E+01	15.19	0.0224	0.0229	0.1781
Beef-based dinner	Meatless dinner	6558	0.000704	9.11E-08	24.01	0.0138	0.0445	0.8425
Pork-based dinner	Meatless dinner	55	0.000295	7.75E-08	20.24	0.0018	0.0421	-0.0037
Chicken-based dinner	Meatless dinner	-11	0.00017	3.80E-08	11.09	0.0011	0.0205	-0.0010
Fish-based dinner	Meatless dinner	215	0.001903	2.18E-07	40.19	0.0042	0.0112	0.0191
Average meat-based dinner	Meatless dinner	1789	0.000621	1.26E+01	20.02	0.0156	0.0272	0.2325

[33] The meat-based meal averages are defined here as the arithmetic average contents of all meals reported which contained the flesh of any animal, including fish. Meat, as defined here does not include eggs or dairy. and is categorized as either beef, pork, chicken, or fish. Table 5 and Table 8 provide more detail on the content and representation of meat within the meals assessment. The meal averages are based on the relative disappearance of the four meat types listed based on USDA ERS (2015c) and as listed in Table 8.

As is seen in Table 22 through Table 24, the type of meat substituted has a large effect on the environmental impact of meat-containing meals. In particular beef-containing meals show a larger impact than for pork, which in turn shows a larger impact than for chicken. The impact of substituting for a fish meal is between the range of a pork meal and chicken meal for most indicators.

Appendix F: Product Contribution by life cycle stage

Contribution of life cycle stages to all end-point and mid-point indicators for six MorningStar Farms® veggie products

Table 25: Carbon Footprint contribution analysis results for six MorningStar Farms® veggie products

	Raw materials	Manufacturing	Packaging	Retail and Dist.	Consumer use
Grillers® Crumbles™	19%	25%	3%	18%	35%
Grillers® Original Burgers	55%	13%	2%	10%	20%
Spicy Black Bean Burgers	40%	21%	2%	13%	24%
Roasted Garlic & Quinoa Burgers	42%	20%	2%	12%	24%
Original Sausage Patties	47%	14%	2%	12%	25%
Chik Patties®	28%	26%	3%	15%	29%

Table 26: Water Use contribution analysis results for six MorningStar Farms® veggie products

	Raw materials	Manufacturing	Packaging	Retail and Dist.	Consumer use
Original *Crumbles™*	27%	28%	2%	10%	32%
Grillers® Original Burgers	47%	27%	2%	6%	19%
Spicy Black Bean Burgers	60%	10%	2%	7%	21%
Roasted Garlic & Quinoa Burgers	16%	33%	3%	11%	37%
Original Sausage Patties	36%	26%	2%	8%	27%
Chik Patties®	60%	14%	2%	6%	19%

Table 27: Health Impact of Pollution contribution analysis results for six MorningStar Farms® veggie products

	Raw materials	Manufacturing	Packaging	Retail and Dist.	Consumer use
Grillers® Crumbles™	14%	24%	5%	20%	37%
Grillers® Original Burgers	39%	16%	4%	14%	27%
Spicy Black Bean Burgers	37%	20%	4%	14%	25%
Roasted Garlic & Quinoa Burgers	54%	14%	3%	10%	19%
Original Sausage Patties	29%	17%	4%	16%	34%
Chik Patties®	22%	26%	5%	16%	31%

Table 28: Ecosystem Quality contribution analysis results for six MorningStar Farms® veggie products

	Raw materials	Manufacturing	Packaging	Retail and Dist.	Consumer use
Grillers® Crumbles™	67%	10%	1%	6%	16%
Grillers® Original Burgers	89%	3%	0%	2%	6%
Spicy Black Bean Burgers	80%	5%	0%	4%	11%
Roasted Garlic & Quinoa Burgers	86%	3%	0%	3%	7%
Original Sausage Patties	83%	4%	0%	3%	9%
Chik Patties®	75%	9%	0%	4%	11%

Table 29: Resource Consumption contribution analysis results for six MorningStar Farms® veggie products

	Raw materials	Manufacturing	Packaging	Retail and Dist.	Consumer use
Grillers® Crumbles™	12%	27%	5%	19%	37%
Grillers® Original Burgers	31%	20%	4%	15%	30%
Spicy Black Bean Burgers	25%	26%	4%	15%	30%
Roasted Garlic & Quinoa Burgers	22%	27%	5%	15%	31%
Original Sausage Patties	24%	19%	4%	16%	36%
Chik Patties®	13%	31%	5%	17%	34%

Table 30: Mid-point indicator contribution analysis for MorningStar Farms® Chik Patties®

Impact category	Raw materials	Manufacturing	Packaging	Retail and Dist.	Consumer use	Total impact	Unit
Human toxicity, carcinogens	3%	27%	19%	16%	35%	1.6E-02	kg C2H3Cl-eq
Human toxicity, non-carcinogens	70%	9%	1%	5%	15%	1.7E-02	kg C2H3Cl-eq
Respiratory inorganics	25%	26%	2%	17%	29%	2.9E-04	kg PM2.5-eq
Ionizing radiation	2%	31%	4%	19%	43%	6.5E+00	Bq C-14-eq
Ozone layer depletion	6%	35%	2%	18%	38%	2.5E-08	kg CFC-11-eq
Respiratory organics	36%	16%	5%	11%	33%	1.7E-04	kg C2H4-eq
Aquatic ecotoxicity	53%	18%	1%	5%	23%	8.2E+01	kg TEG water
Terrestrial ecotoxicity	83%	6%	0%	3%	7%	4.1E+01	kg TEG soil
Terrestrial acidification and nutrification	52%	19%	1%	12%	16%	1.1E-02	kg SO2-eq
Land use	98%	0%	0%	0%	2%	1.1E-01	m2-yr
Aquatic acidification	35%	24%	2%	16%	24%	2.3E-03	kg SO2-eq
Aquatic eutrophication	14%	25%	2%	13%	46%	7.2E-05	kg PO_4^{3-}-eq
Non-renewable energy	11%	32%	5%	17%	35%	5.5E+00	MJ primary
Mineral extraction	0%	3%	1%	2%	94%	1.7E-02	MJ surplus
Carbon Footprint	26%	27%	3%	15%	29%	4.0E-01	kg CO2-eq
Water Use	0%	28%	3%	17%	52%	9.7E-01	m3

Table 31: Mid-point indicator contribution analysis for MorningStar Farms® Original Sausage Patties

Impact category	Raw materials	Manufacturing	Packaging	Retail and Dist.	Consumer use	Total impact	Unit
Human toxicity, carcinogens	6%	18%	16%	19%	41%	1.3E-02	kg C2H3Cl-eq
Human toxicity, non-carcinogens	82%	4%	0%	4%	11%	2.3E-02	kg C2H3Cl-eq
Respiratory inorganics	39%	15%	2%	15%	29%	2.8E-04	kg PM2.5-eq
Ionizing radiation	7%	20%	4%	22%	47%	5.5E+00	Bq C-14-eq
Ozone layer depletion	17%	24%	2%	15%	41%	2.0E-08	kg CFC-11-eq
Respiratory organics	57%	9%	3%	7%	24%	1.8E-04	kg C2H4-eq
Aquatic ecotoxicity	68%	8%	0%	4%	19%	9.7E+01	kg TEG water
Terrestrial ecotoxicity	91%	2%	0%	2%	5%	5.9E+01	kg TEG soil
Terrestrial acidification and nutrification	71%	8%	1%	8%	11%	1.3E-02	kg SO2-eq
Land use	99%	0%	0%	0%	1%	1.8E-01	m2-yr

Aquatic acidification	52%	13%	1%	13%	21%	2.5E-03	kg SO2-eq
Aquatic eutrophication	28%	13%	2%	12%	45%	7.1E-05	kg PO_4^{3-}-eq
Non-renewable energy	23%	20%	4%	17%	36%	4.9E+00	MJ primary
Mineral extraction	0%	2%	1%	1%	96%	1.6E-02	MJ surplus
Carbon Footprint	47%	14%	2%	12%	25%	4.3E-01	kg CO2-eq
Water Use	0%	18%	3%	19%	60%	8.1E-01	m3

Table 32: Mid-point indicator contribution analysis for MorningStar Farms® Grillers® Crumbles™

Impact category	Raw materials	Manufacturing	Packaging	Retail and Dist.	Consumer use	Total impact	Unit
Human toxicity, carcinogens	6%	18%	16%	19%	41%	1.3E-02	kg C2H3Cl-eq
Human toxicity, non-carcinogens	82%	4%	0%	4%	11%	1.2E-02	kg C2H3Cl-eq
Respiratory inorganics	39%	15%	2%	15%	29%	2.3E-04	kg PM2.5-eq
Ionizing radiation	7%	20%	4%	22%	47%	5.6E+00	Bq C-14-eq
Ozone layer depletion	17%	24%	2%	15%	41%	2.0E-08	kg CFC-11-eq
Respiratory organics	57%	9%	3%	7%	24%	1.1E-04	kg C2H4-eq
Aquatic ecotoxicity	68%	8%	0%	4%	19%	6.2E+01	kg TEG water
Terrestrial ecotoxicity	91%	2%	0%	2%	5%	2.9E+01	kg TEG soil
Terrestrial acidification and nutrification	71%	8%	1%	8%	11%	7.7E-03	kg SO2-eq
Land use	99%	0%	0%	0%	1%	6.0E-02	m2-yr
Aquatic acidification	52%	13%	1%	13%	21%	1.8E-03	kg SO2-eq
Aquatic eutrophication	28%	13%	2%	12%	45%	6.0E-05	kg PO_4^{3-}-eq
Non-renewable energy	23%	20%	4%	17%	36%	4.6E+00	MJ primary
Mineral extraction	0%	2%	1%	1%	96%	1.6E-02	MJ surplus
Carbon Footprint	47%	14%	2%	12%	25%	3.0E-01	kg CO2-eq
Water Use	0%	18%	3%	19%	60%	8.5E-01	m3

Table 33: Mid-point indicator contribution analysis for MorningStar Farms® Spicy Black Bean Burger

Impact category	Raw materials	Manufacturing	Packaging	Retail and Dist.	Consumer use	Total impact	Unit
Human toxicity, carcinogens	9%	25%	17%	15%	34%	1.7E-02	kg C2H3Cl-eq
Human toxicity, non-carcinogens	69%	9%	1%	5%	16%	1.6E-02	kg C2H3Cl-eq
Respiratory inorganics	42%	19%	2%	13%	24%	3.6E-04	kg PM2.5-eq
Ionizing radiation	11%	28%	3%	18%	40%	6.9E+00	Bq C-14-eq
Ozone layer depletion	23%	28%	2%	15%	33%	2.9E-08	kg CFC-11-eq
Respiratory organics	37%	15%	4%	10%	33%	1.7E-04	kg C2H4-eq
Aquatic ecotoxicity	54%	17%	0%	5%	23%	8.3E+01	kg TEG water
Terrestrial ecotoxicity	82%	6%	0%	3%	8%	3.8E+01	kg TEG soil
Terrestrial acidification and nutrification	63%	14%	1%	10%	13%	1.3E-02	kg SO2-eq
Land use	98%	0%	0%	0%	2%	1.2E-01	m2-yr
Aquatic acidification	47%	19%	1%	13%	20%	2.8E-03	kg SO2-eq
Aquatic eutrophication	39%	17%	2%	9%	33%	9.8E-05	kg PO_4^{3-}-eq
Non-renewable energy	23%	26%	5%	15%	31%	6.2E+00	MJ primary
Mineral extraction	1%	3%	1%	1%	93%	1.7E-02	MJ surplus
Carbon Footprint	38%	21%	2%	13%	25%	4.7E-01	kg CO2-eq
Water Use	2%	26%	3%	17%	53%	9.7E-01	m3

Table 34: Mid-point indicator contribution analysis for MorningStar Farms® Grillers® Original Burger

Impact category	Raw materials	Manufacturing	Packaging	Retail and Dist.	Consumer use	Total impact	Unit
Human toxicity, carcinogens	7%	10%	18%	16%	49%	1.6E-02	kg C2H3Cl-eq
Human toxicity, non-carcinogens	87%	0%	0%	2%	91%	3.7E-02	kg C2H3Cl-eq
Respiratory inorganics	48%	0%	2%	12%	67%	4.0E-04	kg PM2.5-eq
Ionizing radiation	10%	28%	4%	18%	41%	6.8E+00	Bq C-14-eq
Ozone layer depletion	21%	11%	2%	15%	51%	2.8E-08	kg CFC-11-eq
Respiratory organics	61%	0%	3%	6%	73%	2.7E-04	kg C2H4-eq
Aquatic ecotoxicity	75%	0%	0%	3%	85%	1.5E+02	kg TEG water
Terrestrial ecotoxicity	93%	0%	0%	1%	96%	9.9E+01	kg TEG soil
Terrestrial acidification and nitrification	77%	0%	1%	6%	86%	2.1E-02	kg SO2-eq
Land use	99%	0%	0%	0%	99%	3.0E-01	m2-yr

Aquatic acidification	61%	0%	1%	10%	76%	3.7E-03	kg SO2-eq
Aquatic eutrophication	36%	0%	2%	10%	55%	9.3E-05	kg PO_4^{3-}-eq
Non-renewable energy	28%	0%	4%	14%	57%	6.5E+00	MJ primary
Mineral extraction	0%	93%	1%	1%	4%	1.6E-02	MJ surplus
Carbon Footprint	53%	0%	2%	10%	71%	6.1E-01	kg CO2-eq
Water Use	0%	51%	3%	17%	29%	9.4E-01	m3

Table 35: Mid-point indicator contribution analysis for MorningStar Farms® Roasted Garlic & Quinoa Burger

Impact category	Raw materials	Manufacturing	Packaging	Retail and Dist.	Consumer use	Total impact	Unit
Human toxicity, carcinogens	9%	25%	17%	15%	34%	1.7E-02	kg C2H3Cl-eq
Human toxicity, non-carcinogens	77%	7%	0%	4%	12%	2.2E-02	kg C2H3Cl-eq
Respiratory inorganics	63%	12%	1%	9%	15%	5.7E-04	kg PM2.5-eq
Ionizing radiation	8%	29%	4%	19%	41%	6.7E+00	Bq C-14-eq
Ozone layer depletion	19%	29%	2%	15%	34%	2.8E-08	kg CFC-11-eq
Respiratory organics	48%	13%	4%	9%	27%	2.1E-04	kg C2H4-eq
Aquatic ecotoxicity	58%	16%	0%	5%	21%	9.0E+01	kg TEG water
Terrestrial ecotoxicity	87%	5%	0%	2%	6%	5.2E+01	kg TEG soil
Terrestrial acidification and nutrification	87%	5%	0%	3%	5%	3.7E-02	kg SO2-eq
Land use	99%	0%	0%	0%	1%	2.7E-01	m2-yr
Aquatic acidification	74%	9%	1%	6%	10%	5.7E-03	kg SO2-eq
Aquatic eutrophication	47%	15%	1%	8%	29%	1.1E-04	kg PO_4^{3-}-eq
Non-renewable energy	21%	27%	5%	15%	31%	6.1E+00	MJ primary
Mineral extraction	2%	3%	1%	1%	93%	1.7E-02	MJ surplus
Carbon Footprint	41%	20%	2%	12%	24%	4.9E-01	kg CO2-eq
Water Use	2%	26%	3%	17%	52%	9.7E-01	m3

Contribution of life cycle stages to all endpoint and midpoint indicators for three meat products[34]

Table 36: Carbon Footprint contribution analysis results for three meat products

	Raw materials	Manufacturing	Packaging	Retail and Dist.	Consumer use
Frozen beef burger	93%	2%	0%	1%	3%
Frozen pork sausage patty	58%	13%	2%	9%	19%
Frozen chicken patty	51%	19%	2%	10%	18%

Table 37: Water Use contribution analysis results for three meat products

	Raw materials	Manufacturing	Packaging	Retail and Dist.	Consumer use
Frozen beef burger	92%	7%	0%	0%	1%
Frozen pork sausage patty	60%	33%	1%	2%	5%
Frozen chicken patty	59%	33%	1%	2%	5%

Table 38: Resource Consumption contribution analysis results for three meat products

	Raw materials	Manufacturing	Packaging	Retail and Dist.	Consumer use
Frozen beef burger	75%	7%	2%	5%	11%
Frozen pork sausage patty	47%	12%	4%	11%	26%
Frozen chicken patty	43%	20%	3%	11%	22%

Table 39: Health Impact of Pollution contribution analysis results for three meat products

	Raw materials	Manufacturing	Packaging	Retail and Dist.	Consumer use
Frozen beef burger	96%	1%	0%	1%	2%
Frozen pork sausage patty	64%	11%	2%	7%	16%
Frozen chicken patty	63%	16%	2%	7%	13%

Table 40: Ecosystem Quality contribution analysis results for three meat products

	Raw materials	Manufacturing	Packaging	Retail and Dist.	Consumer use
Frozen beef burger	99%	0%	0%	0%	0%
Frozen pork sausage patty	84%	9%	1%	1%	5%
Frozen chicken patty	77%	16%	1%	2%	4%

[34] See Section 3.3 and Appendices H, I, J and K for further information on the modeling of the meat products.

Table 41: Mid-point indicator contribution analysis for beef burger (60g)

Impact category	Raw materials	Manufacturing	Packaging	Retail and Dist.	Consumer use	Total impact	Unit
Human toxicity, carcinogens	59%	13%	1%	8%	19%	3.00E-02	kg C2H3Cl-eq
Human toxicity, non-carcinogens	99%	0%	0%	0%	1%	3.00E-01	kg C2H3Cl-eq
Respiratory inorganics	97%	0%	0%	1%	2%	5.10E-03	kg PM2.5-eq
Ionizing radiation	60%	12%	2%	8%	18%	1.50E+01	Bq C-14-eq
Ozone layer depletion	69%	4%	2%	8%	18%	5.40E-08	kg CFC-11-eq
Respiratory organics	77%	1%	2%	5%	16%	3.60E-04	kg C2H4-eq
Aquatic ecotoxicity	99%	0%	0%	0%	1%	2.40E+03	kg TEG water
Terrestrial ecotoxicity	100%	0%	0%	0%	0%	1.30E+03	kg TEG soil
Terrestrial acidification and nutrification	99%	0%	0%	0%	0%	5.30E-01	kg SO2-eq
Land use	100%	0%	0%	0%	0%	4.10E+00	m2-yr
Aquatic acidification	99%	0%	0%	1%	1%	6.90E-02	kg SO2-eq
Aquatic eutrophication	88%	1%	1%	2%	8%	4.10E-04	kg PO_4^{3-}-eq
Non-renewable energy	74%	5%	2%	6%	12%	1.50E+01	MJ primary
Mineral extraction	15%	1%	1%	1%	83%	1.90E-02	MJ surplus
Carbon Footprint	95%	0%	0%	2%	3%	3.90E+00	kg CO2-eq
Water Use	21%	18%	3%	14%	43%	1.20E+00	m3

Table 42: Mid-point indicator contribution analysis for breaded chicken sausage patties (60 g)

Impact category	Raw materials	Manufacturing	Packaging	Retail and Dist.	Consumer use	Total impact	Unit
Human toxicity, carcinogens	48%	18%	1%	11%	21%	2.60E-02	kg C2H3Cl-eq
Human toxicity, non-carcinogens	43%	31%	2%	6%	17%	1.54E-02	kg C2H3Cl-eq
Respiratory inorganics	71%	9%	2%	6%	12%	9.23E-04	kg PM2.5-eq
Ionizing radiation	43%	18%	3%	11%	25%	1.30E+01	Bq C-14-eq
Ozone layer depletion	52%	9%	2%	12%	25%	4.62E-08	kg CFC-11-eq
Respiratory organics	52%	11%	4%	12%	22%	1.89E-04	kg C2H4-eq
Aquatic ecotoxicity	52%	24%	0%	4%	19%	1.18E+02	kg TEG water
Terrestrial ecotoxicity	40%	42%	1%	5%	12%	2.96E+01	kg TEG soil
Terrestrial acidification and nutrification	86%	5%	1%	3%	4%	4.73E-02	kg SO2-eq
Land use	97%	2%	1%	0%	0%	6.75E-01	m2-yr

Aquatic acidification	77%	9%	1%	5%	8%	8.17E-03	kg SO2-eq
Aquatic eutrophication	76%	4%	2%	4%	14%	2.84E-04	kg PO_4^{3-}-eq
Non-renewable energy	46%	16%	3%	11%	22%	9.94E+00	MJ primary
Mineral extraction	6%	1%	1%	1%	91%	2.01E-02	MJ surplus
Carbon Footprint	55%	15%	2%	10%	19%	7.46E-01	kg CO2-eq
Water Use	10%	23%	4%	16%	48%	1.30E+00	m3

Table 43: Mid-point indicator contribution analysis for pork sausage patties (60 g)

Impact category	Raw materials	Manufacturing	Packaging	Retail and Dist.	Consumer use	Total impact	Unit
Human toxicity, carcinogens	50%	12%	1%	13%	24%	1.27E-02	kg C2H3Cl-eq
Human toxicity, non-carcinogens	32%	26%	4%	10%	29%	5.13E-03	kg C2H3Cl-eq
Respiratory inorganics	69%	8%	2%	6%	14%	4.05E-04	kg PM2.5-eq
Ionizing radiation	46%	11%	3%	12%	28%	6.33E+00	Bq C-14-eq
Ozone layer depletion	54%	6%	3%	9%	28%	2.22E-08	kg CFC-11-eq
Respiratory organics	54%	7%	5%	9%	25%	8.87E-05	kg C2H4-eq
Aquatic ecotoxicity	53%	17%	1%	5%	24%	4.81E+01	kg TEG water
Terrestrial ecotoxicity	9%	51%	2%	9%	30%	6.33E+00	kg TEG soil
Terrestrial acidification and nutrification	84%	7%	1%	3%	5%	2.09E-02	kg SO2-eq
Land use	96%	3%	1%	0%	0%	3.42E-01	m2-yr
Aquatic acidification	76%	8%	1%	5%	9%	3.74E-03	kg SO2-eq
Aquatic eutrophication	77%	3%	2%	4%	14%	1.46E-04	kg PO_4^{3-}-eq
Non-renewable energy	49%	11%	4%	11%	26%	4.69E+00	MJ primary
Mineral extraction	5%	1%	1%	1%	92%	1.08E-02	MJ surplus
Carbon Footprint	59%	11%	2%	9%	19%	3.80E-01	kg CO2-eq
Water Use	11%	14%	4%	17%	54%	5.95E-01	m3

Appendix G: Ingredients of *MorningStar Farms®* veggie products

Confidential and proprietary recipe information has been redacted.

Appendix H: Quinoa production

This appendix presents all the input data and assumptions for modeling the Quinoa grain, based on data collected directly from Kellogg Company's supplier located in South America. The inputs and outputs for the customized process "Quinoa, at farm" are summarized in Table 44.

Table 44: Inputs and outputs for modeling of "Quinoa, at farm"

	AMOUNT	UNIT	Process LCI data used (from the Ecoinvent 3.1 database)
Output			
Quinoa, at farm/adapted Bolivia	700[35]	kg	
Inputs from Nature			
Carbon dioxide	337.5[36]	kg	Carbon dioxide, in air
Energy	12217[37]	MJ	Energy, biomass
Irrigation water (included in "Quinoa irrigation input sub-process" below)	24.1[38]	m3	Water, well, in ground, BO
	320	m3	Water, river, BO
Inputs from technosphere			
Organic quinoa seed	5	kg	Pea seed, organic, for sowing {RoW}/production/Alloc Rec, U
Quinoa fertilizer input	1	ha	

[35] The output of quinoa, 700 kg/ha, was reported through a survey response reported to a supplier of Kellogg Company.

[36] The CO_2 uptake from air during quinoa during crop growth was calculated based on Bengoa et al. 2015.

[37] The carbon content of quinoa was calculated by using the carbon-content (C-content) factors in Bengoa et al. 2015 and the nutrient fact information (e.g. x g of carbohydrates per kg of quinoa) (USDA 2015b). The value of CO_2 uptake was then calculated by multiplying the value of carbon content with a factor of 44/12. Similarly, the energy content of quinoa was calculated by using the same nutrient fact information.

[38] The irrigation water applied (amount and sources), techniques (e.g. sprinkler irrigation (or spray irrigation), electricity) and emissions to the environment (e.g. evaporated water from field) were calculated by using an irrigation module tool with the irrigation practice data provided by Kellogg Company.

Patent potassium	10	kg	Potassium chloride, as K2O{RER}/ potassium chloride production/Alloc Rec, U
Urea	1.84	kg	Urea, as N {RER}/ production/Alloc Rec, U
Quinoa pesticide input	1[39]	ha	
URPI	200	g	Pesticide, unspecified {GLO}/market for/Alloc Rec, U
ENTRUST	200	g	Pesticide, unspecified {GLO}/market for/Alloc Rec, U
Quinoa machinery input	1	ha	
Share of diesel used for soil cultivation	3.76	ha	tillage, cultivating, chiseling CH/U
Share of diesel used for sowing, planting	4.36/0.99	ha	"sowing {CH}/processing/Alloc Rec, U " and "Planting {CH}/processing/Alloc Rec, U" (assume 50% each)
Share of tillage	3.76	Ha	Tillage, cultivating, chiseling {CH} processing/Alloc Rec, U
Quinoa irrigation input	1	ha	
Surface irrigation (gravity or flood irrigation); no energy	270	m3	Input as zero
Sprinkler irrigation (or spray irrigation), electricity	3.5	m3	Irrigating, sprinkler, electricity powered/BR U (m3)
Sprinkler irrigation (or spray irrigation), diesel	14	m3	Irrigating, sprinkler, diesel powered/GLO U (m3)
Drip irrigation (or micro-irrigation), electricity	17.5	m3	Irrigating, drip, electricity powered/BRU (m3)
Direct field emissions from Quinoa cultivation	1[40]	ha	Direct field emissions from Quinoa cultivation (Calculated based on Bengoa et al. 2015)
Heavy metal emission from Quinoa cultivation	1	ha	Heavy metal emission from Quinoa cultivation (Calculated based on Bengoa et al. 2015)
Water emission to the environment from Quinoa cultivation	1	ha	Water emission to the environment from Quinoa cultivation (Calculated based on Bengoa et al. 2015)

We assume that the quinoa is transported 1000 km from Bolivia to the coast and from there with freight ship 8,210 km to California.

Appendix I: Cattle raising and beef production

This appendix presents all the input data and assumptions for modeling of beef production.

[39] As there is no close proxy for the organic pesticide URPI and ENTRUST, "Insecticide, at regional storehouse/CH U" was used as a proxy.

[40] The "direct emission" (e.g. N_2O, CO_2, etc.) and "heavy metal emission" (to soil and water bodies) from the use of fertilizers were modeled using Bengoa et al. 2015.

Raising of beef cattle in the US

The raising of beef cattle in the US was modeled by adapting the existing process “beef cattle, for slaughter, at beef farm/IE Economic” in Agri-footprint database (Blonk 2014). As compared to the original process, the major change of the inputs in the adapted process are the feed mix (type and amount following Eshel et al 2014a and 2014b), energy and transportation, and source of water input to better reflect US conditions. The feed mix for raising the beef cattle is modeled based on the data in Table 46. The inputs and outputs for the updated process “beef cattle, for slaughter, at beef farm/adapted US, Economic” process are summarized in Table 45.

Table 45: Inputs and outputs for modeling of “beef cattle, for slaughter, at beef farm/adapted US”

	AMOUNT	UNIT	Process LCI data used (from the Ecoinvent 3.1 database)
OUTPUT			
Beef cattle, for slaughter, at beef farm/adapted US, Economic	1.17E4	kg	
Inputs from Nature			
Water for raising cattle	1609.38	m3	Water, unspecified natural origin, US
Inputs from technosphere			
Sorghum silage	3054	kg	Sweet sorghum stem {CN}/sweet sorghum production/Alloc Rec, U
Corn silage	59605	kg	Silage maize IP, at farm/CH U w/o hmt
Total hay, haylage, grass silage, and greenchop	270092	kg	Grass silage IP, at farm/CH U
Pasture	560712	kg	Grass, grazed in pasture/IE Economic
Compound feed	40055	kg	Customized process “Compound feed/Adapted US, Economic”
Energy for raising	68043.7	MJ	Energy, from diesel burned in machinery/RER Economic
Transportation of feed to the farm	3280.3	tkm	Transport, truck >20t, EURO4, 80%, default/GLO Economic
Emission to air			
Methane emission due to enteric fermentation	4.05E3	kg	Methane, biogenic
Methane emission due to manure management in stable	642.54	kg	Methane, biogenic
Direct emission of N2O from stable	4.25	kg	Dinitrogen monoxide
Indirect emission of N2O from stable	5.95	kg	Dinitrogen monoxide
Ammonia emission from stable	459.69	kg	Ammonia
Particulate matter	10200	g	Particulates, <10um

Feed composition

The customized process “Compound feed” contains a variety of feeds that are necessary for raising cattle, pigs and chickens. The inputs and outputs of the “Compound feed” process are summarized in Table 46 and follow information from Eshel et al (2014a).

Table 46: Inputs and outputs of the "Compound feed" process

	AMOUNT	UNIT	Process LCI data used (from the Ecoinvent 3.1 database)
OUTPUT			
Compound feed/Adapted US, Economic	1	kg	
Inputs from technosphere			
Sorghum grains	20	g	Sorghum, at farm/US Economic
Barley	10	g	Barley grain, consumption mix, at feed compound plant/IE Economic
Wheat	30	g	Wheat grain {US}/Wheat production/Alloc Rec, U
Oats	10	g	Oat grain, consumption mix, at feed compound plant/IE Economic
Soybean	170	g	Soybean {US}/production/Alloc Rec, U
Corn grains	770	g	Maize grain {US}/production, Water Use US/Alloc Rec, U
Electricity input	0.293	MJ	Electricity, low voltage, at grid/US U
Heat input	0.126	MJ	Heat, natural gas, at industrial furnace >100kw/RER U

Beef meat processing

The beef meat production process includes the transportation of beef cattle to the slaughtering plant and the slaughtering process to produce beef meat. The co-products from the beef meat production process include hide, fat and carcass. An economic allocation was applied among beef meat and the co-products. The inputs and outputs of the "Beef meat, fresh, from beef cattle, at slaughterhouse/adapted US, Economic" process are summarized in Table 47.

Table 47: Inputs and outputs for the "Beef meat, fresh, from beef cattle, at slaughterhouse/adapted US, Economic" process

	AMOUNT	UNIT	Process LCI data used (from the Ecoinvent 3.1 database)
OUTPUT			
Beef meat, fresh, from beef cattle, at slaughterhouse/adapted US, Economic	0.459	kg	
	0.187	kg	Beef co-product, food grade, from beef cattle, at slaughterhouse/adapted US, Economic
	0.141	kg	Beef co-product, feed grade, from beef cattle, at slaughterhouse/adapted US, Economic
	0.214	kg	Beef co-product, other, from beef cattle, at slaughterhouse/adapted US, Economic
Inputs from technosphere			
Beef cattle	1	kg	beef cattle, for slaughter, at beef farm/adapted US, Economic
Water input	2	kg	Drinking water, water purification treatment, production mix, at plant, from groundwater RER S system
Transportation of cattle to slaughtering house	0.1	tkm	Transport, truck >20t, EURO4, 80%, default/GLO Economic
Electricity use	0.391	MJ	Electricity, low voltage, at grid/US U
Heat use	0.15	MJ	Heat, natural gas, at industrial furnace >100kw/RER U
Emissions to water			
Biological oxygen demand (BOD)	0.0044	kg	Based on Verheijen 1996
Nitrogen	0.0011	Kg N_{kj}	Based on Verheijen 1996

The outputs of the slaughterhouse are allocated based on their economic value. The allocation system from the Agri-footprint database has been adopted here. This has not been adjusted for costs in the US market, which is based on an assumption that the costs of the outputs are the same in the US market, but that the relative ratio of costs is highly similar between the EU and US markets. The values used for the allocation are reproduced in Table 48.

Table 48: Economic data used to allocate the outputs of the slaughterhouse (based on Blonk 2014)

Type of animal	Parameter	Economic allocation (€/kg)	Allocation on energy content (MJ/kg)
Chicken	Fresh meat	1.50	6.14
	Food grade	0.60	7.39
	Feed grade	0.10	6.95
	Other	0.10	7.39
Pig	Fresh meat	1.90	7.00
	Food grade	0.15	14.19
	Feed grade	0.04	9.63
	Other	0.00	7.86
Dairy cattle	Fresh meat	3.00	7.00
	Food grade	0.30	23.68
	Feed grade	0.05	13.15
	Other	0	8.23
Beef cattle	Fresh meat	4.00	7.00
	Food grade	0.30	23.68
	Feed grade	0.05	13.15
	Other	0	8.23

Beef burger production

It was assumed that the burger production (e.g. grinding of beef meat) and packaging occurred within the slaughtering plant. Therefore, no transportation occurred during this process. The energy, water inputs (e.g. cleaning the equipment and facility), packaging processes (primary and tertiary packaging), and waste disposal were assumed to the same as those in *MorningStar Farms®* veggie product production process used within this assessment. It was also assumed that heat input was minimal since the beef was not cooked during the process. A meat loss factor (5%) was used to account for the loss of beef meat during the burger production process. The inputs and outputs of the model are summarized in Table 49.

Table 49: Inputs and outputs of the "Beef burger production (one serving) with packaging" process

	AMOUNT	UNIT	Process LCI data used (from the Ecoinvent 3.1 database)
OUTPUT			
Beef burger production (one serving) with packaging	1	p	
Inputs from technosphere			
Beef meat for burger production	0.119	kg	Beef meat, fresh, from beef cattle, at slaughterhouse/adapted US, Economic
Beef burger primary packaging	1	p	Customized process "Beef burger production-primary packaging"
Beef burger tertiary packaging	1	p	Customized process "Beef burger production-tertiary packaging"
Water input	1.52	kg	Tap water, at user/RER U
Electricity input	0.108	kWh	Electricity, medium voltage, at grid/US U
Waste and emissions to treatment			
Scarp packaging materials	8.1E-6	kg	Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U/AusSD U
Disposal of lost meat	4.25E-7	kg	Disposal, digester sludge, to municipal incineration/CH U
Wastewater	0.00135	m3	Treatment, sewage, to wastewater treatment, class 3/CHU

Appendix J: Pig raising and pork production

This appendix presents all the input data and assumptions for modeling of pig raising and production of pork meat and patties.

Raising pigs in the US

The raising of pigs in the US was modeled by adapting the existing process "pigs to slaughter, pig fattening, at farm/NE Economic" in the Agri-footprint database. As compared to the original processes, the major changes of the inputs in the adapted processes are the feed mix (type and amount following Eshel et al. 2014a and 2014b), energy and transportation, and source of water input. The feed mix for raising the pig in the US is modeled based on the data in Table 46. The inputs and outputs of the "Pigs to slaughter, pig fattening, at farm/adapted US, Economic" process are summarized in Table 50.

Table 50: Inputs and outputs of the "Pigs to slaughter, pig fattening, at farm/adapted US, Economic" process

	AMOUNT	UNIT	Process LCI data used (from the Ecoinvent 3.1 database)
OUTPUT			
Pigs to slaughter, pig fattening, at farm/adapted US, Economic	371	kg	
Inputs from technosphere			
Compound feed	1973	kg	Customized process "Compound feed/Adapted US, Economic"
Piglets for fattening	3.14	P	piglets, sow-piglet system, at farm/adapted US, Economic
Transportation of feed to the farm	76.3	tkm	Transport, truck >20t, EURO4, 80%, default/GLO Economic
Electricity inputs	5	kWh	Electricity, low voltage, at grid/US U
Heat inputs	36.8	MJ	Heat, natural gas, at industrial furnace >100kw/RER U
Water for pigs	3179	kg	Drinking water, water purification treatment, production mix, at plant, from groundwater RER U
Emission to air			
Methane emission due to enteric fermentation	1.5	kg	Methane, biogenic
Methane emission due to manure management in stable	5.37	kg	Methane, biogenic
Direct emission of N2O from stable	0.0982	kg	Dinitrogen monoxide
Indirect emission of N2O from stable	0.0635	kg	Dinitrogen monoxide
Ammonia emission from stable	4.9	kg	Ammonia
Particulate matter	56.6	g	Particulates, <10um

Pork meat production

The pork meat production process includes the transportation of pigs to the slaughtering plant and the slaughtering process to produce pork meat. The co-products from the pork meat production process include hide, fat and carcass. An economic allocation was applied among pork meat and the co-products. The inputs and outputs of the "Pig meat, fresh, at slaughterhouse/adapted US, Economic" process are summarized in Table 51.

Table 51: Inputs and outputs for the "Pig meat, fresh, at slaughterhouse/adapted US, Economic" process

	AMOUNT	UNIT	Process LCI data used (from the Ecoinvent 3.1 database)
OUTPUT			
Pig meat, fresh, at slaughterhouse/adapted US, Economic	0.57	Kg	
	0.103	Kg	Pig co-product, food grade, from beef cattle, at slaughterhouse/adapted US, Economic
	0.28	Kg	Pig co-product, feed grade, from beef cattle, at slaughterhouse/adapted US, Economic
	0.0473	Kg	Pig co-product, other, from beef cattle, at slaughterhouse/adapted US, Economic
Inputs from technosphere			
Pigs for meat production	1	Kg	Pigs to slaughter, pig fattening, at farm/adapted US, Economic
Water input	2.47	Kg	Drinking water, water purification treatment, production mix, at plant, from groundwater RER S system
Transportation of pig to slaughtering house	0.1	Tkm	Transport, truck >20t, EURO4, 80%, default/GLO Economic
Electricity use	0.383	MJ	Electricity, low voltage, at grid/US U
Heat use	0.24	MJ	Heat, natural gas, at industrial furnace >100kw/RER U
Emissions to water			
Biological oxygen demand (BOD)	0.0024	Kg	Based on Verheijen 1996
Nitrogen	0.0006	Kg N_{kj}	Based on Verheijen 1996

See Appendix I for information on the allocation of products from the slaughterhouse.

Pork product production

It was assumed that the pork product production (e.g., cutting pork meat into serving size) and packaging occurred within the slaughtering plant. Therefore, no transportation occurred during this process. The energy, water inputs (e.g. cleaning the equipment and facility), packaging processes (primary and tertiary packaging), and waste disposal were assumed to the same as those in *MorningStar Farms®* product production process, as well as those shown for beef product production in Table 49. A meat loss factor (5%) was used to account for the loss of pork meat during the production process.

Appendix K: Chicken raising and production

This appendix presents all the input data and assumptions for modeling the "chicken meat food product."

Raising chickens in the US

The raising of chickens in the US was modeled by adapting the existing process "Broilers, for slaughter, at farm/NE Economic" in Agri-footprint database. As compared to the original process, the major changes of the inputs in the adapted process are the feed mix (type and amount following Eshel et al. 2014a and

2014b), energy and transportation, and source of water input. The feed mix for raising the chickens in the US is modeled based on the data in Table 46. The inputs and outputs of the “Broilers, for slaughter, at farm/adapted US, Economic” process are summarized in Table 52.

Table 52: Summary of inputs and outputs of the “Broilers, for slaughter, at farmUS, Economic” process

	AMOUNT	UNIT	Process LCI data used (from the Ecoinvent 3.1 database)
OUTPUT			
Broilers, for slaughter, at farm/adapted US, Economic	16.76	kg	
Inputs from technosphere			
Compound feed	67.21	kg	Customized process “Compound feed/Adapted US, Economic”
Chicken at hatchery	7.69	P	One-day-chickens, at hatchery/NL Economic
Transportation of feed to the farm	2.82	tkm	Transport, truck >20t, EURO4, 80%, default/GLO Economic
Electricity inputs	0.819	kWh	Electricity, low voltage, at grid/US U
Heat inputs	19.76	MJ	Heat, natural gas, at industrial furnace >100kw/RER U
Water for chickens	52.14	kg	Drinking water, water purification treatment, production mix, at plant, from groundwater RER U
Emission to air			
Methane emission due to manure management in stable	0.00727	kg	Methane, biogenic
Direct emission of N2O from stable	0.00068	kg	Dinitrogen monoxide
Indirect emission of N2O from stable	0.00287	kg	Dinitrogen monoxide
Ammonia emission from stable	0.222	kg	Ammonia
Particulate matter	17.8	g	Particulates, <10um

Chicken meat production

The chicken meat production process includes the transportation of chickens to the slaughtering plant and the slaughtering process to produce chicken meat. The co-products from the chicken meat production process include fat and carcass. An economic allocation was applied among chicken meat and the co-products. The inputs and outputs of the “Chicken meat, fresh, at slaughterhouse/adapted US, Economic” process are summarized in Table 53.

Table 53: Summary of inputs and outputs for the "Chicken meat, fresh, at slaughterhouse/adapted US, Economic" process

	AMOUNT	UNIT	Process LCI data used (from the Ecoinvent 3.1 database)
OUTPUT			
Chicken meat, fresh, at slaughterhouse/adapted US, Economic	0.68	Kg	
	0.0448	Kg	Chicken co-product, food grade, from beef cattle, at slaughterhouse/adapted US, Economic
	0.138	Kg	Chicken co-product, feed grade, from beef cattle, at slaughterhouse/adapted US, Economic
	0.138	Kg	Chicken co-product, other, from beef cattle, at slaughterhouse/adapted US, Economic
Inputs from technosphere			
Chickens for meat production	1	Kg	Broilers, for slaughter, at farm/adapted US, Economic
Water input	2.19	Kg	Drinking water, water purification treatment, production mix, at plant, from groundwater RER S system
Transportation of cattle to slaughtering house	0.1	Tkm	Transport, truck >20t, EURO4, 80%, default/GLO Economic
Electricity use	0.466	MJ	Electricity, low voltage, at grid/US U
Heat use	0.13	MJ	Heat, natural gas, at industrial furnace >100kw/RER U

See Appendix I for information on the allocation of products from the slaughterhouse.

Chicken product production

It was assumed that the chicken product production and packaging occurred within the slaughtering plant. Therefore, no transportation occurred during this process. The energy, water inputs (e.g. cleaning the equipment and facility), packaging processes (primary and tertiary packaging), and waste disposal were assumed to the same as those in *MorningStar Farms®* product production process and are the same as those shown for beef products in Table 49. It was assumed that heat input was minimal since the chicken was not cooked during the process. A meat loss factor (5%) was used to account for the loss of chicken meat during the production process.

Appendix L: Fish production

Fish and seafood consumed in the US is approximately a mixture of half wild-caught and half farmed fish (Live Science, 2009). We have therefore represented fish and seafood as a mixture of these two categories. The farmed fish are modeled based on an existing process from the Ecoinvent v3.1 database (SCLIC 2015): "Large trout, 2-4 kg, conventional, at farm gate/FR U." The wild-caught fish are represented based on the information in Table 54. For each of these, the additional processing and yields are accounted for as detailed in Table 55 and

Table 56.

Table 54: Inputs and outputs for the "Fish and seafood, high value species, wild-caught, per kg edible" process

	Amount	Reference
Output		
Fish and seafood, high value species, wild-caught, per kg edible, RER (screening)	1 kg	
Inputs from technosphere		
Diesel, burned in building machine/GLO U	72.59 MJ	2'000 L/t landed (for high value species - Tyedmers et al. 2005), density of 0.85, 42.7 MJ/kg (inverse of the unit process chosen value)
Diuron, at regional storehouse/RER U	8E-7 kg	assumption for antifouling (1 kg/y, 1250 t fished/y)
Copper oxide, at plant/RER U	8E-7 kg	
Barge/RER/I U	4E-8 p	assumption for boat infrastructure (assuming 25'000 t fished/lifetime)
Maintenance, barge/RER/I U	4E-8 p	assumption for boat maintenance (assuming 25'000 t fished/lifetime)
Nylon 6, at plant/RER U	0.001 kg	assumption for fishnets (1 kg per t landed)
Emission to water		
Diuron	8E-7 kg	Chemical emission from antifouling
Copper	8E-7 kg	

Table 55: Inputs and outputs for the "Fish and seafood, farmed, per kg edible, at supermarket" process

	Amount	Reference
Output		
Fish and seafood, farmed, per kg edible, at supermarket/RER (screening)	1 kg	
Inputs from technosphere		
Large trout, 2-4 kg, conventional, at farm gate/FR U	2 kg	Typical yield (50% edible part in a fish landed - can be higher for salmon, etc. or lower for shrimp, etc.); http://www.fao.org/wairdocs/tan/x5898e/x5898e01.htm
Packaging film, LDPE, at plant/RER U	0.1 kg	Packaging;
Electricity, low voltage, production UCTE, at grid/UCTE U	0.01 kWh	Fish processing

Table 56: Inputs and outputs for the "Fish and seafood, high value species, wild-caught, per kg edible, at supermarket" process

	Amount	Reference
Output		
Fish and seafood, high value species, wild-caught, per kg edible, at supermarket/RER (screening)	1 kg	
Inputs from technosphere		
Fish and seafood, high species, wild-caught, per kg edible /RER (screening)	2 kg	Typical yield (50% edible part in a fish landed - can be higher for salmon, etc. or lower for shrimp, etc.); http://www.fao.org/wairdocs/tan/x5898e/x5898e01.htm
Packaging film, LDPE, at plant/RER U	0.1 kg	Packaging

Electricity, low voltage, production UCTE, at grid/UCTE U	0.01 kWh	Fish processing

Appendix M: Modeling of other customized processes

Cooking of beans

Cooked beans are an input to some of the *MorningStar Farms* ® veggie products. The customized process "cooked beans" was modeled by following a recipe for cooking black beans, suggesting a cooking time of 40 minutes and the water-to-bean mass ratio of 3:1 (bean cooking time is based on range of times in Bettay 2016). The associated energy consumption was 6.67 MJ by natural gas for 1kg of cooked beans. The inputs and outputs of the process are summarized in Table 57 .

Table 57: Summary of inputs and outputs for customized process "cooked beans"

	AMOUNT	UNIT	Process LCI data used (from the Ecoinvent 3.1 database)
OUTPUT			
Cooked beans	1	kg	
Inputs from technosphere			
Beans	0.4	kg	Fava bean, Swiss integrated production {CH}
Water for cooking	0.77	kg	Tap water, at user/RER U
Energy for cooking	6.77	MJ	Heat, natural gas, at boiler condensing modulating <100kW/RER U

Cooking of rice

Cooked brown rice is an input to some of the *MorningStar Farms* ® veggie products. Similar to "cooked beans", the customized process "cooked brown rice" was model by estimating the common cooking practice for brown rice and the inputs and outputs of the process are summarized in Table 58 . Brown rice cooking instructions are taken from Rogers 2008.

Table 58: Inputs and outputs for customized process "cooked brown rice"

	AMOUNT	UNIT	Process LCI data used (from the Ecoinvent 3.1 database)
OUTPUT			
Cooked brown rice	1	kg	
Inputs from technosphere			
Brown rice	0.5	kg	Rice {US}/production/Alloc Rec, U
Water for cooking	1	kg	Tap water, at user/RER U

Energy for cooking	4.97	MJ	Heat, natural gas, at boiler condensing modulating <100kW/RER U

Onion powder

Onion powder is an input to some of the *MorningStar Farms ®* veggie products. Onion powder was modeled as dehydrating fresh onion, accounting for the necessary input of fresh onion to achieve the yield of dried product. For 1kg of onion power, the input "Onion {GLO}/855 production/Alloc Rec, U" was 6.64 kg.

Spice mix

Spices are an input to some of the *MorningStar Farms ®* veggie products, as well as some of the meat products. The spice mix was modeled as a mix of the following processes from the Ecoinvent v3.1 database (SCLIC 2015): 50% salt ("Sodium chloride, powder, at plant/RER U") and 50% pepper ("Pepper (Brazil)/US").

Refrigerated and frozen storage and distribution processes

As the products assessed are refrigerated or frozen during transportation, a customized process was developed based on "Transport, lorry>16t, fleet average/RER U" and the amount of extra fuel (and associate emission) that is needed for refrigeration purpose.

The frozen products have to be kept frozen in 3 locations: at the distributor, at the supermarket and at home until the products is cooked. For the distributor, we have assumed and energy consumption of freezers of 40kWh/(m^3 volume occupied*year) and a storage time of 4 weeks. For the supermarket, we have assumed an energy consumption of freezers of 2700kWh/(m^3 volume occupied*year) and a storage time of 4 weeks.

Assuming an average burger to be 1cm high and to be a disc of 10cm radius, the occupied volume in a rectangular packaging box equals to: $0.1*0.1*0.01m^3=0.0001m^3$. Conservatively, twice the product volume is considered in the final calculation obtaining for the electricity consumption at the various stations:

- Electricity consumption during distribution: 0.000614kWh.
- Electricity consumption at supermarket: 0.0414kWh.

Storage, cooking and washing by the consumer

The customer use of the products was modeled in various stages, including transportation for grocery shopping, energy use for cooking, washing dishes and utensils, and infrastructure (production of cooking appliances and equipment). The *MorningStar Farms®* products and meat products are assumed to be handled the same way by the consumer.

According to the cooking instruction the product was assumed to be thawed in the microwave for 1 minute (half power) before being cooked in a skillet on the stove for 6.5 minutes. It was assumed that the lifetime of a microwave oven and skillet were 8 years (5 uses per week) and 500 times of cooking use. It was also assumed that 4 burgers were cooked together each time. The inputs and outputs of the model are summarized in Table 59.

Table 59: Inputs and outputs for the cooking process

	AMOUNT	UNIT	Process LCI data used (from the Ecoinvent 3.1 database)
OUTPUT			
Burger cooking in skillet	1	p	
Inputs from technosphere			
Transportation for grocery shopping	0.138	Person-km	Transport, passenger car, petrol, fleet average/RER U
Microwave oven	0.00205	P	Customized process "Microwave oven (with recycling)"
Skillet[41]	0.0005	P	Customized process "Skillet with recycling"
Kitchen stove[42]	0.000856	P	Customized process "Kitchen stove (with recycling)"
Electricity use for thawing[43]	0.0092	kWh	Electricity, medium voltage, at grid/US U
Electricity use for cooking on a stove	0.025	kWh	Electricity, medium voltage, at grid/US U
Electricity use for storing product at a household refrigerator [44]	0.02	kWh	Electricity, medium voltage, at grid/US U
Washing dishes and utensils[45]	3.25	p	Customized process "Handwashing, 1 object"

[41] The cooking skillet is represented as 2kg steel and 0.2 kg plastic, with and assumed lifetime of 500 uses.

[42] For the stove, an average weight of 50kg was assumed subdivided into 20 kg aluminum, 20 kg of steel, 9.5 kg of LDPE and 0.5 kg of electronics.

[43] average maximum powers of microwave ovens currently on the market are around 1100W. Hence, for thawing, one minute at medium power corresponds to an electric energy of 0.0092kWh. The electric energy for frying 4 burgers in a skillet is assumed to be 0.1kWh.

[44] Data for energy consumption of household freezer is based on an energy consumption by a freezer of 1300kWh per m^3 volume occupied per year and a storage time of 4 weeks, resulting in an Electricity consumption at for home storage of 0.02kWh.

[45] Washing is modelled assuming that for each object which needs washing 0.5 liters of water are used, with 0.5 grams of soap and heating up the water to 40°C with 0.015kWh of gas heating

9. External panel review

An external panel review has been performed for the present study, based on the guidelines in the ISO 14044 standard for assessments intending to support public disclosure of comparative statements. This external review was chaired by Michael Hauschild, PhD, of the Technical University of Denmark and included also Greg Thoma, PhD, of the University of Arkansas and Joan Sabaté of Loma Linda University. Below is the final statement issued by the panel, following by the comments made by the panel and the response of the study authors. Comments that are purely of an editorial nature (e.g., typographical errors or simpler clarifications) have been removed from the comments table for brevity. All other comments and responses are retained.

Panel statement of conformance with ISO 14044:

The Scope of the Critical Review

The review panel had the task to assess whether

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

The analysis or verification of individual datasets and LCA software models used to calculate the results was outside the scope of this review.

The process and outcome of the review

The review was performed on a final draft of the report and proceeded over two rounds of commenting resulting in a total of 126 comments of general, technical or editorial nature from the review panel. The general and technical comments and their processing are documented in Chapter 9 of the report.

Overall, the critical review found the quality of the chosen methodology and its application in the analysis to be adequate for the purposes of the study. The reporting of the study and its results is transparent. The discussion of the results covers the relevant aspects in accordance with the goal of the study, and the conclusions are well founded on the outcome of the study and in accordance with the defined goal.

Michael Hauschild | Greg Thoma | Joan Sabaté

Comments from the review panel and responses

No.	Clause No./ Subclause No./ Annex (e.g. 3.1)	Paragraph/ Figure/Table /Note (e.g. Table 1)	Comment (justification for change	Proposed change	Response
3	Executive summary	Pg iii, para 2, Line 12	This use of weight as an equivalence between meals seems difficult to justify from a nutritional perspective; meats are generally more nutritionally dense than vegetable products.	Including some of the justifications used later in the report for the equivalence based on weight may be relevant in the executive summary. For example, some of the discussion on p 17 §2.1 seem relevant.	Several sentences have been added to the end of this paragraph to address this point within the Executive Summary.
4	Executive Summary	Page iii, para 2	"The meat-containing and meatless meals have been scaled to ensure the same amount of food (by weight) has been present in each." Meatless meals tend to be less dense than meat containing meals. Thus for the same volume they have less weight. Adjusting for weight introduces a systematic error (bias) in the meals comparison.	Please explain this in methods section.	A footnote has been added to this section in the Executive Summary to explain this point further.
7	Executive Summary	Pg iv, para 2, line 24	Again, some further justification for a weight basis is important in my opinion.		See responses to points 3 and 4 above.
10	Abbreviations and Acronys	p. 14	"PDF*m²*y Potentially Disappeared Fraction per Square Meter of land per Year" The unit is not per m^2 and year but times m^2 and year (so potential loss of species over a certain area and for a certain duration)	Please correct	Done.
13	2.1 Objectives	P 17 third para	It is not the intention of this study to consider wholesale changes of the US population from its current state of predominantly meat eaters to a state of total vegetarianism. Vegetarian**<u>ism</u>** like all other isms is an ideology. More adequate terms will be vegetarian diets, vegetarian meals or meatless diets.	Please revise	Changed to "a state of entirely meatless diets."
14	3. Scope and boundaries	Table 1. Data sources: characterizin g amounts of materials	Feed materials are sourced locally and transported an average of 3.5 km from their point of production to reach the animal raising operation. This is unlikely to be the case in US operations. The distance would be much greater.	Please explain/ justify and Revise if appropriate	We have reviewed again some other references on similar topics to benchmark this assumption for reasonableness. Castellini et al (2012) in their assessment of US pork use an assumption of 30 miles. Battagliese et al. (2013), assessing US beef use and assumption

					of 500 miles. Neither cites a source for their assumption. Castellini mentions that their assumption is based on relatively close proximity between feed production an animal raising in many cases. We have decided to increase our assumption to 100 miles.
15	3. Scope and boundaries	Table 1. Data sources: characterizing amounts of materials	All food commodities are transported 500 miles by truck to arrive at their next point of processing. The raising and growing of animal and plant food respectively is very regionalized in the US and many foods come from abroad. Generalizing to 500 miles for all food commodities loses specificity when comparing meal types.	Please revise or list it as a methodological limitation	This is indeed both a highly unknown value with a high amount of variability between food types and between specific manufacturing facilities. Here we are attempting only to arrive as a correct (or reasonable) average value and are less concerned with characterizing the range around the average. For the distance between primary food production and processing, we believe that this distance is reasonable, although short in comparison to the width of the US (about 3000 miles). Reasons for believing so are that food manufacturing facilities are likely to be located near growing regions for those commodities (e.g., flour mills near wheat growing regions, fruit canning near the central valley of California, etc. In addition, we believe this effect would be more pronounced for the heaviest and largest production volume commodities, where the economic forces favouring local production will be highest. Although it is admitted that there is no firm substantiation for this assumption, we prefer to keep it without a strong reason to choose another value. Its effect on the comparative result between meal types is zero in absolute terms and very small in relative terms due to the small contribution of transportation.
16	3. Scope and boundaries	Table 1, Data sources: Characterizing amounts of materials	"Feed materials are sourced locally and transported an average of 3.5 km from their point of production to reach the animal raising operation." This seems to be a questionable assumption as US imports fodder components (e.g. soybean from South America).	Justify this assumption in the text (possibly in chapter 3.3. where the transport distances are decided)	See response to comment 14 above

19	3.Scope and boundaries	Table 1, key assumptions	Food ingredients are generally represented by the raw food commodity from which they are derived (e.g., all wheat consumption is represented as wheat grain). For some foods but not all, the weight of the food at the table is very different than the weight of the raw food commodity. This generalization will lead to bias in the meals comparison. For exampleexample, the weight of pasta at the table is many orders of magnitude greater than wheat flour/grain. The weight of Legumes at the table is 2 and half times greater than raw legumes. From table 16. We learn that meat containing meals have an average of 8 g of legumes while meatless meals contain 15g of legumes.	Please revise or list as a methodological limitation	Thank you for catching this point. We have reviewed the list of foods and identified four categories where we believe this difference in water content between the way data are represented in NHANES and the LCI data used to represent them causes an inaccuracy. These are legumes, pasta, grains, and dried fruit. The values have been adjusted based on the ratio of dry to wet weights for these products as described in the footnotes to table 16. The caloric content of dry and wet versions of these items from the USDA has been used as the basis for these ratios.
20	3. Scope and boundaries	Table 1, key assumptions	**Vegetarian** food requires no systematic difference in manufacture, per weight of food	Please change to **plant** food requires no systematic difference in manufacture, per weight of food	We have removed the use of the term “vegetarian” throughout the report to describe the meals and products in question, using “meatless” and occasionally “plant-based” instead, with some use of “veggie” in regard to the MSF products, as this is part of their branding. The few remaining instances of “vegetarian” refer to this is a total dietary pattern.
22	3 Scope and Boundaries	Pg 20 Table 1, retail/Key assumptions	We have a paper under review on food waste which found differences in post farm supply chain may offset production savings due to differential loss rates of different food types; thus the assumption of no differences in post-production (as seems the case here) may miss some differences that are important.	Consider this assumption in the study limitations section	The statement that the same food waste rates are used throughout the food chain for both meal types was not correct and was a hold-over from a prior draft before the Buzby et al 2014 reference was used to define the waste rates. This statement has been removed. Table 14 summarizes the assumptions used regarding food loss at retail and consumer, clearly showing a difference among the food types.
23	3 Scope and Boundaries	Pg 20, table 1, waste/ key assumptions	The ERS LAFA database as well as the Buzby (2014) do not appear to support this assumption that vegetables and meats have equal loss rates in the supply chain. The differences are not large, except possibly for fish	If differential loss rates were included in the detailed models, rephrase this assumption. If not, either include an assessment of the impact of the assumption in	See point 22 above.

			products, but may still exceed the 1% cut off threshold	your discussion or to account for differential loss rates.	
24	3 Scope and Boundaries	Pg 20, table 1, manufacturing/ env impact	which of the ecoinvent allocation models was used?	Please clarify	The "cut-off system model" was used. Mention of this was added in a new footnote to Table 17, as well as in the reference to this database in the references list.
25	3.1 General description of the systems studied	Pg. 22 second para under the meal systems	Therefore, it is possible to capture information about foods reported to be consumed at breakfast, lunch, and dinner (it is also possible to capture snacks and other eating occasions, however, these data were not captured for this report). Excluding snacks and foods from other eating occasions introduces a bias in the type of meal comparison. Meat is not typically consumed on such occasions thus amplifying, magnifying the difference between the meat- containing and the meatless diet patterns.	Please include an explanation in the text	Because we are not looking at total diet patterns, but rather individual meals, we don't believe that omitting snacks adds a bias to how these data are used. While it is true that if making a comparison of total consumption of meat-containing and meatless options over a day or longer period would be biased if omitting snacking occasions, we believe these snacking occasions can be ignored for the purposes of this study as the focus is on evaluating and communicating on the breakfast, lunch and dinner meals. In addition, it is not clear how snacks could reasonably be included in the definitions of meals used here if they were to be included. We have used data specific to each meal occasion (breakfast, lunch, dinner) rather than taking a total daily consumption and divided by three. There is therefore no clear way to apportion the food consumed as snacks to the meal occasions.
26	3.1 Meatless and meat-containing meal classifications and characterization	p. 23 3rd para	mathematical average is not specific – both median, arithmetic average and geometric average are mathematical averages.	I suggest that you replace mathematical average by arithmetic average throughout the report and keep the explanation of how it is calculated here, the first time that the term is used	Done.
27	3.1 General description of the systems studied	Pg. 24 first paragraph	As the focus of the present assessment is on **what** food people choose to eat, this removes the confounding effect of **how much** food they choose to eat. What people chose to eat is not independent of the amount (how much) they eat. If meatless meals on average weigh less than meat containing meals standardizing the weight	Please give a rational. Also, present results without standardizing the weight of meals.	The data used here do show that meals containing no meat weigh less than those containing meat. However, it is not clear that this is a causal relationship or simply correlational and due to other factors. For example, 60% of American vegetarians are female and it can be presumed that women eat less than men do. In addition, there may be other factors that correlate with both

			introduces bias to the meal pattern comparison. See my 2nd comment.		vegetarianism and smaller meals beside gender, but that are not causal relationships. Another potential factor is a likelihood of inverse causation that is that choosing a small meal makes it more likely for that meal to be meatless rather than choosing a meatless meal makes it more likely that the meal would be small. Due to all these factors, we feel it is more justifiable to assume that the choice of meatless or meat-containing meal has no bearing on how much food one will eat on that occasion rather than assuming that the difference seen in the data is a causal effect of meatless choices on food weight. We have added to the discussion of this topic in this section (footnote on p 26)
28	3.1 General description of the system studied	Pg 24, para 1, line 3	By avoiding one problem (food type rather than quantity), another one potentially arises: based for example on caloric requirements non-meat meals would generally require more mass (to be iso-caloric), despite the fact that the self-reported meatless meals had lower mass?	I understand this is out of the scope of the study, but should, I think, be included in discussion of limitations on the conclusions. Or, perhaps you mentioned this point of the sensitivity analysis presented in appendix. Another point which may be relevant to make in the context of ISO requirements of the equivalence of functional unit used in comparative studies is that, for an individual meal, many people will eat to satiety which is likely a function of quantity rather than nutritional quality of the meal.	We have added a disclaimer in several places to both call attention to this topic and to be clear that it is not the intention here to be able to thoroughly address these complicated issues around nutrition and function of food. We feel this is the best that can be done within the scope of such an assessment, as the topic deserves to be addressed in higher detail if attempting to discuss these points.
31	3.1 General description of the systems studied	Pg. 25 last paragraph	All stages downstream of raw material production are represented in a similar way for the meat-containing and meatless meals, as there is no basis for assuming that these stages differ based on whether meals contain meat Besides meat, the proportion of all the foods/ food groups in the meatless and meat-containing meals differs. For example legumes are double, nuts are 4 times more in meatless than meat-containing meals. By homogenizing	Please explain/ justify and Revise if appropriate	We’ve modified this sentence to make it additionally clear that the proportion of various food commodities within the two meals do in fact differ and in more complicated ways than simple substitution, the remainder of the life cycle is assumed to be the same, meaning it is assumed that the packaging, manufacture, transport, cooking, etc. is not systematically different and the

			all the stages downstream for the food groups dilutes the differences among meal patterns.		same broad assumptions described in this section can apply to both meals types.
33	3.1 subset: alternative scenarios within meals assessment	Pg 26, para 3, line	Did you also consider the ERS food availability database? There is no differentiation between breakfast lunch and dinner consumption in that data set, and thus it would not meet the goal and scope definition for the study, but might have served as an alternate choice of the representative average consumption?		We did review this as an alternative data source. As you note, the lack of differentiation of meal types makes it a problematic fit for the current purpose to address the individual meal events, as well as to divide consumption between meals that contain meat and those that do not.
34	3.1 MorningStar Farms® veggie products	p. 27 para 3	"Note that in comparison to Figure 1, the waste disposal stage is omitted. Because it has been assumed that all the product that is purchased is consumed, the only waste materials at the product end-of-life is the packaging materials and the end-of-life management of these materials has been grouped into the packaging stage."	Why is this assumed differently for the meat-based meal systems and how strong is the influence of this assumption?	We believe your comment misinterprets what is represented by Figures 1, 2 and 3 and how this relates to the inclusion of food that is wasted. Figure 1 represents the life cycle stages of meals, both meat-containing and meatless. Food waste is considered in these meal comparisons for both types of meals. Figures 2 and 3 show the life cycle stages for the product comparisons. It is assumed that the entire product is eaten and there is no waste at the consumer stage and so the only material to be dealt with at end of life is the packaging, the management of which has been added into the packaging stage for simplicity.
35	3.1 subset: Product systems	Pg 27, Para 3, line14	This is probably not a very reasonable assumption (that all food purchased is consumed), given the general patterns of food waste by consumers - both in home and food service environments. Why would these products be wasted at a different rate than any other product purchased consumption in the home?	Both the ERS LAFA and Buzby references show some differential food loss rates by commodity at the consumption level. If this assumption is not relaxed, then some discussion regarding limitations of the study, or the potential impact of this assumption on the conclusions seems warranted.	Note that this assumption of no food waste at the consumer applies only to the modelling of the specific MSF and meat products. Within the modelling of meal consumption, the data from Buzby 2014 on food waste by type at both retail and consumer has been applied. If one were to consider consumer waste in the product evaluation, one could essential scale up the impact of the product by the percentage wasted in order to fulfil the same functional unit. We considered applying the Buzby data to the products, but the problems are that the MSF products do not fall squarely into one category (they contain legumes, grains, nuts, vegetables and oils) and that if, for example we were to choose to represent them as legumes and give them a waste rate much lower than beef, this could be a source

					of bias and criticism. It seems more sensible to leave these products not adjusted for waste at the consumer stage to fit with the available data.
36	3.1 subset: Product systems	Pg 27, Para 4, line 19	Please clarify: the meat portions are 60 g in the table, but the MorningStar portions are not. Were they scaled to 60 g for the assessment? Or were they compared on the basis presented in the table because this is the intended level substitution?	Please see next comment.	The footnote to this table attempted to explain this and has been edited to try to make this clearer. In short, all products are compared on 60g basis, even if the weight of one packaged serving differs from that. We have also removed the reference to the packaged weights from
40	3.1 product systems	PG29, Second para	We assume here the same set of cooking conditions for both the meat products and the *MorningStar Farms® veggie products* If vege products requires less cooking time than meat products why have you applied the set of cooking conditions to both of them.	Please revise computations	This paragraph was revised to provide better clarity of the basis for the assumption. The statement that the MSF products do not require cooking for safety was removed to avoid confusion on this point. The key point is that it is believed consumers will cook both products and there is no good basis for assuming one would be cooked in a different way or for more or less time than another.
41	3.1 subset: product systems	Pg 29 para 2 line 13	Is this an important caveat? The implication appears to be that the products would be cooked for longer time and thus incur higher energy consumption burden	Please comment	Same as above (comment 40)
42	3.1 subset: product systems	Pg 29 para 3 line 17	Nonetheless, if there are differences in packaging which are required by product differences, shouldn't this be counted as there are environmental effects of packaging? In one of our studies, the absorbent pad (viscose) was a surprisingly large contributor to land occupation-due to the 25 to 30 year land occupation of tree plantations, as may be the case with cardboard products.	Please consider and comment	The packaging for the meat alternatives has not been possible to quantify here based on a complete market survey and so it was decided to take the assumption that the packaging is the same as for the MSF products to avoid any bias introduced in either direction by selecting just one packaging option among many on the market for meat products. Note that most of the meat products represented are represented as frozen and would therefore not use the absorbent viscose pad mentioned in the comment. In addition, some packaging for fresh ground meat does not use such a pad.
43	3.1 subset: product systems	Pg 29 para 3 line19	Is credit taken for this recycling cardboard? Or is it simply cut off and subsequent treatment of the cardboard not included in the impact calculations?	Explain modelling assumptions.	Text has been added on page 53 to explain this. In short, the cut-off approach has been used, not representing any benefit for recovering recycled material. This is not

					expected to have an important effect on the conclusions of the study and so further assessment or scenarios are not done in this case.
45	3.3 System characterization and data sources	Pg. 32 second para	For all products originating from within the US a fixed transport, distance of 930 miles has been assumed. Why is the real distance and truck payload not used here? The company can provide you the location of the supplier, way of transportation of the ingredient and the location of the two facilities where the products are manufactured.	Please revise computations	Most of the inputs to these products are commodities purchased from among the pool of available commodities on the market, and so the locations and suppliers they are purchased from one month or year are in many cases not reliable indicators of where they would be purchased from in the next period, as availability, price, quality, etc. are factored in to meet sourcing needs. We've therefore taken 930 miles, as approximately 1/3 the width of the continental US as a reasonable estimate of the distance between an unknown point and the production facilities. This is likely to be on the pessimistic side, as in actuality the main sourcing areas for many domestic commodities will be more closely located to the production facilities than if positioned at random. However, we feel it is an appropriate assumption to make in the absence of specific long-term data. Regarding the payload, for the type of bulk commodities in question, shipment of fully weighed-out trucks should be an accurate assumption. Note that this transport leg has a very small impact on the overall result and so was not made a priority for further evaluation.
46	3.3 System characterization and data sources	Pg. 32 second para	Whereas for quinoa, transport to the production site has been modelled through ocean transport to the US and truck transport for the shipping within the US to the point of manufacture. Include transportation in Bolivia from the farm to the silo and to the harbor. The country of Bolivia, the origin of the ingredient quinoa is land lock and the farm is far from the harbor.	Please revise computations	Thank you for catching this omission, we have added a transport stage of 1000 km by truck to reach the shipping port from production in Bolivia. This has been noted in this section

47	3. 3Morning Star Farms manufacturing	Pg.33 first para	In table 5, the proportion of inputs and outputs differs greatly between Facility A and Facility B. Is it because of difference in efficiency and technology of the plants or due to difference in the products that are manufactured	Please explain	Kellogg's has explained that the differences are due to a combination of the scale of the two plants and their operating conditions. They validated that the numbers are correct based on their facility records.
48	3.3 System Characterization and data sources	Pg 33 para 1 line 5	Mass allocation for MorningStar products seems reasonable as all of the products have essentially equivalent function after leaving the manufacturing facility.	Based on the adapted LCI in the appendix for meat product manufacturing, I assume this is based on an economic allocation key? See also later comment on this point.	Yes, the allocation of animal raising to meat products is based on an economic allocation for all meat products.
49	3.3. Animal feed production and animal raising	Pg. 34 first para	The following table shows an example of the amounts used in the beef production model, which has been based on the "*Beef cattle for slaughter, at beef farm*" model from the agri-footprint database (Blonk 2014), Can the European data be applicable to the US?	Please explain	While the original structure of the model is taken from the source cited, many of the aspects of cattle raising, and especially the feed composition, have been updated to reflect US production conditions based on the best information we have available. Details of this updated modelling are provided in Appendix I for transparency.
50	3.3. Animal feed production and animal raising	Pg. 34 second para	In addition, the animal raising processes are assumed to require the inputs of feed materials. The feed materials included are listed in the Appendix I. Lacking a source on average distances for transport of grains to farms, it is assumed here that these feed materials are sourced locally and transported an average of 3.5 km from their point of production to reach the animal raising operation.	This is very unlikely in US. Consider and revise if you agree.	This has been addressed and changes made as described in the response to comment 14
51	3.3 Animal slaughter and processing	Table 8: Inputs for meat processing	What about emissions from the slaughterhouse? One could expect substantial eutrophication impacts from emissions of BOD and nutrients	Please comment on this in text	Emissions of BOD and nutrients from processing at the slaughterhouse were not contained in any of the relevant datasets from either the Ecoinvent or Agri-footprint databases. Following some research, we were able to find a reference for water emissions of these substances from this stage in an FAO reference. This has been added into the modelling and is described in the relevant appendix tables for pork and beef processing.
52	3.3 System Characterization and data sources	Pg 35 para 1 line 2	In the appendix, an adapted data set from agri-footprint/economic is reported. Based on that, I had assumed that an economic allocation was applied to meat processing. However here it	Explain modelling assumptions. The LEAP guidelines recommend economic allocation for product with dissimilar uses. Thus for MSF,	The statement on mass allocation on page 35 is in reference to the MSF product manufacturing at Kellogg's facilities. You are correct that animal production has been

			seems that mass allocation including rendering and other non-edible co-products like the hides, bones, etcetc. has been adopted?	a mass allocation between products all having similar functions seems appropriate, while in the case of meat processing the functions of different coproducts are not similar.	allocated on an economic basis and an additional clarifying statement on that was added to the report as noted for comment 48 above.
53	3.3 Morning star farms and meat product distribution and retail	Pg.35 second para	It is assumed that both the meat products and *MorningStar Farms®* veggie products follow equivalent paths from the point of production to reach the consumer's home. Morning star products are produced only in two facilities for the whole US. So they require longer distribution distance to the retail outlets and consumers, compared to multiple slaughter houses and meat patty production facilities in the US.	Please revise the assumption.	Although animal raising and slaughter are overall more distributed than for the MSF product production, it is not clear that the supply for the products as they reach the consumer is any more local than for the MSF product. For example, large volumes of these products are purchased through large retail chains and these chains may have one or very few suppliers nationally and distribute to all of the US from those suppliers. Without more detailed knowledge of how the meat product distribution might be different, it Is believed to introduce the least bias in the study to assume this transport is the same for both product types. Note that even with this assumption of a national level distribution for meat products, the overall influence of the product distribution on the results is relatively small.
54	3.3 System Characterization and data sources	Pg 35 Table 9	**Typographic mistake: beached**		Fixed.
55	3.3 System Characterization and data sources	Pg 36 para 2 line 10	Data exist from the National Highway and Transportation Study to support this (as an approximation); since you give a number of items here, I assume you are using a number based allocation. Why not remain consistent with a mass allocation? Data exist on what people purchase - about 1440 kg/household/year and about 100 trips for shopping per year. I doubt this changes the results, but would be consistent allocation approach.	Give an explicit explanation of consumer transport allocation.	This has been revised drawing on the reference you provided. The National Household Transportation Survey (latest data represents 2009) indicates that the average US household travels a total of 2980 miles each year over 470 shopping trips, or an average of 6.4 vehicle miles per trip. The Food Marketing Institute has reported that US households spent approximately $50 in total per grocery shopping trip between 2006 and 2012. The resulting 0.13 miles of vehicle travel has been assigned to both the product life cycle based on an assumption of $0.5 paid per

					60 g serving for all products, or 0.065 vehicle miles travelled per functional unit. With regard to the question on use of a mass allocation, we believe it is not a good fit at this stage because product weight would not frequently be determinant or limit on the amount purchased in a given trip. We don't have a statistic on the weight of total grocery purchases, but we expect the outcome would not be greatly affected if the trip were assigned by weight.
56	3.3 System Characterization and data sources	Pg 36 table 11 line 19	Does the patty volume include overhead? That is, the warehouse is not 100% filled with products (aisles, clearances at the top, etc).	Explain LCI information.	*This response addresses comments 56-60, which each deal with the assumptions used for refrigeration. Both the values used in the modelling and the representation in the report has been reviewed and updated, with some updates made to the values. The following text has now replaced these tables in the report with the idea that the text can describe the relationship of the values more clearly. Key references is also cited. "The storage of products throughout the food chain is based on an adaptation of the recommendations in Humbert and Guignard, 2015. The products are assumed to occupy 0.0002 m3 (2cm x 10cm x 10cm box and are stored with an overall ration of product volume to storage volume of 1/3 for frozen products and ½ for refrigerated products. The meat products are assumed to be kept frozen at the distribution center (4 weeks) and at the retailer stores (and additional 4 weeks), except for the fresh ground beef, which is assumed to be at refrigerated temperature and only kept at the distribution center for 1 day and at retail for 2 weeks. Chilled storage at distribution centers is assumed to use 35 kWh/m3-year. Storage at retail assumed 1100 Kwh/m3-year for chilled and 1500 Kwh/m3-year for frozen. Note that retail refrigerators and freezers are highly inefficiency compared to a large distribution center, due both to scale and the frequent*

					opening or permanent open state of these commercial coolers. The total energy consumption for storing the frozen products is therefore 0.00054 kWh at distribution and 0.023 kWh at retail, while the energy consumption for the refrigerated product (fresh ground beef is 0.000019 kWh at distribution and 0.0085 kWh at retail."
57	3.3 System Characterization and data sources	Pg 36 table 11 line 20	Why the large difference between DC and retail refrigeration intensity?	Provide citation for data source	See response to comment 56 above.
58	3.3 System Characterization and data sources	Pg 36 table 12 line 24	Again, storage volume is probably larger than the container volume. That is, is overhead volume included in the product line?		See response to comment 56 above.
59	3.3 System Characterization and data sources	Pg 36 table 12 line 26	What is the source of these data (both tables).		See response to comment 56 above.
60	3.3 System Characterization and data sources	Pg 36 table 12 line 28	Energy consumption of refrigeration at retailer is a repeated real, but numerical values are not consistent - 3800 kWh/m3y == 3.8 kWh/Ly not 1.24 kWh/Ly	Check calculations	See response to comment 56 above.
61	3.3 MorningStar Farms® veggie product and meat product use	p. 37 last para	"In the oven preparation, it is assumed that eight servings of food overall are contained in the recipe being baked, so that one-fourth of the baking is allocated to the meat product or MorningStar Farms® product representing the serving in question." Not clear why two servings are considered for oven preparation when one serving is considered for stovetop preparation	Please explain	This should have said one-eighth. Fixed in text.
63	3.3 System Characterization and data sources	Pg 38	Perhaps I have not understood the ERS database, but I thought that there were detailed, supply chain stage specific loss rates for different food commodities. In table 54, 1 kg of beef cattle is an input and the sum of coproducts is also 1 kg, thus it is not clear where the 5% by weight loss is accounted. Is the reference flow of beef meat, fresh into the downstream supply chain inflated by 5% to account for loss at manufacturing? Similarly, how are these losses for MSF products account in calculations?	Explain calculations in a little bit more detail.	Table 14 summarizes the loss rates at retail and consumer based on the Buzby 2014 reference. Loss at the farm level is accounted for within the farm-level production process (i.e., the output of the farm process represents the useful amount of the commodity in question leaving the farm. The 5% loss at manufacture is handled as you suggest in your comment. For each 1 kg of, for example, beef exiting the manufacturing process, an extra 0.05 kg is added as additional input required.

64	3.3 System Characterization and data sources	Pg 38 para 2 line 22	Is plate waste included in the analysis? Earlier it was stated that 100% of purchased MSF products were consumed; does this contradict that earlier statement?	Please clarify	As discussed in response to comments 34 and 35, waste at the consumer is considered within the assessment of meals, but not within the assessment of products, where is assumed the entire product is consumed. Within the meals comparison, the waste rates of Buzby 2014 are applied (see Table 7)
66	3.3 System Characterization and data sources	Pg 39 Table 14 Last column	A small point, but it is not mathematically correct to add loss percentages to get total loss: e.g. 10% loss at retail (1kg in = 0.9 kg sold) means that 20% loss at consumption is applied to only 0.9kg, so overall loss is 28%, not 30%; in looking at the Buzby reference, I see that the basis is food supply and not the amount flowing into each subsequent supply chain stage.	In your calculations did you use these percentages directly in SimaPro? If so, then you have most likely overestimated food loss, because, of course, Simapro applies the loss rate to the reference flow entering the current process and not to the originally available quantity at the beginning of the supply chain.	These values have been updated.
67	3.3 MorningStar Farms® and meat product loss in manufacture, retail and consumer storage	Table 14: Loss of foods at the retail operations and consumer (p. 39)	The percentages given for loss at retail level and loss at consumer level refer to different stocks and are thus not immediately additive. The loss fraction r at retail level refers to the stock A delivered from the producer, so the loss at the retail level is r*A. The loss c at consumer level refers to the stock B delivered from the retail level, B=(1-r)*A, so the loss at the consumer level is c*B=c*(1-r)*A. The aggregated loss at retailer and consumer level is thus r*A+c(1-r)*A = r*A+c*A-cr*A= (r+c-cr)*A. In order to make the combined loss fraction applicable to the produced quantity A, the combined loss should thus be calculated as r+c-cr rather than as r+c.	Consider and revise if you agree	This has been revised as described in the response to comment 66 above.
69	3.3 System Characterization and data sources	Pg 40 table 15 amount of raw / primary data sources	In our study, we found it impossible to reproduce the USDA NASS reported total production using NHANES data; it may not be a critical point for this study at the meal scale, but I think that it is relevant if any broader conclusions are implied about shifting diets. The LAFA data set is internally consistent with overall production data.	Informational only	Indeed, we have not intended to use the outcomes here to reach conclusions about the total US food consumption, as the present assessment is focused on addressing discrete meal choices rather than consideration of large-scale shifts in the diet towards vegetarism.
70	3.3 System Characterization and data sources	Pg 40 table 15 Env impact	Incorrect copy and paste in the 3rd column.	Please correct	Done.

		per amount/ how beef is represented			
72	3.3 Raw material production and delivery for meat-containing meals and meatless meals	Pg.40 Table 15	Amount of raw materials produced to provide meal. Following are missing from the report: the adjustment factors for scaling up (or down) the weight of the food at the table (provided by (NHANES data) to the amount of the food needed to be produced (farm gate). For example, Hydration factors for grain/flours, legumes, meats or scale down factors for a live animal to a carcass to meat at the table (patty).		See response to comment 19 above.
75	Packaging for meatless and meat-containing meals	Pg49. Second paragraph	Note that snacks were not considered in apportioning the packaging waste to three daily meals. The computation of allocation of packaging to 3 meals in this paragraph is an over estimation. Commercial snacks and beverages were not included in this report. These foods and beverages have a higher proportion of packaging than the 3 regular meals.	Please revise and re compute.	This is a very good point. The data we have available suggest that snacks represent approximately 25% of food intake by calories. Accounting also for beverages and assuming that these two categories are high contributors to packaging relative to their calorie content, we have divided the total packaging as estimated in the report by a factor of 2 to arrive at the amount attributable to meals.
77	4.2 Impact assessment	p. 53 2nd para	"This set of five indicators allows an overview of the results,…"	I would change into: "This set of five endpoint indicators allows an overview of the results,…"	We've avoided referring to this set of five indicators due to two of the indicators (carbon footprint and water use) not being endpoint-level indicators. The water use metric is technically inventory-level information with no impact assessment applied and the carbon footprint is a midpoint indicator that predicts a physical change in the environmental. This set of five are focussed on because it is anticipated that they are overall of the highest level of interest to the audience.
79	4.4 Uncertainty analysis	p. 56 first para	" Monte Carlo analysis was used here to understand the uncertainty within the product systems assessed here, using 100 iterations for each product system …"	Please comment on whether this was sufficient to reach stable values for the mean and standard deviation	Done.

80	4.4 Uncertainty analysis	Pg 56 para 1 line 6	I don't see why MCS of meals was not conducted. Clearly the meals will have different foods, but provide the same function in the context of the study. Since the meals are well characterized ,it seems more relevant to me to make the MCS at the meal level rather than product level	Please comment	Calculation of the meals requires the use of a large set of data to produce a set of average meals, which are an average within a very wide range of actual meals that the sampled population reported eating and are intended to represent and even wider set of actual meals that the population the study is intended to represent might choose. It is therefore believed that the variation in the results of the meals assessment is very broad and much broader than would be shown by conducting a Monte Carlo assessment of the type done here for products. Here, we speak to the average result for meals only. We feel that showing the result of a Monte Carlo assessment on this data, may give an impression that the range of results to be found in comparing meals is much narrower than it is in actuality because it would not address the component of meal variability. We find it more informative to simply acknowledge that the range of outcomes for specific meals will be quite broad. Certainly, one could imagine a meatless meal that would be more impacting and a meat-containing meal and at the same time could imagine a meat-containing meal that is more impacting than a meatless meal by much more than what is shown here. A further technical reason to not perform a Monte Carlo assessment on this data is that the results have been taken from the SimaPro software at a commodity level and combined in MS Excel to more efficiently assess the various meal scenarios for the long list of food types. These meal models would need to be re-constructed in SimaPro to allow for the Monte Carlo to be run. Some discussion on this was added.to section 4.4

81	4.4 Uncertainty analysis	Pg 56 para 2 line 17	No uncertainty in characterization factors.	Add a note that due to this limitation, the reported uncertainty ranges represent a lower bound.	A statement on this topic was added to section 4.4.
83	5.1 Environmental impact of meatless and meat-containing meals	Pg 57 figure 6 Waste managemen t	I may have missed it, but where is food loss /waste accounted? The major impact occurs on-farm but is induced by downstream behaviour. So it doesn't quite fit in waste management.	Clarify the accounting of food loss and waste-particularly since this is mentioned as important area for mitigation later in the document.	See discussion above in comments 34, 35 and 64.
85	5.2 Comparison of meatless and meat-containing meals	Figure 13 and following figures	Legend: “Meat with other” – meaning not clear	Please explain	The following footnote has been added to all figures where this label appears: *“Meat with Other” describes categories from NHANES that are classified within meats, but whose description indicates that they are likely not entirely meat. As described in Section 3.1 and Table 17, these are represented as a mixture of meat, vegetables and grains, depending on their description.*
88		Table 20, p. 76	Alternate value of the carbon footprint	This is about 20% higher than the value reported by Battagliese, 2013 for beef and about 50% higher than reported by Castellini, C., A. Boggia, L. Paolotti, G. J. Thoma, and D. Kim. 2012. Environmental Impacts and Life Cycle Analysis of Organic Meat Production and Processing. In: S. C. Ricke, E. J. Van Loo, M. G. Johnson, and C. A. O’Bryan, editors. Organic Meat Production and Processing. Wiley-Blackwell, Oxford, UK. p. 113–136. for pork (1.05kg CO_2e/4 oz boneless serving); I think this would not change the study conclusions in terms of directionality, but would change the magnitude of the differences by more than the cutoff threshold chosen. Because you have modified several datasets from	We’ve reviewed these documents to identify any potential improvements that could be made. As noted elsewhere in our responses, we have made some adjustments to transportation assumptions based partly on these references. We did not find other information in these references that were documented well enough that appeared to be improvements over the reference sources. Although it is not our goal to replicate the results found elsewhere, it is interesting to benchmark with other similar information sources to understand differences. One point that stands out from the Castellini reference that could explain a reasonable amount of the difference is that that reference shows a ratio of weight of feed input to weight of the animal at slaughter of 2:1 for pork, whereas the Eshel et al. 2015 reference that we have used for this information gives a value of 3.2. This roughly correlates to the 1.5X difference in carbon footprint results you mention. Given that the Eshel study is very recent and

				Agri-footprint, these modifications would not be inconsistent to apply.	thorough, we don't currently see a reason to change this value.
93	5.6 Comparison of MorningStar Farms veggie products and meat products	Pg 80 para 3 line 29	A caveat here, again, regarding possible differences in nutritional content of the chosen FU may be needed.	I understand that in this work, the function is a meal and its contents and not an overall dietary comparison, yet it seems relevant to mention the larger context as the backdrop of these evaluations.	A caveat on this point was added to the end of this paragraph.
95	5.6	Pg 81 figure 23, 24 …	The horizontal format used above (figure 21) would work nicely for this chart (and maybe most of the contribution charts as it makes the product name easier to read.	Consider and introduce if relevant	We have adopted this horizontal chart format for several additional charts throughout the report, particularly where the number of categories requires the titles to be displayed vertically if a vertical chart is used.
99	6.1Key findings	Pg.83 last paragraph	The environmental impact differences between meatless meals and meat-containing meals in will be some-what reduced if the beverages which have been excluded from the computations, were to be included. Beverages typically require proportionally more packaging than the foods. And there is no reason to believe that the meal patterns are differentially in the use of beverages.	Please include this comment in the conclusion	A comment on this point was added to section 6.1
101	6.1 Key findings	Pg 84 para 4 line 17	There remain nutritional considerations and potential effects to healthy diets. Adam Drewnowski has some interesting studies comparing diets which are relevant in the larger context.	Consider to address the larger context of nutritional balance in the discussion. As this will be used for public comparative assertions, I am concerned of the potential to cause nutritional harm if decisions are made on too narrow a basis. These citations are relevant in this larger context: a) Drewnowski, A., C. D. Rehm, A. Martin, E. O. Verger, M. Voinnesson, and P. Imbert. 2015. Energy and nutrient density of foods in relation to their carbon footprint. Am. J. Clin. Nutr. 101:184–91. Available from: http://www.ncbi.nlm.nih.gov/pubmed/25527762	[An additional paragraph was added to the end of section 6.1 to further discuss the use of the current results in consideration of the potential nutritional differences.

				b) Fern, E. B., H. Watzke, D. V. Barclay, A. Roulin, and A. Drewnowski. 2015. The Nutrient Balance Concept: A New Quality Metric for Composite Meals and Diets. PLoS One 10:e0130491. Available from: http://dx.plos.org/10.1371/journal.pone.0130491	
102	6.1 Key findings	p. 85 third para	"Across the set of comparisons made here, it is found that choosing to substitute non-meat products for meat products in meals is likely to lead American adults, on average, to achieve a lesser environmental impact of that selected meal." The reduction must accompany the opposite substitution – of meat products for non-meat products	Consider and revise	This sentence has been revised to ensure the meaning is clear.
103	6.2 Discussion	Pg85. Third paragraph	The World Bank and other organizations have recommended that meat analogs replace meat. But haven't provided any data to substantiate this recommendation. This report provides some of this data.	It would be worth mentioning something to this effect in the discussion section.	A paragraph was added to section 6.2 raising this topic.
104	6.1 Key findings	Throughout the chapter	I miss a discussion of the uncertainty of the conclusions of the lower impacts associated with non-meat meals	Please refer the findings of the uncertainty analysis in Appendix D here	A paragraph was added to the discussion section, which focusses on the uncertainty in the results.
105	Page 94	Table 22	What are the MSF values? The results below are counter-intuitive to me. If meat has a higher protein content on a mass basis, then wouldn't a larger mass of veggie be needed to deliver the same protein? Yet the protein basis shows a smaller impact than the weight basis in figure 27.	Based on the results presented in figure, it appears that the MSF product has more protein per 100 g than the meat products.	Indeed, the MorningStar Farms® (MSF) products in many cases do have a higher protein density than meat. Per 60 grams, beef, pork and chicken have protein content of 8, 9 and 16 grams respectively. Per 60 grams, the protein content of the MSF products ranges from 9 grams in the case of the quinoa burger and Chik Patty, to 40 grams in the case of the breakfast sausage. Note that the meat protein content will vary depending on the leanness of the cut of meat. It is assumed here that pork and beef used for sausage and hamburger will have a relatively high fat content.

106	6.2 Discussion	Pg.95. Figure 29	The blue dots representing the difference based on weight are all close to a 100% (no difference). This is strange since the weight was the way the comparisons were made through out the report.	Please check and revise	We discovered that the results for several of the figures in the body of the report were showing the comparative results on a basis of calorie comparison rather than weight comparison. This has been corrected. The most important implication is that the relative benefit of the comparison with pork products is somewhat smaller than shown previously in the body of the report.
113	Appendix H Quinoa production	Table 51: Inputs and outputs for modeling of "Quinoa, at farm" (p. 123)	Sequestration of CO_2 is quantified as an input. If this is counted as a negative emission in the inventory analysis, the release of CO_2 upon consumption, wasting etc. in the use and disposal stages must be counted as an emission. The two should balance each other as no carbon is permanently stored in the quinoa crop	Check that this is the case and perhaps make a not in the appendix to ensure the reader that the carbon balance is considered.	As with other agricultural products modelled in the LCI databases used here, uptake of CO2 by plants is indeed counted as a negative emission and is labelled in the inventory as biogenic. The issue you mention of balancing the uptake with the emission is handled in the impact assessment stage, where biogenic uptake and emissions are given a characterization of 0 CO2eq, essentially ignoring this biogenic "short-cycle" carbon.
114	Appendices I, J and K	Tables 52, 56 and 58	Distinction between Direct emission of N_2O from stable and Indirect emission of N_2O from stable not clear	Please explain	The IPCC uses the term "indirect" but "induced" would be better. The "indirect" or induced N2O emissions are those from all reactive N emissions (NH3, NO3, NOx). The indirect N2O are therefore those induced by e.g. the ammonia emissions in stables.
115	Beef meat processing	Table 54	Were economic values for allocation adjusted to US conditions from EU conditions?	There is some lack of full transparency on some allocation decisions.	No, the original economic allocation from the Agrifootprint dataset were used, without adjustment. This does not necessarily assume that the prices are the same between the European and US markets for meat products, but rather that the ratio of costs of the various parts of the animal are the same or very similar between these geographies. The specific economic assumptions for these datasets can be found in the documentation "Agri-Footprint - Part 2 - Description of data" (Blonk Agri-footprint BV, 2014)
116	Appendices I, J and K	p. 126 2nd para, p. 128 last para and p. 130 last para	An economic allocation was applied among the meat and the co-products.How large a share did this result in for the meat?	Please clarify	A table with the economic values used to make the allocation of meats and co-products has been added to the appendix sections dealing with the meat modelling.

117	Appendix M	Tables 63 and 64	Why is energy for cooking measured in kg?	Check and revise if needed	This was a typo and should have read "MJ" rather than "Kg." It has been fixed in the report.
2.2	Page 28 line 19			stages … are	Done
2.3	Page 28 line 21		Many aspects of these stages are proportional to the weight of food and so the activity in these stages for breakfasts, lunches and dinners differ primarily based on the differences in average weight for each meal type.	Please explain: if the comparison is made after adjusting the meal weights to be the same, how can weight difference be a source of difference?	This seems to be a misinterpretation of what we have done in adjusting the NHANES meals data. In the original data, dinners contain more weight than lunches, which have more weight than breakfasts. In all cases, meat-containing meals had more weight than meatless meals. We adjusted the weight for each of the three meal occasions so that the meat-containing and meatless meals for that occasion were equal, but not such that the weight across the three meal occasions are all equal. In all cases, the weight for meat-containing meals for each meal occasion was used. So, the statement cited here is saying that for some stages of the life cycle, such as transporting food products to the market, etc., dinners will show a higher impact here because these have been represented as a function on weight. Some text has been added to page 28 to try to make this weight adjusting more clear to avoid confusion on this point.
2.7	Page 89 line 6		Note that individual choices will not be reflected, but these results could be achieved across a population when meatless is used as a meal choice criterion.	is this assertion consistent with the statement in section 2.1 : "The scale of such a change would likely lead to changes in our food production systems that are not intended to be assessed with the methodology and scope of study chosen here." ? And the statement below regarding complete dietary change? My question is in the use of the term population with regard to meal choice criterion of meatless, and the implied scale. I think it safer to simply assert that based	There are two separate concepts being addressed in these two passages. On page 89, the discussion is on the statistical idea of reversion to the mean, which is that as a sample size grows, it is increasingly likely for the mean of the selected set to approach the mean of the larger set of instances from which the sample is taken. In short, we are saying that if taking just one meal, the carbon footprint benefits, etc., shown in the report might be very different than the outcomes of that one meal. However, as the number of meals in question goes from one to hundreds or thousands, it is much more likely that the outcome would reflect the results shown in the report. The second concept which you

				on this evaluation the selection of meatless meals is strongly shown to result in lower impacts.	mention being referred to in section 2.1 refers to a complete system shift, or a much higher number of meals needed to see this "reversion to the mean" effect. This concept is that if the shift to meatless meals were substantial enough to, for example, remove meat production from the economy, the changes due to this systematic change might be different in some ways than a simple scaling-up of the impact predicted at the single meal level. If everyone on earth were eating 3 meals daily, there would be 8 trillion meals consumed annually, and so the hundred, thousand or even millions of meals over which one might apply these results would still be less than one-thousandth of one percent of meals consumed annually and so unlikely to result in major changes in the global food system. Some changes have been applied on page 89 to clarify that we are talking about a reversion to the mean with a larger sample size.
2.8	Appendix C	Pg 100 Table 19	The Protein content of the different meats (g / 100 g) is underestimated, since the value is from raw meat. However, the cooked value, the way people typically eats meat, is much higher. For example: Cooked beef (USDA NDB No 23502) contains 26 % protein versus the 17.4 % for raw beef in your computations. This is due to the loss of water when cooked. Such loss of water does not occur with the MSF Veggie Burgers. However, in real life conditions, people eat cooked burgers, not raw! Thus, your computations give an unreal and disproportional advantage to the MSP products in the comparative analysis of protein, as functional unit.	Please consider to use the protein values of cooked burgers for the Sensitive analysis computations.	Thanks for raising this point. In evaluating this comment and the options for implementing it, we have come to believe that the nutritional equivalencies we have used, representing raw meats, are appropriate ones for establishing this equivalency. Although it is cooked meat that people eat, the life cycle inventory data being used represents raw meat. The numbers you cite indicate that approximately 1/3 the mass of the beef is lost as water in cooking. If setting the protein equivalence based on the cooked meat weight (2/3 of what has been used), we would need to scale this amount of meat up by 50% to arrive at the amount of fresh beef to be cooked, arriving at the same number already being used. Regardless of whether one sets the equivalence at the point of cooked or raw meat, as long as all meats in the comparison are measured in the same way which they are, the amount of fresh meat

					input needed to achieve an equivalent amount of protein in the cooked product is the same. In considering this issue, it has occurred to us that this issue effects more the comparison on a weight basis rather than protein or calories. If we assume it is mostly water weight that is lost in cooking, the protein and caloric content would remain essentially unchanged when meat is cooked, but the weight of the meat changes. Here, we have set the equivalence by weight at the point of raw ingredients (the weight in the recipe rather than the weight on the plate), for both meat and the MSF products. We have added a note in the definition of the functional unit to point this out. If doing the opposite (setting it as the weight on the plate), it would increase the amount of meat needed to provide the functional unit by weight leading to a larger advantage for the MSF products.
2.9	Comment 48	Page 150	I understand the choice to allocate the MSF products by mass and meat products by economic allocation, but thinking again, my understanding of the ISO standard is that allocation decisions at similar stages of the supply chain should be based on the same allocation methodology.	Please comment on any potential effect that this may have in the analysis. Specifically, I'm wondering if the choice of mass allocation for meat products would narrow the difference between the meals while economic allocation for the veggie products might widen the gap. If the results are sensitive to this problem choice, that should be mentioned.	We believe the application of allocation between the plant-based and meat systems has been misunderstood in this comment and that they are in-fact allocated similarly. For all agricultural products, including meats, economic value has been used as the basis for allocation for the division of products that come from a single agricultural production process. This applies to beef, dairy and leather from cattle. It also applies to plant co-products like wheat and straw, as well as to division of soy, wheat, corn, etc, to oils, protein concentrates, etc. This same logic is applied to both meat and plant products. In addition, the same approach has been applied in allocating the manufacturing processes in which these agricultural ingredients are mixed or otherwise processed to create food products. All such manufacturing processes have been allocated based on mass. This

					includes the manufacturing of the MSF products, the manufacture of the meat products and the representation of the manufacturing stages within both types of meals.