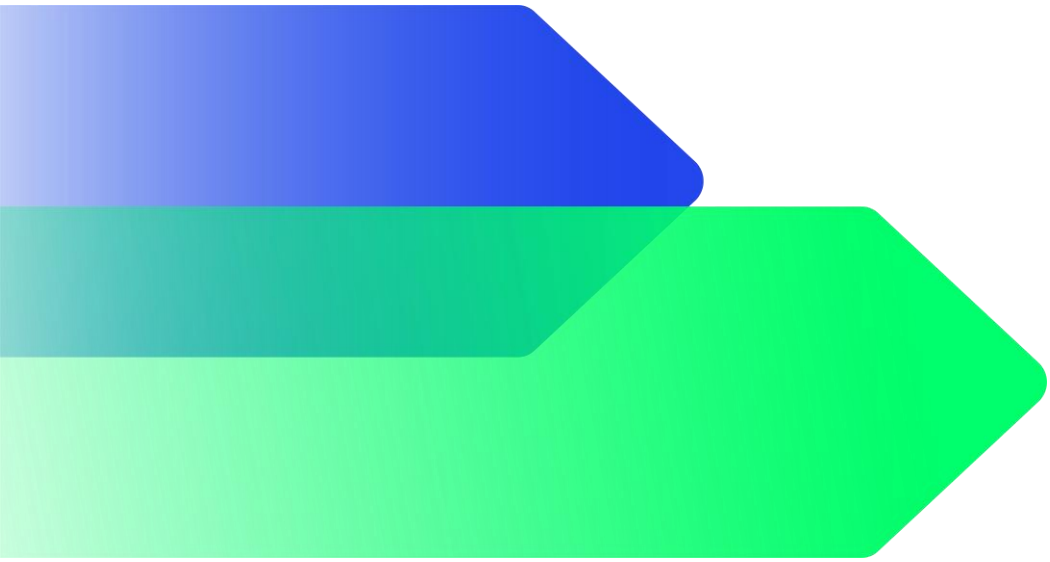
CARBON TRUST

COMPARISON REPORT

Kellogg's MorningStar Farms®

August 2022



INTRODUCTION

About the report

This report summarises the Carbon Trust's research into carbon, water, and land use footprints for the comparison of meat-based products with plant-based alternative protein MorningStar Farms® products.

The product carbon footprint figures in this report have been agreed with, but not been certified by, the Carbon Trust and should be seen as indicative of the best available data sources.

The full scope and objective of this project was to achieve a baseline to be able to compare best-selling MorningStar Farms® products to the most appropriate meat comparator products available in the market. This was in part achieved by conducting a full value chain report, as well as calculating the product footprint of key MorningStar Farms® products.

The lower end of footprints for common comparator protein sources were calculated and compared against the relevant upper end of the uncertainty range for MorningStar Farm's proteins – by comparing best case and worst-case footprints, we have guaranteed that the footprints can be seen as lower, and this is the approach we have taken in the project.

Some of the data in this report came from the value chain project – including origins of soy, and how it was transported, for example.

This comparison project is part of a bigger scope of work to help MorningStar Farms® evaluate the greenhouse gas impact of products in a cradle to grave cycle, with help from global climate consultancy, the Carbon Trust.

Acknowledgments

The Carbon Trust authored this report based on an impartial analysis of primary and secondary sources.

Who we are

We are a trusted, expert guide to Net Zero, bringing purpose led, vital expertise from the climate change frontline. We have been pioneering decarbonisation for more than 20 years for businesses, governments, and organisations around the world.

We draw on the experience of over three hundred experts internationally, accelerating progress and providing solutions to this existential crisis. We have supported over 3,000 organisations in 50 countries with their climate action planning, collaborating with 150+ partners in setting science-based targets, and supporting cities across 5 continents on the journey to Net Zero.

CARBON TRUST

The Carbon Trust's mission is to accelerate the move to a decarbonised future.

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Table of Contents

Table of Figures

Abbreviations

CT	Carbon Trust
GBP	Great British Pounds
GHG	Greenhouse Gas
LCA	Life Cycle Analysis
tCO2e	Tonnes Carbon Dioxide Equivalent

1. Introduction

This report summarises the Carbon Trust's research into carbon, water, and land use footprints for the comparison of selected MorningStar Farms® meatless products with their meat-based counterparts.

In this report a comparison has been made between the MSF product with the highest carbon footprint per category, against its equivalent meat product. Assumptions were made so that the meat product would have the least possible emissions. This means we are comparing the MSF product with the highest emissions with the equivalent meat product with the least. The lower limit footprints were used to conduct a "lower than" comparison analysis. To have confidence that one product can be said to have a lower environmental impact than another, the variability and uncertainty of footprinting must be considered. For example, to state that a specific product has a lower impact it must:

1. Be compared against the market dominant products that fulfil the same defined function
2. Be compared against substitutable products in a specifically defined geographical region
3. Account for uncertainty and variability in the comparison: Specifically, the upper end of this product's uncertainty range, lies below the lower end of the market standard products' uncertainty range. In both cases accounting for reasonable but not extreme uncertainty.

Based upon this, the research took the following approach:

- The lower end of footprints for **common comparator protein sources** were calculated and compared against the relevant upper end of the uncertainty range for **MorningStar Farm's proteins** (*Table 1*)

The analysis in this report compares the footprints on a 60 gram of product basis rather than on a per equalised kilogram of protein basis. A per kilogram of protein approach is taken to compare the footprints of different food items within the context of a balanced diet and will yield different comparison numbers based on the protein content of each product. Since the aim of this analysis was to directly compare the footprints of the final products, the per kilogram of product approach was deemed to be the most relevant.

We acknowledge there are differences in the production methods and resource requirements within each source of protein. As such, there can be uncertainties when evaluating and reporting the impacts of agriculture and food production. To account for this, and to ensure that any comparisons include and reflect the uncertainties and variability as far as possible, this research has prioritised studies that evaluate the lowest reasonable impact of these sources of protein and compared them with the upper uncertainty limit of the MorningStar Farms®' products. Where information was available, country specific research has been used. See Appendix 1: for the uncertainty analysis between MSF and meat products.

Table **1***: Comparison of footprints for competing protein inputs*

MSF Product	Comparator Product	Target Countries
Chik Patties Original	US Chicken Patties	USA
Veggie Breakfast Bacon Strips	US Bacon strips	USA
Buffalo Wings CN	US Chicken Wings	USA
Griller's Burger Style Veggie Crumbles	US Ground Beef	USA
America's Original Veggie Dog	US Beef Sausage	USA
Chik'n Nuggets CN (Vegan)	US Chicken Nugget	USA
MSF Italian Style Crumbles	US Pork sausage	USA

2. Footprinting introduction

We have researched the carbon, water, and land use footprints for each product in this report to provide a full view of their environmental impact. The databases used for this analysis are Ecoinvent 3.8 and Agri-footprint 5.0, these were complemented with research papers as needed for more specific values needed.

2.1. Carbon footprint

The carbon footprint assesses all the greenhouse gases (GHGs) released from the various processes required to produce the finished product from the 'cradle to grave' boundary. For the comparison of MorningStar Farms® products and meat-based comparator products, emissions associated with upstream transport and distribution, and packaging have been included. While the term carbon footprint is used throughout this report, the measurement units are carbon dioxide equivalent (CO_2e). CO_2e is a reference unit to assess the global warming potential of a range of different GHGs. For example, methane has a global warming potential 28 times greater than carbon dioxide (Greenhouse Gas Protocol).

Using chicken as an example, the lifecycle analysis has evaluated all the GHGs released in the rearing and processing stages of a chicken's life. This includes all the emissions associated with the cultivation of feeds, use and manufacturing of synthetic fertiliser, upstream transportation, heating and lighting requirements, and processing energy required to produce a chicken carcass.

2.2. Land footprint

The land footprint focuses on the physical area required to produce the finished product. For meat products, this involves the land that livestock is raised on (such as the area livestock require to live on), and the land used to grow the feed that the livestock consume. For crops and plant-based products, this involves the land required to grow the crops or produce the raw ingredients that are required to produce the product. The land footprint is expressed in terms of feet^2 per kg of finished product (f^2/kg) and excludes the land use associated with the packaging of each product.

2.3. Water footprint

Water footprints[1] assess the total amount of water used during the processes required to produce the finished product. This includes water consumed by the animals (such as water that livestock have

[1] The Water Footprint Network defines a water footprint as a volumetric "... The water footprint is an indicator of freshwater use that looks not only at direct water use of a consumer or producer, but also at the indirect water use." This is distinct from LCA which requires an additional impact assessment step – for example volumetric data is modified by an appropriate local scarcity modifier.

drunk), water used to produce the feed, rain and dirty water that returns to rivers and water consumed during processing.

The water footprint only includes ‘blue water’ as there was not enough data for ‘green water’ and ‘grey water’ (Water Footprint Network, 2011). This footprint has also not been adjusted for scarcity and therefore includes volumetric data only:

- Blue water is surface and ground water consumed by food production, which relates to the growing of feed for the livestock and the growing of crops

The water footprint is expressed in litres per kg of finished product (US gallon/kg) and excludes the water footprint associated with the packaging of each product.

Regarding the analysis, blue water is the most important footprint for direct comparisons, as it is most easily measured and controlled by businesses. Green water, although often a large value, represents water that although temporarily affected by agriculture, is not removed from the natural system. Grey water is difficult to estimate.

3. Assumptions

We made several assumptions in the process of gathering and calculating the environmental footprints for the food products. For carbon, all MorningStar Farms® and meat products were compared with the 'cradle to grave' boundary. For MorningStar Farms® products specific data from the sites was used for every step of the process, and when possible, conservative assumptions were made (for example assuming all products were frozen instead of chilled), while for meat it was assumed that the meat was local and chilled instead of frozen to build up a best-case scenario. See a list with all the assumptions made in Appendix 1:.

With regards to the calculation of the land and water footprints, the scope has been limited to direct land and water used and **does not consider the impact of land-use change** associated with production. For example, if the land was converted from forest to grow soy, then there would be an impact on the local water cycle and indirectly effect the water footprint of the soy. Including this type of analysis would increase the emissions of the comparator products more than that of the MorningStar Farms® products. Therefore, since a conservative approach was taken in this comparison analysis, indirect land-use change was not included.

All footprints for meat and MSF products were reported in kgCO2e per 1kg of product so that they could be fairly compared to the MorningStar Farms® products. For each of the meat-equivalent products only one analysis was made, using the lowest reasonable emission factors found in literature for North America. This means it was not possible to compare various sources and obtain average values. In section 5.2 the values are shown per 60g of product (unit chosen by MSF), as well as in the units preferred: ft^2a instead of m^2a, and US gallons instead of Litres.

4. Footprint results

In this section, we summarise the results for each protein source according to the footprints studied. The key assumptions and carbon, land, and water footprints for each protein source (beef, chicken, and pork) are also discussed. To allow for direct comparison between MorningStar Farms® products and their meat counterparts, the Carbon Trust team has assumed that all ingredients are locally sourced. Section 1 provides a detailed analysis of how these footprints compare to the chosen MorningStar Farms® products: Griller's Burger Style Veggie Crumbles, America's Original Veggie Dog, Chik Patties Original, Buffalo Wings CN, Chik'n Nuggets CN (Vegan), Veggie Breakfast Bacon Strips and MSF Italian Style Crumbles

4.1. Beef

In the Beef category, two beef products were compared to MSF products, these are Ground Beef and Beef Sausage. The main element of both these products is beef, therefore this section focuses on this, however, there are other ingredients that are needed to make such beef products (e.g., salt, pepper, onion powder…) and these are also accounted for in the analysis.

4.1.1. Carbon

Results from Stackhouse-Lawson (2012) were used as a proxy for CO2e emissions per kg of cattle in the US beef industry. The methodology follows the Integrated Farm System Model (IFSM), which is representative for the state of California in the US. This model simulates crop growth, feed production and use, animal growth and return of manure nutrients back to the land. Boundary for beef includes all feed production, manure storage and spreading, and enteric methane. In terms of herd structure, simulated beef production systems included cow-calf, stocker, and feedlot phases for the traditional British beef breeds and calf ranch and feedlot phases for Holstein steers (K. R. Stackhouse-Lawson, 2012). The boundary of these footprints is cradle to grave, therefore, the carbon footprint for beef also includes the conversion ratio for live weight to carcass weight (EBLEX, 2012).

A point of continued contention is how to manage the interaction between dairy and beef herds, where surplus dairy calves are transferred to beef production. Holstein steers that entered the beef production system as a by-product of dairy production had the lowest carbon footprint because the emissions associated with their mothers were primarily attributed to milk, rather than meat production (K. R. Stackhouse-Lawson, 2012).

For the context of this analysis, we analysed the systems that would produce the lowest emissions for the meat products. For this reason, assumptions were made to keep the emissions from meat products as low as possible:

- All products were transported and maintained chilled instead of frozen.
- Products were transported for 100km from farm to factory, and 100km from factory to supermarkets.
- meat only stayed in retail distribution centres for 2 days, 7 days in supermarkets and a maximum of 3 days in home refrigeration.

- Meat waste throughout the value chain was obtained from a research paper that accounted for food waste through each stage of the process from cradle-to-grave (M. Karwowska, 2021).

Beef cattle produce several types of valuable outputs meaning there is the need for economic allocation of the different meat cuts. Research by Desjardins (2012) shows the co-products allocation factors in terms of mass and economic value, see *Table 2*. This table was used to calculate the emissions of the meat used for ground beef and for beef sausages which are *primal cuts*, therefore have higher economic value and so are allocated a higher percentage of emissions from the whole animal carcass.

To make ground beef, it was assumed beef is the only ingredient needed. However, to make beef sausages other ingredients were assumed to be added to the recipe: sage, garlic powder, onion powder, salt, and red pepper. The emissions for these were weighed in terms of their proportion to the final product (1kg of beef sausages). The emission factors for each of these ingredients come from the databases Ecoinvent 3.8 and Agri-footprint 5.0. See *Table 3* and *Table 4* for the analysis of each recipe.

Table 2: Slaughtering mass balance and co-product allocation factors for the United States and Canada (R. L. Desjardins, 2012)

	Mass balance	Co-products allocation factors	
	% SLW	Mass	Economic
Wastes	21.3%	-	-
Meat, primal cuts	37.8%	48.0%	83.6%
Rendering product	32.8%	41.7%	6.8%
Hide, raw	4.9%	6.2%	6.8%
Offal	3.2%	4.1%	2.7%
	100%	100%	100%

Table 3: Emissions of ingredients used to make 1kg of ground beef in the US

	Amount in 1kg of ground beef (kg)	Emissions per cut (economic allocation) ($kgCO_2e$)	Emission factor ($kgCO_2e/kg$)
Beef	1.00	38.85	38.85
TOTAL			**38.85**

Table 4: Emissions of ingredients used to make 1kg of beef sausage in the US

	Amount in 1kg of sausage (kg)	Emissions factor ($kgCO_2e/kg$)	$kgCO_2e/kg$ of sausage
Ground beef	0.98	38.84	37.94
Sage	0.01	1.04	0.01
Garlic powder	0.00	8.12	0.03
Onion powder	0.00	2.82	0.01
Salt	0.01	0.04	0.00
Red Pepper	0.00	1.20	0.00
TOTAL			**37.99**

4.1.2. Land

In this analysis land use has only been considered for ingredients needed, and not for any other parts of the value chain.

The land use requirements for beef can vary depending on the production system. The land needed for cattle in the United States has been determined by Asem-Hiablie et al. (2019). As shown in section 4.1.1 for carbon emissions there is the need to do an economic allocation based on the animal cut considered. The same principal as for carbon emissions (Desjardins, 2012) was used for land use (see *Table **2***).

For the remaining ingredients needed to produce the 2 products: ground beef and beef sausage, land use has been taken into consideration. This data comes from Agri-footprint 5.0 for most cases, when not available other research papers were used. In *Table **5*** and *Table **6*** below you can see the land use for each of the ingredients needed in each recipe.

*Table 5**: Land use in the production of 1kg of ground beef in the US*

	Amount in 1kg of ground beef (kg)	Land footprint per cut (economic allocation) (m^2/kg)	Land footprint (m^2)
Beef	1.00	133.15	133.20
TOTAL			**133.20**

Table 6: *Land use in the production of 1kg of beef sausage in the US*

	Amount in 1kg of sausage (kg)	Land footprint per cut (economic allocation) (m^2/kg)	Land footprint (m^2)
Ground beef	0.98	133.20	130.1
Sage	0.01	7.50	0.1
Garlic powder	0.00	4.05	0.01
Onion powder	0.00	6.49	0.02
Salt	0.01	-	0.0
Red Pepper	0.00	2.50	0.01
TOTAL			**130.17**

4.1.3. Water

Like the land footprint of beef, the water footprint can vary depending on production system with different ratios of green, blue, and grey water being used for different production systems. For example, industrial systems on average have a lower overall water footprint per kg beef however they require a larger proportion of blue and grey water compared to grazing systems

For the reasons discussed in section 2.3 of this report, the blue water footprint is considered the most relevant to be used for the comparison. Therefore, the green and grey water footprints from this system were not included in the analysis. The values used for the water usage of beef come from the UNESCO-IHE Institute for Water Education report by Mekonnen & Hoekstra (2010), and water usage for the remaining ingredients come from various research papers. *Table **7*** below shows the water used for the 2 recipes analysed.

Table 7: Water used in the production of 1kg of ground beef in the US

	Amount in 1kg of beef (kg)	Water footprint (m^3/kg)	Water Footprint (m^3)
Ground beef	1.00	0.91	0.91
TOTAL			**0.91**

Table 8: Water used in the production of 1kg of beef sausage in the US

	Amount in 1kg of beef sausage (kg)	Water footprint (m^3/kg)	Water Footprint (m^3)
Ground beef	0.98	0.91	0.89
Sage	0.01	0.90	0.01
Garlic powder	0.00	1.18	0.00
Onion powder	0.00	0.02	0.00
Salt	0.01	0.00	0.00
Red pepper	0.00	100.00	0.22
TOTAL			1.12

4.2. Chicken

In this category, three chicken products (Chicken Nuggets, Chicken Patties and Chicken Wings) were compared to three MSF products. The main element of these products is chicken, therefore that is the focus of the subchapter below, however, there are other ingredients that are needed to make such chicken products, and these are also accounted for in the analysis.

4.2.1. Carbon

The result for carbon comes from the sum of kgCO2e emissions associated with each ingredient in the recipe. Emissions from each ingredient were calculated using a specific ingredient emission factor, multiplied by the percentage contribution of the ingredient to the recipe. The emission factor for chicken was calculated based on the average carcass weight for chicken in the United States and the emission factor associated with the carcass. The average carcass weight was based on 2020 chicken Yield/Carcass weight values by the Food and Agriculture Organization of the United Nations (FAO) on crops and livestock products. The emission factor associated with the carcass was found in the article by Pelletier, 2008 as live weight, and was then converted to a functional unit of kgCO2e/kg carcass weight, which is typically higher than live weight, using a conversion factor. The emission factors for the rest of the ingredients were sourced from Carbon Trusts' external databases Ecoinvent 3.8 and Agri-footprint 5.0. The ingredient percentages for Chicken Nuggets, Chicken Patties and Chicken Wings were taken from the Fully Cooked Chicken Nuggets, Fully Cooked Breaded Chicken Patties and the Buffalo Chicken Hot Wings respectively, all produced by Tyson Brand (*Table **10**, Table **11**,* and *Table **12*** respectively). All ingredients presented as 2% or less of the recipe were assumed to be seasoning.

Just like for the beef analysis, the analysis for the chicken products was also determined by the economic allocation of the different pieces of meat. This was based on previous research by Carbon Trust and FITR (*Table **9***).

Most published research concerning the environmental impacts of broiler poultry production is limited to assessments of on-farm gaseous and nutrient emissions. In this project, ISO-compliant Life Cycle Assessment was used to predict the broader, macroscale environmental impacts of the material and energy inputs and emissions along the US broiler supply chain. It was found that feed provision accounts for 80% of supply chain energy use, 82% of greenhouse gas emissions, 98% of ozone depleting emissions, 96% of acidifying emissions and 97% of eutrophic emissions associated with the cradle-to-farm gate production of broiler poultry. On-farm inputs and emissions, related to heating and ventilation contribute on average only 9% of these impacts. These results underscore the fallacy of "landless farming" and the importance of full supply-chain environmental management for improving sustainability in the US poultry industry.

*Table 9**: Economic allocation of different chicken cuts (internal CT source)***

Cut	Kg/carcass	Price/kg	Economic Value
Breast - B/S	0.599	£2.41	£1.44
Thighs - B/S	0.225	£1.63	£0.37
Ground	0.195	£1.12	£0.22
Skins	0.200	£0.89	£0.18
Remaining meat	0.778	£1.92	£1.50

Table 10: Emissions of ingredients needed to make 1kg of chicken nuggets in the US

	Amount in 1kg of chicken nuggets (kg)	Emission factor ($kgCO_2e/kg$)	$kgCO_2e$
Chicken breast	0.45	4.75	2.14
Water	0.30	0.00	0.00
Wheat flour	0.20	1.35	0.27
Seasonings	0.05	1.20	0.06
TOTAL			**2.465**

Table 11: Emissions of ingredients needed to make 1kg of chicken patties in the US

	Amount in 1kg of chicken nuggets (kg)	Emission factor ($kgCO_2e/kg$)	$kgCO_2e$
Chicken breast	0.45	4.75	2.14
Water	0.30	0.00	0.00
Wheat flour	0.20	1.35	0.27
Seasonings	0.05	1.20	0.06
TOTAL			**2.465**

Table 12: Emissions of ingredients needed to make 1kg of chicken wings in the US

	Amount in 1kg of chicken wings (kg)	Emission factor ($kgCO_2e/kg$)	$kgCO_2e$
Chicken wing sections	0.60	3.78	2.27
Water	0.20	0.00	0.00
Chili peppers	0.10	1.20	0.12
Seasonings	0.10	1.20	0.12
TOTAL			**2.509**

4.2.2. Land Use

In this analysis land use has only been considered for ingredients needed, and not for any other parts of the value chain.

The land use requirements for chicken can vary depending on the production system. The land needed for chicken in the United States has been determined by Poore & Nemecek, 2018. As shown in section 4.1.1 for carbon emissions, there is the need to do an economic allocation based on the animal cut considered.

Land use factors for the other ingredients were sourced from external databases, namely Ecoinvent 3.8 and Agri-Footprint 5.0. Land use for ingredients in each recipe can be found below in *Table **13***, *Table **14***, *Table **15***.

Table 13: Land use in the production of 1kg of chicken nuggets

	Amount in 1kg of chicken nuggets (kg)	Land footprint (m^2a/kg)	Land footprint (m^2a)
Chicken breast	0.45	21.48	9.67
Water	0.30	0.00	0.00
Wheat flour	0.20	1.89	0.38
Seasonings	0.05	10.26	0.51
TOTAL			**10.56**

Table 14: Land use in the production of 1kg of chicken patties

	Amount in 1kg of chicken patties (kg)	Land footprint (m^2a/kg)	Land footprint (m^2a)
Chicken breast	0.45	21.48	9.67
Water	0.30	0.00	0.00
Wheat flour	0.20	1.89	0.38
Seasonings	0.05	10.26	0.51
TOTAL			**10.56**

Table 15: Land use in the production of 1kg of chicken wings

	Amount in 1kg of chicken wings (kg)	Land footprint (m^2a/kg)	Land footprint (m^2a)
Chicken wing sections	0.60	17.12	10.27
Water	0.20	0.00	0.00
Chili peppers	0.10	10.26	1.03
Seasonings	0.10	10.26	1.03
TOTAL			**12.33**

4.2.3. Water Use

Like the land footprint of chicken, the water footprint can vary depending on production system with different ratios of green, blue, and grey water being used for different production systems. For the reasons discussed in section 2.3 of this report, the blue water footprint is considered the most relevant to be used for the comparison. Therefore, the green and grey water footprints from this system were not included in the analysis.

The values used for the water usage of beef come from the UNESCO-IHE Institute for Water Education report by Mekonnen & Hoekstra (2010).

Blue water footprint factors for the other ingredients were sourced from external databases, namely Ecoinvent 3.8 and Agri-Footprint 5.0. Water use for ingredients in each recipe can be found below in *Table **16**, Table **17**, Table **18***.

Table 16: *Water use in the production of 1kg of chicken nuggets*

	Amount in 1kg of chicken nuggets (kg)	Water footprint (m^3/kg)	Water Footprint (m^3)
Chicken breast	0.45	0.22	0.10
Water	0.30	0.00	0.00
Wheat flour	0.20	0.02	0.00
Seasonings	0.05	0.00	0.00
TOTAL			**0.11**

Table 17: Water use in the production of 1kg of chicken patties

	Amount in 1kg of chicken patties (kg)	Water footprint (m^3/kg)	Water Footprint (m^3)
Chicken breast	0.45	0.22	0.10
Water	0.30	0.00	0.00
Wheat flour	0.20	0.02	0.00
Seasonings	0.05	0.00	0.00
TOTAL			**0.11**

Table 18: Water use in the production of 1kg of chicken wings

	Amount in 1kg of chicken wings (kg)	Water footprint (m^3/kg)	Water Footprint (m^3)
Chicken wing sections	0.60	0.18	0.11
Water	0.20	0.00	0.00
Chili peppers	0.10	0.00	0.00
Seasonings	0.10	0.00	0.00
TOTAL			**0.11**

4.3. Pork

In the Pork category, two pork products were compared to MSF products: pork sausage and bacon strips. These pork-based products contain a variety of other ingredients (salt, sugar, pepper) which are also accounted for in the analysis.

Pigs produce several types of valuable outputs corresponding to different masses and economic values. Research by Verge et. Al (2016) shows the co-products allocation factors in terms of mass and economic value (see *Table 19 b*elow). This table was used to calculate the emissions of the meat used for bacon strips and for pork sausages which are primal cuts, therefore have higher economic value and so are allocated a higher percentage of emissions from the whole animal carcass.

Table 19: Canadian Pork industry allocation method (Verge et al, 2016)

Cut	Mass (%)	Economic (%)	No allocation (%)
Primal cuts	**65**	**93.6**	**100**
Rendering products	**31.1**	**4.25**	**100**
Offal	**3.9**	**2.15**	**100**
Total	**100**	**100**	**300**

4.3.1. Carbon

The result for carbon comes from the sum of kgCO2e emissions associated with each ingredient in the recipe. Emissions from each ingredient were calculated using a specific ingredient emission factor, multiplied by the percentage contribution of the ingredient to the recipe. The emission factor for pork was calculated based on the average carcass weight for pork in the United States and its corresponding emission factor. The average carcass weight for pork was based on 2020 pork Yield/Carcass weight values by the Food and Agriculture Organization of the United Nations (FAO) on crops and livestock products. The emission factor for the average pig (live weight) is based on a study by Pelletier (2010) and was then converted to a consistent functional unit of kgCO2e/kg carcass weight, which is typically higher than live weight, using a conversion factor. The emission factors for the rest of the ingredients were sourced from the Ecoinvent 3.8 and Agri-footprint 5.0 databases. The brands originally used as references to build the meat-based products emissions factors, Jimmy Dean Fully Cooked Original Pork Sausage Links and Oscar Mayer Bacon, did not disclose ingredient percentages publicly. Therefore, typical homemade recipes were used for as proxies for the quantities of ingredients used, considering 89% meat content for bacon strips and 96% meat for the pork sausages.

As for poultry, feed and manure management can have large influences on the carbon footprint for pork. For the context of this analysis, we took a conservative approach, considering the systems that would produce the lowest emissions for the meat products. For this reason, several assumptions were made:

- all products were assumed to be transported and stored chilled rather than frozen
- set distances of 100km from farm to factory, and 100km from factory to supermarkets were used for transport emissions calculations
- length of storage of meat at retail distribution centre was assumed to be 2 days

- length of storage of meat at supermarket was assumed to be 7 days
- length of storage of meat in domestic fridges was assumed to be 3 days
- meat waste throughout the value chain was obtained from a research paper that accounted for food waste through each process stage from cradle-to-grave (consumption, manufacturing, distribution, primary production, and post-harvest) (M. Karwowska, 2021).

Table 20: Emissions of ingredients needed to make 1kg of pork sausages in the US

	Amount in 1kg of pork sausage (kg)	Emission factor ($kgCO_2e/kg$)	$kgCO_2e$
Pork	0.96	8.44	8.14
Herb mix	0.01	1.20	0.01
Sugar	0.01	0.77	0.01
Salt	0.01	0.04	0.00
Red pepper flakes	0.00	1.20	0.00
Ground black pepper	0.00	1.20	0.00
TOTAL			**8.17**

Table 21: Emissions of ingredients needed to make 1kg of bacon strips in the US

	Amount in 1kg of bacon strips (kg)	Emission factor ($kgCO_2e/kg$)	$kgCO_2e$
Pork belly	0.89	8.44	7.49
Brown sugar	0.08	0.77	0.06
Salt	0.02	0.04	0.00
Ground black pepper	0.01	1.20	0.01
Curing salt	0.00	0.04	0.00
TOTAL			**7.56**

4.3.2. Land Use

In this analysis land use has only been considered for ingredients needed, and not for any other parts of the value chain.

The land use requirements for chicken can vary depending on the production system. The land use associated with pork in the United States is based on a study by Thoma, 2015.

Land use factors for the other ingredients were sourced from external databases, namely Ecoinvent 3.8 and Agri-Footprint 5.0. Land use for ingredients in each recipe can be found below in *Table **22**, Table **23***.

Table 22: Land use in the production of 1kg of pork sausage in the US

	Amount in 1kg of pork sausage (kg)	Land footprint (m^2a/kg)	Land footprint (m^2a)
Pork	0.96	14.01	13.52
Herb mix	0.01	10.26	0.10
Sugar	0.01	0.59	0.01
Salt	0.01	-	-
Red pepper flakes	0.00	10.26	0.01
Ground black pepper	0.00	10.26	0.04
TOTAL			13.67

Table 23: Land use in the production of 1kg of bacon strips in the US

	Amount in 1kg of bacon strips (kg)	Land footprint (m^2a/kg)	Land footprint (m^2a)
Pork belly	0.89	14.01	12.44
Brown sugar	0.08	0.59	0.05
Salt	0.02	-	-
Ground black pepper	0.01	10.26	0.05
Curing salt	0.00	-	-
TOTAL			12.54

4.3.3. Water Use

Like the land footprint of pork, the water footprint can vary depending on production system with different ratios of green, blue, and grey water being used for different production systems. For the reasons discussed in section 2.3 of this report, the blue water footprint is considered the most relevant to be used for the comparison. Therefore, the green and grey water footprints from this system were not included in the analysis.

The values used for the water usage of beef come from the UNESCO-IHE Institute for Water Education report by Mekonnen & Hoekstra (2010).

Blue water footprint factors for the other ingredients were sourced from external databases, namely Ecoinvent 3.8 and Agri-Footprint 5.0. Water use for ingredients in each recipe can be found below in *Table **24**, Table **25***.

Table 24: Water use in the production of 1kg of pork sausages

	Amount in 1kg of pork sausage (kg)	Water footprint (m^3/kg)	Water Footprint (m^3)
Pork	0.96	0.66	0.64
Herb mix	0.01	0.00	0.00
Sugar	0.01	0.15	0.00
Salt	0.01	0.00	0.00
Red pepper flakes	0.00	0.00	0.00
Ground black pepper	0.00	0.00	0.00
TOTAL			**0.64**

Table 25: Water use in the production of 1kg of bacon strips

	Amount in 1kg of bacon strips (kg)	Water footprint (m^3/kg)	Water Footprint (m^3)
Pork belly	0.89	0.66	0.59
Brown sugar	0.08	0.00	0.00
Salt	0.02	0.15	0.00
Ground black pepper	0.01	0.00	0.00
Curing salt	0.00	0.00	0.00
TOTAL			**0.59**

5. Footprint comparisons

5.1. Summary of average footprints

The following sections present the results of the footprinting and comparison analysis. Section 5.2 is a summary of the average footprints for the comparator protein products used in the average comparison analysis. Section 5.2 are the results of the comparison analysis conducted in stage 1.

5.2. Footprint comparison of competing products

5.2.1. Griller's Burger Style Veggie Crumbles vs Ground Beef

MSF's Grillers Burger Style Veggie Crumbles is compared against the footprints of ground beef (see *Table* 26). Research suggests that ground beef is made with beef primal cuts, so the emission factors associated with these were used for comparison. An economic approach was used for the allocation of emissions to the beef cuts. From all the MSF products that are equivalent to ground beef, Grillers Burger Veggie Crumbles was chosen after preliminary research that determined this to be the product with the highest footprint. In terms of the meat footprint, assumptions were made for a best-case scenario (e.g., local meat, small period between processing and consumption…) to ensure we are comparing the MSF product (equivalent to ground beef) with the highest footprint, with the version of ground beef that has the lowest footprint. While the carbon emissions were calculated for the entire value chain (including emissions from ingredients, packaging, transportation, storage, refrigeration, food waste…), the land and water footprints were calculated for the ingredients used only, as the main land and water impacts occur in the supply chain of the ingredients i.e., the land and water needed to cultivate crops. Unlike carbon, no uniform standards exist to quantify land or water impacts on a product level. Focusing on the most material impacts helped identify the comparisons for these criteria more efficiently.

Table 26: CO_2 emissions, land and water use value comparison between MSF's Grillers Burger Style Veggie Crumbles and ground beef for the US per 60g of product

	Emissions ($lbsCO_2e$)			**Land use (ft^2a)**			**Water use (US gallons)**		
	MSF	Meat	MSF products emit x% less CO2e	MSF	Meat	MSF products emit x% less CO2e	MSF	Meat	MSF products emit x% less CO2e
Grillers Burger Style Veggie Crumbles / Ground Beef	0.29	5.58	94.9%	2.58	86.03	97.0%	0.68	14.50	95.3%

5.2.2. America's Original Veggie Dog vs Beef Sausage

MSF's America's Original Veggie Dog is compared against the footprints of beef sausage (see *Table 27*). Research suggests that beef sausage is made with beef primal cuts, so the emission factors associated with these were used for comparison. An economic approach was used for the allocation of emissions to the beef cuts. From all the MSF products that are equivalent to beef sausage, America's Original Veggie Dog was chosen after preliminary research that determined this to be the product with the highest footprint. In terms of the meat footprint, assumptions were made for a best-case scenario (e.g., local meat, small period between processing and consumption…) to ensure we are comparing the MSF product (equivalent to ground beef) with the highest footprint, with the version of ground beef that has the lowest footprint. While the carbon emissions were calculated for the entire value chain (including emissions from ingredients, packaging, transportation, storage, refrigeration, food waste…), the land and water footprints were calculated for the ingredients used only, as the main land and water impacts occur in the supply chain of the ingredients i.e., the land and water needed to cultivate crops. Unlike carbon, no uniform standards exist to quantify land or water impacts on a product level. Focusing on the most material impacts helped identify the comparisons for these criteria more efficiently.

Table 27: CO_2 emissions, land and water use value comparison between MSF's America's Original Veggie Dog and beef sausage for the US per 60g of product

	Emissions ($lbsCO_2e$)			**Land use (ft^2a)**			**Water use (US gallons)**		
	MSF	Meat	MSF products emit x% less CO2e	MSF	Meat	MSF products emit x% less CO2e	MSF	Meat	MSF products emit x% less CO2e
America's Original Veggie Dog / Beef Sausage	0.23	5.47	95.8%	1.09	84.07	98.7%	0.03	17.75	99.8%

5.2.3. Chik Patties Original vs Chicken Patties

MSF's Chik Patties Original is compared against the footprints of chicken patties (see *Table 28*). Research suggests that chicken patties are made with chicken primal cuts, so the emission factors associated with these were used for comparison. An economic approach was used for the allocation of emissions to the chicken cuts. From all the MSF products that are equivalent to chicken patties, Chik Patties Original was chosen after preliminary research that determined this to be the product with the highest footprint. In terms of the meat footprint, assumptions were made for a best-case scenario (e.g., local meat, small period between processing and consumption…) to ensure we are comparing the MSF product (equivalent to chicken patties) with the highest footprint, with the version of chicken patties that has the lowest footprint. While the carbon emissions were calculated for the entire value chain (including emissions from ingredients, packaging, transportation, storage, refrigeration, food waste…), the land and water footprints were calculated for the ingredients used only, as the main land and water impacts occur in the supply chain of the ingredients i.e., the land and water needed to cultivate crops. Unlike carbon, no uniform standards exist to quantify land or water impacts on a product level. Focusing on the most material impacts helped identify the comparisons for these criteria more efficiently.

Table 28: CO_2 emissions, land and water use value comparison between MSF's Chik Patties and chicken patties for the US per 60g of product

	Emissions ($lbsCO_2e$)			Land use (ft^2a)			Water use (US gallons)		
	MSF	Meat	MSF products emit x% less CO2e	MSF	Meat	MSF products emit x% less CO2e	MSF	Meat	MSF products emit x% less CO2e
Chik Patties Original / Chicken Patties	0.34	0.54	37.7%	0.90	6.82	86.8%	0.22	1.67	86.9%

5.2.4. Buffalo Wings CN vs. Chicken Wings

MSF's Buffalo Wings CN is compared against the footprints of chicken wings (see *Table 29*). Research suggests that chicken wings are made with the wing section of a chicken, so the emission factors associated with these were used for comparison. An economic approach was used for the allocation of emissions to the chicken cuts. From all the MSF products that are equivalent to chicken wings, Buffalo Wings CN was chosen after preliminary research that determined this to be the product with the highest footprint. In terms of the meat footprint, assumptions were made for a best-case scenario (e.g., local meat, small period between processing and consumption…) to ensure we are comparing the MSF product (equivalent to chicken wings) with the highest footprint, with the version of chicken wings that has the lowest footprint. While the carbon emissions were calculated for the entire value chain (including emissions from ingredients, packaging, transportation, storage, refrigeration, food waste…), the land and water footprints were calculated for the ingredients used only, as the main land and water impacts occur in the supply chain of the ingredients i.e., the land and water needed to cultivate crops. Unlike carbon, no uniform standards exist to quantify land or water impacts on a product level. Focusing on the most material impacts helped identify the comparisons for these criteria more efficiently.

Table 29: CO_2 emissions, land and water use value comparison between MSF's Buffalo Wings CN and chicken wings for the US per 60g of product

	Emissions ($lbsCO_2e$)			Land use (ft^2a)			Water use (US gallons)		
	MSF	Meat	MSF products emit x% less CO2e	MSF	Meat	MSF products emit x% less CO2e	MSF	Meat	MSF products emit x% less CO2e
Buffalo Wings CN / Chicken Wings	0.35	0.58	39.6%	0.88	7.96	89.0%	0.18	1.70	89.3%

5.2.5. Chik'n Nuggets CN (Vegan) vs. Chicken Nuggets

MSF's Chik'n Nuggets CN (Vegan) is compared against the footprints of chicken nuggets (see *Table 30*). Research suggests that chicken nuggets are made with chicken primal cuts, so the emission factors associated with these were used for comparison. An economic approach was used for the allocation of emissions to the chicken cuts. From all the MSF products that are equivalent to chicken nuggets, Chik'n Nuggets CN (Vegan) was chosen after preliminary research that determined this to be the product with the highest footprint. In terms of the meat footprint, assumptions were made for a best-case scenario (e.g., local meat, small period between processing and consumption…) to ensure we are comparing the MSF product (equivalent to chicken nuggets) with the highest footprint, with the version of chicken nuggets that has the lowest footprint. While the carbon emissions were calculated for the entire value chain (including emissions from ingredients, packaging, transportation, storage, refrigeration, food waste…), the land and water footprints were calculated for the ingredients used only, as the main land and water impacts occur in the supply chain of the ingredients i.e., the land and water needed to cultivate crops. Unlike carbon, no uniform standards exist to quantify land or water impacts on a product level. Focusing on the most material impacts helped identify the comparisons for these criteria more efficiently.

Table 30: CO_2 emissions, land, and water use value comparison between MSF's Chik'n Nuggets CN (Vegan) and chicken wings for the US per 60g of product

	Emissions (lbsCO_2e)			**Land use (ft^2a)**			**Water use (US gallons)**		
	MSF	Meat	MSF products emit x% less CO2e	MSF	Meat	MSF products emit x% less CO2e	MSF	Meat	MSF products emit x% less CO2e
Chik'n Nuggets CN (Vegan) / Chicken Nuggets	0.36	0.54	33.8%	0.94	6.82	86.1%	0.18	1.67	89.2%

5.2.6. Veggie Breakfast Bacon Strips vs Bacon Strips

MSF's Veggie Breakfast Bacon Strips is compared against the footprints of bacon strips (see *Table 31*). Research suggests that bacon strips are made with pork primal cuts, so the emission factors associated with these were used for comparison. An economic approach was used for the allocation of emissions to the pork cuts. From all the MSF products that are equivalent to bacon strips, Veggie Breakfast Bacon Strips was chosen after preliminary research that determined this to be the product with the highest footprint. In terms of the meat footprint, assumptions were made for a best-case scenario (e.g., local meat, small period between processing and consumption…) to ensure we are comparing the MSF product (equivalent to bacon strips) with the highest footprint, with the version of bacon strips that has the lowest footprint. While the carbon emissions were calculated for the entire value chain (including emissions from ingredients, packaging, transportation, storage, refrigeration, food waste…), the land and water footprints were calculated for the ingredients used only, as the main land and water impacts occur in the supply chain of the ingredients i.e., the land and water needed to cultivate crops. Unlike carbon, no uniform standards exist to quantify land or water impacts on a

product level. Focusing on the most material impacts helped identify the comparisons for these criteria more efficiently.

Table 31: CO_2 emissions, land and water use value comparison between MSF's Veggie Breakfast Bacon Strips and bacon strips for the US per 60g of product

	Emissions ($lbsCO_2e$)			Land use (ft^2a)			Water use (US gallons)		
	MSF	Meat	MSF products emit x% less CO2e	MSF	Meat	MSF products emit x% less CO2e	MSF	Meat	MSF products emit x% less CO2e
Veggie Breakfast Bacon Strips / Bacon Strips	0.40	1.25	68.2%	2.13	8.10	73.7%	0.42	9.40	95.5%

5.2.7. MSF Italian Style Crumbles vs Pork Sausage

MSF's Italian Style Crumbles is compared against the footprints of pork sausage (see *Table 32*). Research suggests that pork sausage is made with pork primal cuts, so the emission factors associated with these were used for comparison. An economic approach was used for the allocation of emissions to the pork cuts. From all the MSF products that are equivalent to pork sausage, Italian Style Crumbles was chosen after preliminary research that determined this to be the product with the highest footprint. In terms of the meat footprint, assumptions were made for a best-case scenario (e.g., local meat, small period between processing and consumption…) to ensure we are comparing the MSF product (equivalent to pork sausage) with the highest footprint, with the version of pork sausage that has the lowest footprint. While the carbon emissions were calculated for the entire value chain (including emissions from ingredients, packaging, transportation, storage, refrigeration, food waste…), the land and water footprints were calculated for the ingredients used only, as this is where the main land and water impacts occur i.e., the land and water needed to cultivate crops. Unlike carbon, no uniform standards exist to quantify land or water impacts on a product level. Focusing on the most material impacts for land and water helped identify the comparisons from these criteria more efficiently.

Table 32: CO_2 emissions, land and water use value comparison between MSF's Italian Style Crumbles and pork sausage for the US per 60g of product

	Emissions ($lbsCO_2e$)			Land use (ft^2a)			Water use (US gallons)		
	MSF	Meat	MSF products	MSF	Meat	MSF products	MSF	Meat	MSF products

			emit x% less CO2e			emit x% less CO2e			emit x% less CO2e
MSF Italian Style Crumbles / Pork Sausage	0.32	1.33	76.0%	1.86	8.83	79.0%	0.34	10.18	96.7%

Appendix 1: Assumptions

Category	Tab	Topic	Assumptions made	Source
MSF SKUs	Ingredients (Upstream)	Ingredient EF	As MSF has 254 different ingredients, we tried to assign an appropriate Emission Factor to each of them. However, some very ingredients required very obscure EFs. The difficulty of finding these specific EFs and the sheer number of different ingredients made it hard to assign each ingredient with a unique EF. In the case of "Flavouring", "Colouring", "Spice" and some "Food Chemicals" we assigned an average EF that was based on the EF for "Mustard seed, at farm". This EF seemed appropriate because it closely resembles the average EF of the other ingredients. The total weight of the ingredients that use this generic EF is no more than 4% of the total ingredient weight.	
MSF SKUs	Ingredients (Upstream)	Recipes	When the recipe is totalling more than 100%, that is due to evaporation in the cooking process.	
MSF SKUs	Ingredients Lookups	Lookup distance	Since there are many different suppliers, the distance was chosen according to the distance travelled from the main supplier for each ingredient from the VC model.	
MSF SKUs	Ingredients (Upstream)	Ingredient quantity	Some of the recipes exceed 100%, that's due to evaporation.	
MSF SKUs	Packaging	Packaging EoL EF	Assumption that paper/cardboard packaging is recyclable.	
MSF SKUs	Packaging	Packaging Waste rates	Assumption that 5% of packaging material was wasted at manufacturing site. So, this 5% from Packaging Waste (End of Life) is going to be assigned in Category 5. While the rest of the 95% that is used for sold product packaging will be allocated to Category 12.	
MSF SKUs	Outbound transport and storage	Food waste	The Carbon Trust team has assumed a 1/3rd of food waste was wasted at retail, 1/3rd at customer's home before being cooked, 1/3rd at customer's home after being cooked.	
MSF SKUs	Downstream Lookups	Days in Home Refrigeration	Assumption that products stay 14 days in domestic freezer before being cooked (aligned with other Kellogg's brand project assumption)	
MSF SKUs	Downstream Lookups	Home Refrigeration EF	There is no data for the home refrigeration of the products once they have been bought. For the home refrigeration emission factor, a series of assumptions had to be made to perform the analysis with the help of Footprint Expert. The electricity and gas emission factor for USA were chosen as an average across all countries that MSF sells their products in. More specifically it was assumed that: the average temperature of the home is 18°C, while being frozen for the entirety of the duration, they are only removed once to be cooked and the full portion is cooked at once. The average product is 1kg, with 908 grams of vegetables with a density of 0.97 t/m3 and packaging of 92grams of solid plastic with density of 0.94 t/m3.	
MSF SKUs	Downstream Lookups	Cooking emission factor	The average cooking emission factor for all products was calculated using data for the 7 SKUs analysed in the SKU model	
MSF SKUs	Downstream Lookups	Cooking emissions	The Carbon Trust team calculated cooking emissions based on the assumption that the entire box of SKU is cooked each time.	
MSF SKUs	Downstream Lookups	RDC EF	For the Retail Distribution Centre emissions, a series of assumptions had to be made to perform the analysis with the help of Footprint Expert. Even though MSF sells their products in several countries we have calculated an average EF for this stage based on the electricity and gas emission factor for USA. It is assumed that during the RDC phase the products are packed in "Standard Euro Pallets (1x1.2x1)" with a total weight of 1,500kg per pallet.	
MSF SKUs	Downstream Lookups	Days at inventory (RDC)	The average number of days at inventory for the period was calculated using data for the 7 SKUs analysed in the SKU model	
MSF SKUs	Downstream Lookups	Retail EF	For the retail emission factor, a series of assumptions had to be made to perform the analysis with the help of Footprint Expert. The electricity and gas emission factor for USA were chosen as an average across all countries that MSF sells their products in. More specifically for the frozen MSF products it was assumed that: the average temperature of store is 18°C. It was agreed with the MSF team that storage in supermarket freezers is 5%-95% open-closed doors. The average product is 1kg, with 908 grams of vegetable with a density of 0.97 t/m3 and packaging of 92 grams of solid plastic with density of 0.94 t/m3. The ingredient to packaging ratio was based on the average between the SKUs analysed in the SKU tool.	
MSF SKUs	Downstream Lookups	Days at retail	Assumption that products stay 7 days at retail before being sold to consumers (aligned with other Kellogg's brand project assumption)	

MSF SKUs	Downstream Lookups	Outbound transportation - Customer pick-ups	MSF described customer pick-ups as being subsidised by Kellogg, therefore these emissions would fall under category 4 (transport that is paid for by the company) rather than category 9 (transport that is paid for by the customer) even if in this case it's the customers that make the trip to pick up the products.	
MSF SKUs	Downstream Lookups	Outbound transport emission factors	For outbound transport described as 'customer pickup', 'LTL', 'Intermodal' or 'truck expedited', an average laden emission factor was used in calculations as a default, conservative approach, as no information or evidence of the load was provided.	
MSF SKUs	Downstream Lookups	Outbound transport emission factors	For outbound transport described as full truckload, a full truckload emission factor was used in calculations	
MSF SKUs	Downstream Lookups	Outbound transport calculations	The provided dataset for outbound transportation and other downstream categories included 2 legs of transport: transport from manufacturing sites to RDC and transport from RDC to retail. For rows containing data on transport between the manufacturing sites and RDC, emissions were calculated for the transport and storage at RDC. For rows containing data on transport between RDCs and retail, emissions were calculated for the transport, storage at retail, domestic storage in consumers' freezer, cooking, and waste.	
MSF SKUs	Waste	End-of-Life of waste materials	All non-recyclable waste is assumed to go to landfill, and emissions factors for landfilled waste are chosen depending on the waste type.	
MSF SKUs	Waste	Recycled content - End-of-Life	Assumed that 35% of recyclable material is recycled. Source : https://www.greenmatters.com/p/what-percent-recycling-actually-gets-recycled	
MSF SKUs	Ingredients Lookups	Sea distances	Used https://sea-distances.org/ to calculate sea distances. Given that both Zanesville and Request Foods Greenly are on the east coast, the New Jersey port was chosen as it is the biggest and closest port. For the origin countries, the closest port to the manufacturing company was chosen.	
MSF SKUs	Ingredients Lookups	Distances within the same town	Assumed distance between Holland and Georgetown for transport within Holland, MI (30 min car drive). Assumed distance between North Zanesville and South Zanesville for transport within Zanesville.	
MSF SKUs	Organisational	MSF Data - Natural Gas	Assumed the natural gas used in 2020 is the same as that used in 2019.	
Meat	Product level meat calcs	Packaging weight per SKU	Assumption that packaging weight is 3.5% of the entire product weight	Pongrácz, Eva. (2007). The Environmental Impacts of Packaging. 10.1002/9780470168219.ch9.
Meat	Product level meat calcs	Packaging materials	Assumption that packaging is 100% average plastic for all meat products	
Meat	Product level meat calcs	Packaging materials	Density of plastic used is 1.09g/cm3	Link
Meat	Product level meat calcs	Transport from supplier to plant	Assumption that the meat is sourced locally and distance to plant is 100km	
Meat	Product level meat calcs	Transport to RDC and retail	Assumption that meat is sold locally and distance to RDC and supermarket is 100km with a 50/50 split.	
Meat	Product level meat calcs	Transport emission factor	Assumption that meat is refrigerated during transport	
Meat	Product level meat calcs	Average cooking guidelines for pork sausage	Assumption that the product is cooked to 160 °F according to average guidelines for uncooked sausages	Link
Meat	Product level meat calcs	Average cooking guidelines for bacon strips	Conservative assumption that the product is cooked to 160 °F according to average guidelines for pork meat sauteing	Link

Meat	Product level meat calcs	Average cooking guidelines for ground beef	Needs to be cooked to 160ºF for around 15 minutes	Link
Meat	Product level meat calcs	Average cooking guidelines for beef sausage	Product is cooked for 9 minutes in 1 cup of boiling water	Link
Meat	Product level meat calcs	Average cooking guidelines for chicken nuggets	Product is cooked in the oven for 20 minutes at 190C	Link
Meat	Product level meat calcs	Average cooking guidelines for chicken patties	Product is cooked in the oven for 10 minutes at 218C	Link
Meat	Product level meat calcs	Average cooking guidelines for chicken wings	Product is cooked in the oven for 25 minutes	Link
Meat	Product level meat calcs	Average cooking guidelines for pork sausage	Product is cooked in the oven for 12 minutes	Link
Meat	Product level meat calcs	Average cooking guidelines for bacon strips	Product is cooked in the oven for 12 minutes	Link
Meat	Product level meat calcs	Food waste at end of life	Only chicken wings have a waste % after cooking as it is the only product with parts that are non-edible	
Meat	Product level meat calcs	Food waste at end of life	Waste of chicken wings post cooking is equal to 46% as that is the bone %	Link
Meat	Product level meat calcs	End of life	Meat cannot be composted; therefore, it is not an option in EOL calculations	
Meat	Downstream Lookups	Manufacturing emissions	519 g CO2 eq. per 1 kg according to study in a medium-sized farm in Poland	Link
Meat	Product level meat calcs	RDC	For the Retail Distribution Centre and Retail emissions a series of assumptions had to be made to perform the analysis with the help of Footprint Expert. Even though MSF sells their products in the US we have calculated an average EF for this stage based on the electricity and gas emission factor for UK. It is assumed that during the RDC phase the products are packed in "Standard Euro Pallets (1x1.2x1)" with a total weight of 1,500kg per pallet. It is also assumed to take max 2 days before meat is at supermarket (for chilled meat) as outlined by the source provided, based in the US.	Link
Meat	Product level meat calcs	Retail	For the Retail Distribution Centre and Retail emissions a series of assumptions had to be made to perform the analysis with the help of Footprint Expert. Even though MSF sells their products in the US we have calculated an average EF for this stage based on the electricity and gas emission factor for UK. It is assumed that the chilled products stay for 7 days. The last assumption is based on the PEFCR (Product Environmental Footprint Category Rules) Guidance for red meat.	PEFCR
Meat	Product level meat calcs	Home Refrigeration	There is no data for the home refrigeration of the products once they have been bought. For the home refrigeration emission factor, a series of assumptions had to be made to perform the analysis with the help of Footprint Expert. The electricity and gas emission factor for UK were chosen as an average across all countries that Dawn Meats sells their products in. More specifically it was assumed that: the average temperature of the home is 18°C, the items stay 3 days on average before being cooked while being chilled or frozen for the entirety of the duration, they are only removed once to be cooked and the full portion is cooked at once. The average product is 1kg, with 996.5 grams of meat with a density of 0.38 t/m3 and packaging of 3.5 grams of solid plastic with density of 1.09 t/m3. The home refrigeration assumption is based on the PEFCR (Product Environmental Footprint Category Rules) Guidance for red meat. Lastly, some of the Dawn Meats products are sold in the Foodservice sector. We are using the same EF for home refrigeration for this stage. Although a restaurant might have more efficient chillers/freezers than an average home.	PEFCR

Meat	Product level meat calcs	Food waste	The assumption on meat being wasted at various stages of the Value Chain is based on "Food Loss and Waste in Meat Sector—Why the Consumption Stage Generates the Most Losses?" by Karwowska at al (2021). These are calculated ratios based on the below information contained in pages 6-7. 23% of meat is wasted across all stages of the Value Chain. 23.5% of the wasted meat is wasted during manufacturing, primary production and post-harvest (0.23*0.235=5.4%) 12 % of the wasted meat is wasted during distribution (0.23*0.12=0.0276 or 2.76%) 64% of meat waste takes place during the use phase (consumption phase). (0.23*0.64=0.1472 or 14.72%) More specifically for this we will also assume that half of this waste takes place BEFORE the meat is cooked (0.0736 or 7.36%) and the other half AFTER it has been cooked. The calculations made for meat waste in the value chain are not the standard calculations made by CT for other projects due to source used. This is relevant if this model is ever to be updated by CT. https://www.mdpi.com/2071-1050/13/11/6227/pdf	

Appendix 2: Uncertainty analysis results

The graphs below show the uncertainty analysis carried out between the MSF and meat products. Due to the accurate and precise data given by MSF we have attributed a 5% error to the MSF products. As the meat analysis was made based on secondary data, a higher uncertainty of 10% was attributed.

For the beef comparisons the difference between the highest error bar for MSF products and the lowest bar for meat products is very high. Showing there is a very high confidence that in any case the MSF products beef equivalent products will have lower emissions than the beef products.

For the chicken products the difference between the highest MSF error bar and the lowest meat error bars are significantly smaller than the ones for beef, meaning the products differ (as the error bars do not cross each other), but the difference is less relevant.

For the pork products the difference between the highest MSF error bar and the lowest meat error bars is larger than for chicken products, but still significantly lower than for beef products, meaning the products differ (as the error bars do not cross each other), but the difference is not as obvious as for the beef comparison.

Figure 1: Uncertainty analysis Griller's Burger Style Veggie Crumbles vs US Ground Beef

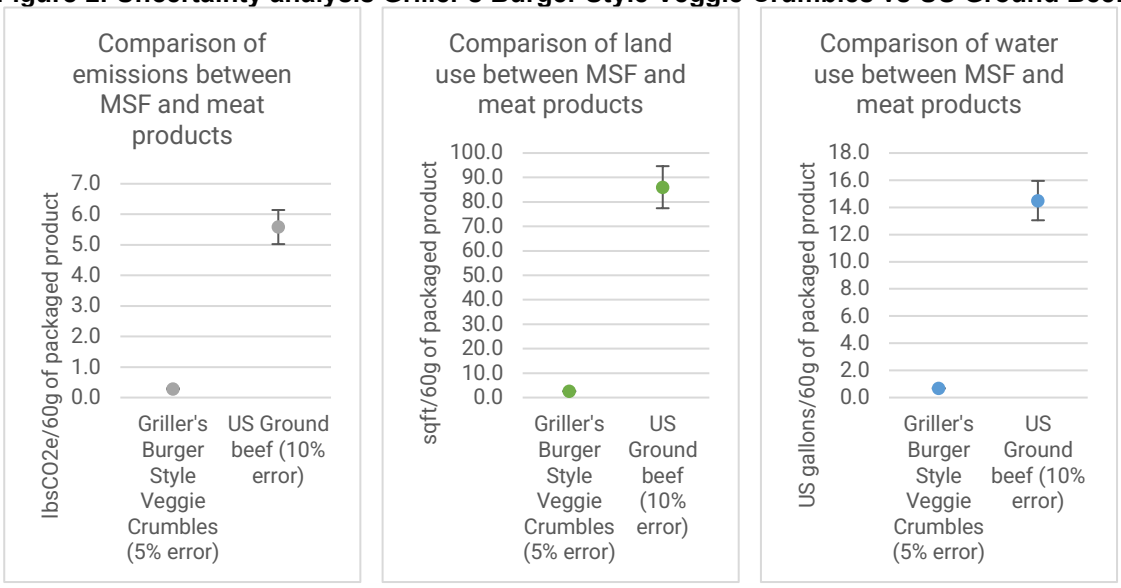

Figure 2: Uncertainty analysis America's Original Veggie Dog vs US Beef Sausage

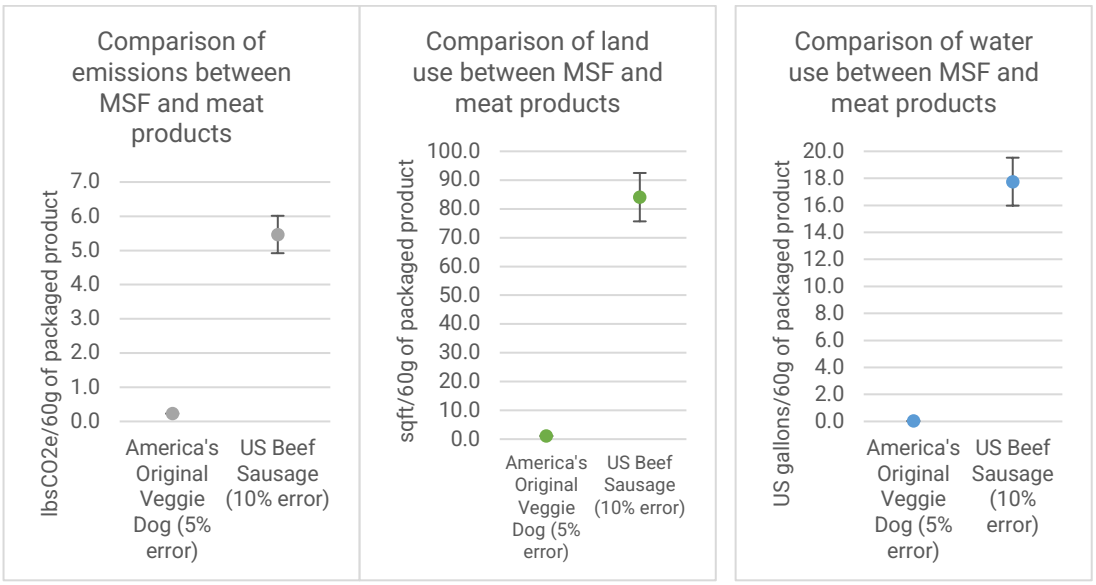

Figure 3: Uncertainty analysis Chik Patties Original vs US Chicken Patties

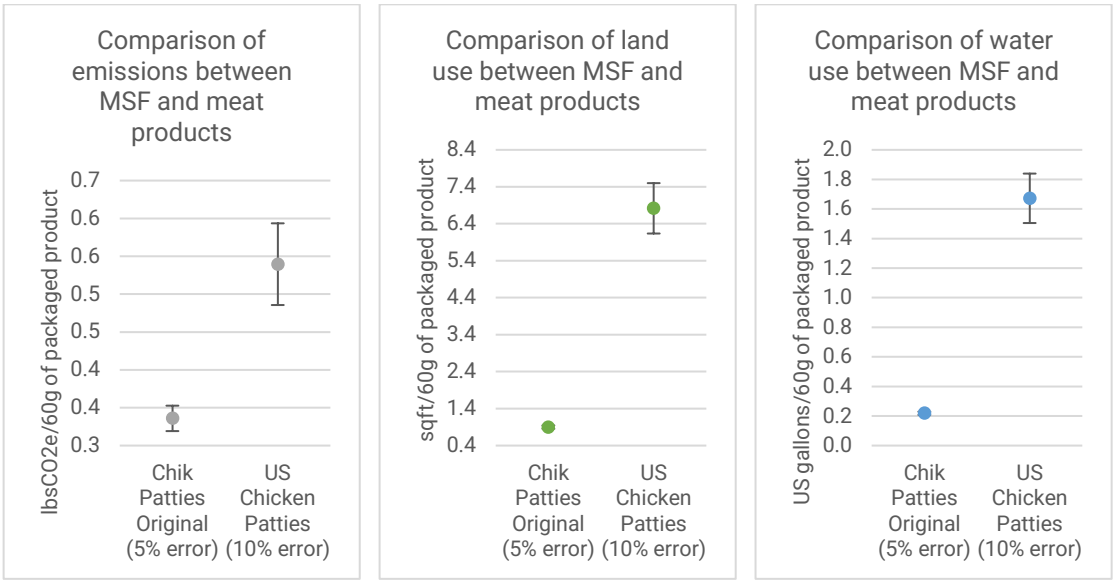

Figure 4: Uncertainty analysis Buffalo Wings CN vs US Chicken Wings

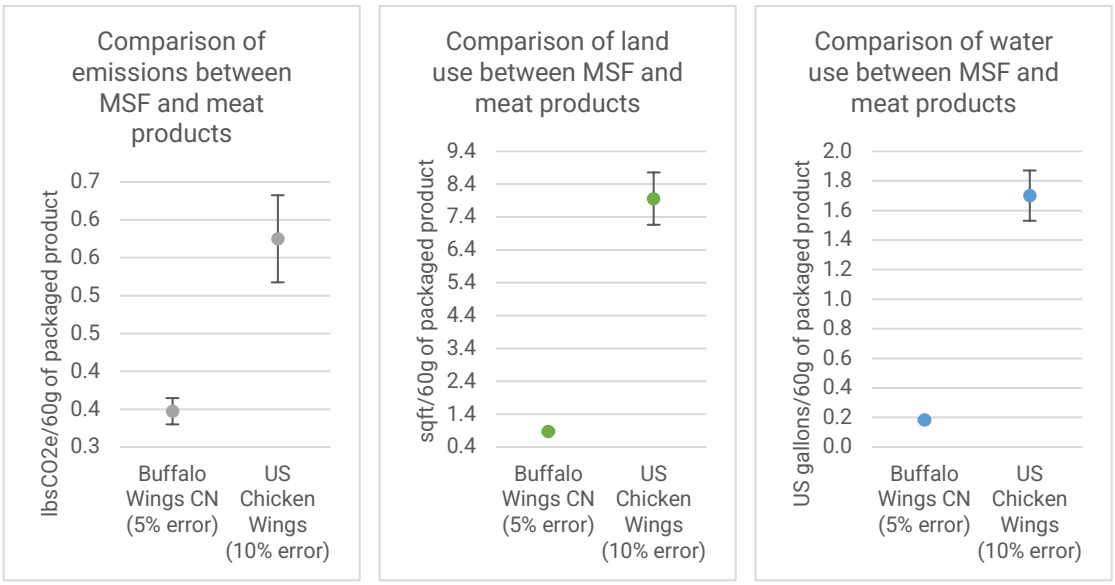

Figure 5: Uncertainty analysis Chik'n Nuggets CN vs US Chicken Nuggets

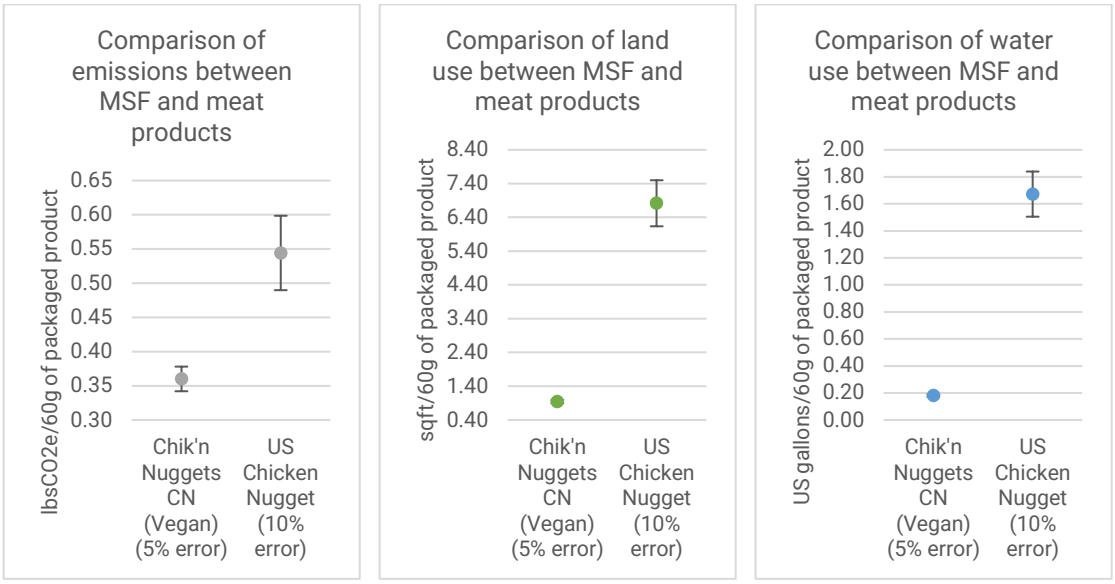

Figure 6: Uncertainty analysis Veggie Breakfast Bacon Strips vs US Bacon Strips

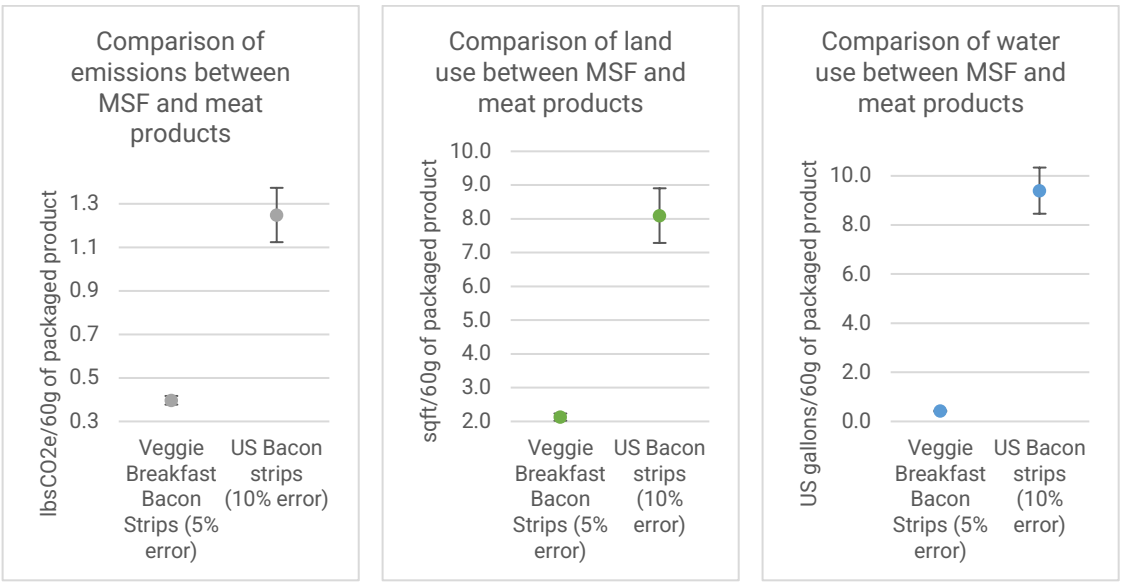

Figure 7: Uncertainty analysis MSF Italian Style Crumbles vs US Pork Sausage