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A life cycle assessment of processed meat products supplied to Barrow Island: A Western Australian case study

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ABSTRACT

This research aims to assess the emissions of greenhouse gases (GHGs) as well as the embodied energy associated with two value added processed meat products supplied to an offshore mining site at Barrow Island, Western Australia. A beef product (Canon Foods Swedish Meatballs) and a chicken product (Canon Foods Crunchy Garlic Chicken Breast) are produced at the Canon Foods facility in Cannington, Western Australia and transported to the final location of Barrow Island by way of their gateway port at Dampier, Western Australia. Using streamlined life cycle assessment (SLCA) methodology, it was estimated that the environmental impact of 1 kJ equivalent amount of Canon's Swedish Meatballs is 1.09 g CO_2-e of GHG emissions and 4.15 kJ of embodied energy, while the impact of Canon's Crunchy Garlic Chicken Breast is 0.38 g CO_2-e of GHG emissions and 5.08 kJ of embodied energy. The life cycle assessment demonstrates that the main cause of the GHG emissions and the high final embodied energy of the product can be linked primarily to the pre-farm inputs of the meat products and not the value adding process itself. The bulk of the GHG emissions of the final value added product can be attributed to the livestock ingredients, particularly beef based products, while the high embodied energy can be attributed to the amount of processing that inputs underwent prior to the Canon value adding process.

1. Introduction

The food processing sector is expected to expand further in order to keep pace with international demand (Jonas and Julia, 2013), and is responsible for around 20% of global greenhouse emissions (EurActive, 2009; Hertwich and Peters, 2009). Also food is one of the three main priorities along with housing and transport, which are responsible for 70% of the environmental impacts in most categories (Tukker and Jansen, 2006). In the case of Australia, the food and beverage sector accounts for a large portion (23.5%) of the total Australian manufacturing sector (Australian Department of Industry, (2014)), and it is therefore essential to keep this sector both financially viable and environmentally sustainable in order to compete in the international market. About 21% of the food manufacturing sector is the meat and meat product manufacturing sub-sector (Australian Department of Industry, (2014)). The main challenges for the Australian meat and meat product manufacturing industry today are not only to produce enough to be commercially viable, but also to expand in order to meet rising global demand and to develop in a way that is environmentally sustainable and does not put a disproportionate strain on the environment.

According to Troy and Kerry (2010), meat production and meat consumption have an environmental impact and are linked to climate change. A holistic method is required to measure the industry's impact on the environment that sustains it. One of the most effective methods is the application of a life cycle assessment (LCA) (Curran, 2012), which is widely valued as a means of evaluating environmental impact during the life cycle of products. This would provide valuable insight into Australia's rapidly changing meat and meat product manufacturing industry (Jonas and Julia, 2013).

Over the past 10 years there has been a sharp increase in the popularity of life cycle assessments (LCAs) in Australia, with around 75 published LCA studies and 63 undergoing a structured review to identify the coverage and comprehensiveness (system boundaries, impact categories) of past assessments (Renouf and Fujita-Dimas, 2013). Most of these LCA studies (70%) were conducted on the agri-food sector and involved the assessment of primary production or primary processing, with only 30% of studies taking the

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'cradle to factory gate' approach of considering the full supply chain (Renouf and Fujita-Dimas, 2013). This unfortunately leaves the Australian LCA community at a crossroads where the environmental impact of the primary product of the nation is quite comprehensively known but the impact of final products largely remains a mystery.

Part of the aforementioned comprehensive Australian coverage of primary produce is related to the processed meat industry, including extensive assessments of beef, chicken, pork and lamb (Bengtsson and Seddon, 2013; Biswas, 2015; Biswas et al., 2010; Peters et al., 2010; Wiedemann et al., 2015, 2012). These studies have provided a unique insight into the challenges that need to be considered in the Australian agri-food industry.

Eady et al. (2010) went into further detail by assessing the carbon footprint of a basket of primary and downstream products from the Australian context, such as bread, tinned lentils, fresh beef, pork and chicken, and two types of pet food. However, this study was limited to generic estimations of very basic downstream foods with very few inputs and did not cover complex, value added processed and packaged foods or the assessment of the goods with regard to embodied energy.

There have been preliminary LCA assessments of some basic downstream products, such as bread and milk, by Eady et al. (2010), and some primary work by Beer et al. (2005) on the production of corn chips from Australian maize. There has even been research nationally into commercially available restaurant served roast chicken (Jonas and Julia, 2013). Although the topics of both meat production and basic downstream product production have been covered to some extent locally, the combined topic of value added, composite processed meat product has not yet been assessed. To date, there is no published Australian study that has focused on the LCA of processed meat products. Therefore, this paper fills the gap in the Australian body of knowledge by providing an LCA analysis of the Australian processed food industry. This research provides a comprehensive analysis of one composite chicken and one composite beef value added product delivered to one of Western Australia's most remote islands builds upon the extensive Australian research into meat and is aided by the previously laid groundwork on basic downstream products that make up a large portion of these value added goods.

This research will assess the environmental impact of the processed meat industry using the local processed meat product manufacturer Canon Foods as a case study. Firstly, the study investigates the Australian processed meat product manufacturing industry using Canon Foods as a case study, in order to create a full process flow for the current methods of manufacture for two of their most commercially successful products. Secondly, it presents an life cycle inventory (LCI) consisting of all inputs and outputs in order to determine the carbon footprint and embodied energy consumption using SimaPro software based on one package of a popular processed beef product and one package of a popular chicken product shipped to Barrow Island in Western Australia. Finally, this paper provides the industry with an overview of the typical parts of the process that are likely to increase environmental impact, in order to select strategies to mitigate this impact.

Carbon footprint and embodied energy consumption impact categories were selected because they are considered to be key environmental impacts of food production (Mattsson, 1999; Swedish Institute of Food and Biotechnology, (2009)). Embodied energy has been defined as: 'the energy required to provide a product (both directly and indirectly) through all upstream processes (i.e. traceable backwards from the finished product to consideration of raw materials)' (Langston and Langston, 2008). This embodied energy consumption or cumulative energy demand (CED) can also be used as a screening indicator for environmental performance instead of performing a full LCA, for instance, in the absence of sufficient data (Huijbregts et al., 2006). Since the very first LCA studies, the cumulative energy demand CED has been one of the key indicators being addressed (Frischknecht et al., 2015). For carbon footprint, it is one of the most important indicator for Australia as the Prime Minister has reaffirmed "the country would "meet and beat" its 2020 emissions reduction goal - a reduction of 5 per cent compared with 2000 levels" (Tom Arup, 2015) during the Paris conference in December 2015.

The use of these two impact categories is deemed sufficient to accomplish these aims, similar to LCAs that have used these categories to great effect in both Western Australian and Australian cases (Biswas, 2015; Gunady et al., 2012; Wiedemann et al., 2012).

Canon Foods produces a 'Swedish Meatball' and 'Crunchy Garlic Chicken Breast', which are a beef and chicken product respectively, and similar to what WA workers in remote areas consume on a daily basis (Raj Gopal, R. pers comm., Canon Foods, Canning Vale, Perth, Australia). Canon Foods is a Western Australian business that sources its ingredients as much as possible from local Australian sources. This implies that their products are relatively low 'food mile' products and present a real case for sustainable food production in the Western Australian industry. Taking a representative case study for the production of food using local ingredients and then transporting it to one of the most difficult to access locations provides indicative data regarding the impact on Western Australian value added meat production. This can be applied to any location in Western Australia without the fear of impact values being underestimated, which might occur if this research had adopted a traditional 'cradle to remote island' approach to LCA analysis.

This streamlined LCA has been applied mainly to assess the environmental implications of the operations and production of an existing facility, Canon Foods, and their 'industrially common' process, with the aim of providing information for decision-makers and researchers primarily concerned with the 'production phase' of processed meat product production (Andersson, 2000).

2. Methodology

The LCA in this study follows the ISO 14040:2006 guideline (International Organization for Standardization, 2006), which consists of the following four steps: i) goal and scope definition, ii) inventory analysis, iii) impact assessment and iv) interpretation (which takes place in the Results and Discussions section).

2.1. Goals and scope

The goal of this life cycle assessment is to evaluate the environmental impact of the production of two processed meat products in Western Australia, one chicken-based and one beef-based, and to identify the environmental improvement opportunity.

Specific objectives pertaining to the overall goals are:

- To assess the environmental impact of Canon Foods' 'Crunchy Garlic Chicken Breasts' based upon the carbon footprint and embodied energy consumption.
- To assess the environmental impact of Canon Foods' 'Swedish Meatballs' based upon the carbon footprint and embodied energy consumption.

The processed chicken meat product selected for assessment was Canon Foods' 'Crunchy Garlic Chicken Breasts'. This product consists of chicken meat, breadcrumbs, soy protein, onion, garlic, vegetable oil and spices, and is produced in Canning Vale, Western Australia, from ingredients sourced both locally in Western

Australia and in Australia as a whole.

The processed beef product selected for assessment was Canon Foods' 'Swedish Meatball'. This product consists of beef, soy protein, onion, garlic, vegetable oil and spices, and is also produced in Canning Vale, Western Australia, from ingredients sourced both locally in Western Australia and in Australia as a whole.

In order to conduct a life cycle assessment, a unit is chosen to which all the environmental calculations relate, and this is known as the 'functional unit'. The functional unit that determines the system boundary or the scope of the work is 1 kJ (kilojoule) equivalent nutritional value (in terms of energy content of the food) of 'Crunchy Garlic Chicken Breasts' and 'Swedish Meatballs' transported to Barrow Island.

2.1.1. System boundaries

Since the functional unit in both cases includes the final packaged product being delivered to a specific consumer in a remote island, this system boundary is considered to be a 'farm to island' approach involving the transportation of Canon Foods products to a specified remote location (Table 1).

This LCA excluded downstream activities including the consumption of the food product and disposal of associated food waste (with the exception of transport considerations). It also eliminated trace elements (e.g. food additives) and is thus termed a streamlined LCA (Hunt et al., 1998). In this research, the input and output data for developing an inventory for pre-processing activities as discussed below were not required as direct emissions from chicken and beef production were obtained from local research in Western Australia. Canon Foods provided monthly basis data for inputs for producing chicken and beef products and their transportation to Barrow Island in order to develop inventories for 1 kJ nutritional value equivalent Swedish meatballs and garlic chicken breast during the food processing and post processing stages.

Figs. 1 and 2 show the system boundaries for Swedish Meatballs and Crunchy Garlic Chicken Breasts respectively, and each of these boundaries consists of the following steps:

- The *Pre-Food Processing* includes all farming activities associated with the production of beef and chicken. The inputs required for these activities are as follows: animal feed, fertiliser application, diesel fuel for farm equipment and water inputs for pasture and chicken feed production for beef and chicken farms.
- The *Food Processing* includes all electrical and chemical inputs into the Canon Foods machinery that is used to refine or process the raw ingredients into the basic ingredients for the chosen products. This includes all electrical, fuel and lubricant usage in the production of the final ingredients.
- The *Post-Processing* includes all transportation and storage required from when the final packaged product leaves Canon Foods until it arrives at the specified location of Barrow Island.

2.1.2. Data sources and data quality

Data used in this study was collected through site visits, personal communications by telephone and email in partnership with Canon Foods, and data collected from databases as well as from established literature. Due to the nature of Canon Foods' processes, many of their products share common ingredients and sub-processes (such as the mixer, mincer, former, precooler, spiral freezer and packaging sub-processes), so the datasets for these elements are identical for both of the selected products. It was not feasible to make inventories of all ingredients through personal visits or direct firsthand experience, which would have provided the most accurate assessment. This is due to lack of access to certain suppliers engaged by Canon, uncertainty or ambiguity about the operations of certain suppliers, and the presence of certain trade secrets which limit the depth to which the specific ingredients present in the two products can be analysed.

Therefore, the philosophy of this study was to provide datasets for these ingredients that were as indicative as possible, through the use of relevant database entries and the existing literature on the ingredients in question. For example, where the exact recipe for Canon Foods' spice mix was unavailable due to it being considered an invaluable trade secret, the company's representatives provided the literature basis for their recipe which gave an indicative ratio for the composition of the mix. As access to the supplier of the spice mix was limited, the study substituted literature and database entries for each of the constituent parts of the spices, assuming that all constituents were sourced from the 'most local suppliers' as stated by Canon Foods.

2.1.3. Allocation of inputs to products

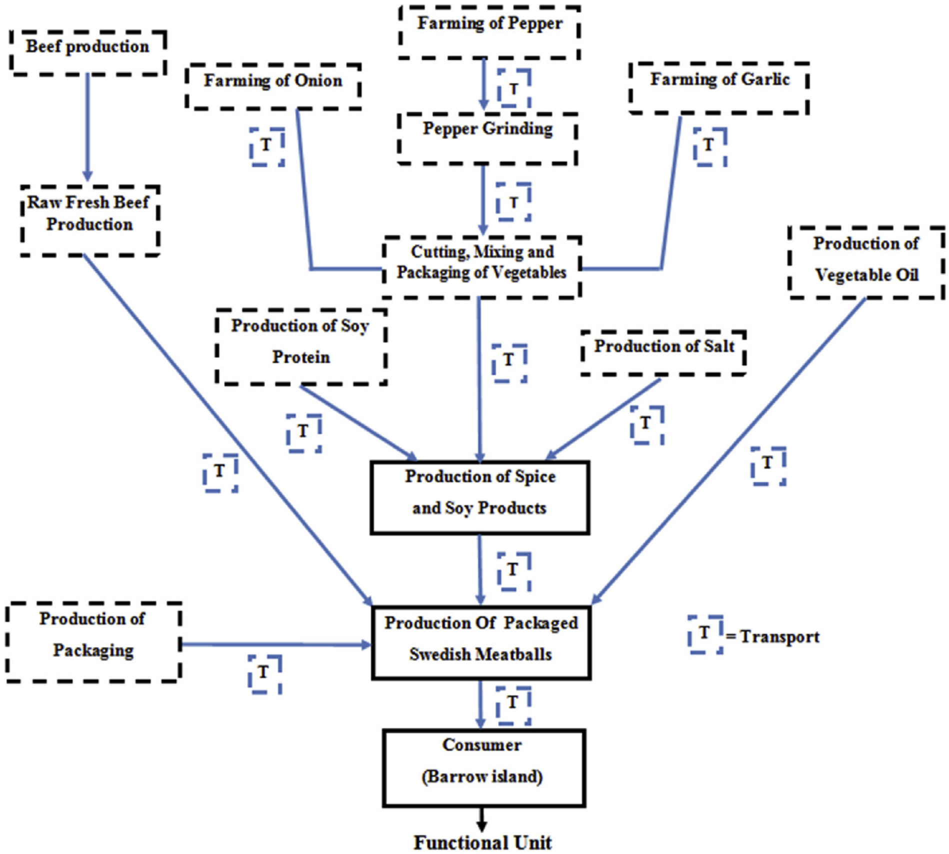
In an LCA analysis, when there is more than one product produced in the same production step or activity, it is necessary for the environmental impact of that step or activity to be allocated between the products. The monthly power usage for the Canon Foods process equipment was only available as data for the whole facility, instead of on a per batch basis. In this instance, the power usage was allocated by converting power usage to a per hour value based upon the standard operation times of Canon Foods, then allocating a power usage to each unit of equipment based on its percentage draw of total power (as provided by the company from its energy audit study), over the time of a batch operation. The majority of the primary data excluding electricity on basic inputs (e.g. meat and non-meat ingredient requirements, as well as process water requirements per unit of final product) and outputs (e.g final product and process wastages per final unit) for the direct production process was readily available and required no allocation procedure.

2.1.4. Assumptions and limitations of the study

The assumptions and limitations associated with time and location of data collection, transport, waste management and ingredient exclusion which may directly or indirectly affect the LCA results are as follows:

Table 1
Canon Foods LCA analysis stages.

Pre food processing	Food processing	Post processing
On farm management practices and transportation • On-farm transport • Machinery use • Fertiliser used • Primary feed and inputs • Irrigation • Transportation to production	Processing or raw ingredients and basic ingredients • Machinery use • Electrical usage • Water usages • Packaging	Transportation to final location or 'gate' • Transport • Storage

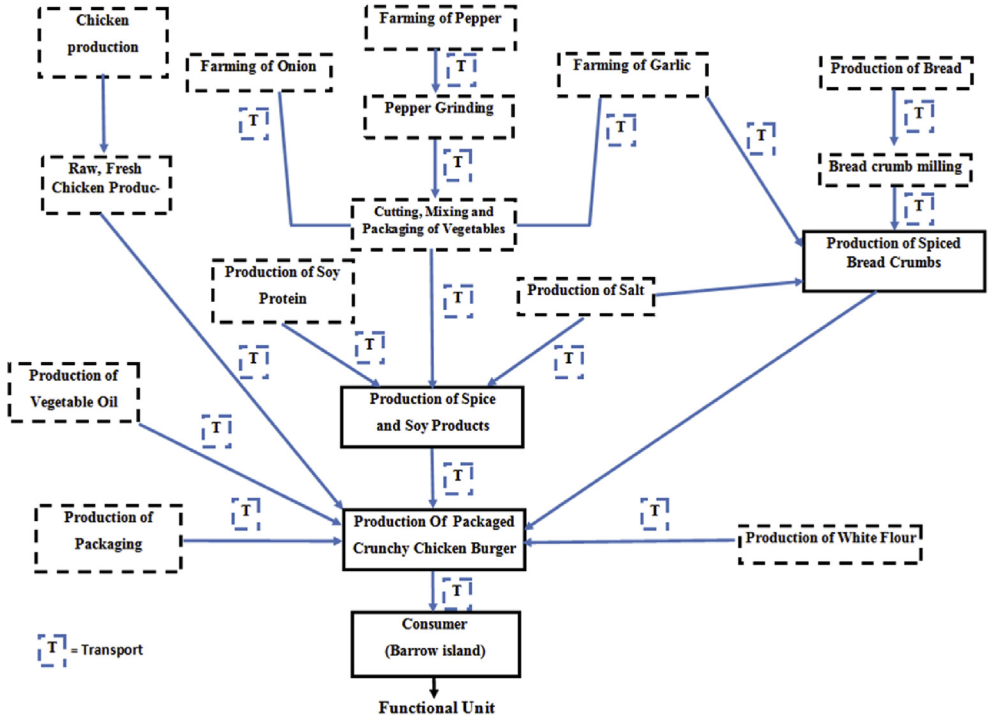


The system under study for Swedish Meatballs:

- T is an abbreviation for transport.
- For steps illustrated with boxes, the solid boxes and lines denote that data for the respective unit process has been obtained from primary sources via means such as questionnaires and direct industrial consultation. The dotted lines and boxes denote unit processes that have been derived from tertiary sources such as from literature or recognised LCA databases (please see 2.2 Life cycle Inventory).

Fig. 1. Swedish Meatball scope visualisation.

- The primary limitation of this study is the heavy reliance on tertiary information for the pre-food processing, including a heavy reliance on literature sources for the initial carbon footprint and embodied energy of the raw meat components of the two selected products.
- It must be noted, however, that some data required surrogacy to be reflected in this analysis, an example being the surrogacy of inventory datasets for garlic production in Iran as local data for this product was limited. In these cases, the datasets were converted to WA conditions by the addition of an equivalence factor or by using partially modified components, such as transport for instance.
- Thirdly, there was a lack of ideal datasets and it was therefore necessary in this research to make some reasonable substitutions, which are covered under the standard methodology for the streamlined life cycle assessment (Hunt et al., 1998):
  i. In some situations, the carbon footprint and embodied energy for WA chicken meat was not available at the time of this study. Therefore the emissions factor for other states within Australia was considered to be a reasonable substitute due to the relative uniformity of social and environmental situations in all Australian states.
  ii. In the absence of both Western Australian and Australian emission factor databases (e.g. 0.161 kg of CO_2-e/kg of Soy protein), a European emission factor database was used (e.g. the embodied energy consumption for crumbs and minced chicken) just to calculate the emissions from inputs.
- Canon Foods only mentioned that the ingredients were sourced as locally as possible. Accordingly, it was assumed that the sub-primary ingredients were sourced from two closely located industrial areas, Welshpool and Cannington in Western Australia. These would conceivably have the capital to process the raw sub-primary ingredients into their required form for use by Canon Foods in Cannington. The second assumption was that the primary mode of food transport in Australia, with trucks being suitably equipped to handle the ingredients they are transporting, for example being outfitted with refrigeration or freezer systems if necessary.
- This study excluded solid food wastes as they are sent to an animal waste renderer. In addition the waste associated with the disposal of packaging and other wastes in the consumption stages were excluded from this study, due to the focus of this research being on the production stages of the processed meat product industry.



The system under study for Crunchy Garlic Chicken Breasts:

- T is an abbreviation for transport.
- For steps illustrated with boxes, the solid boxes and lines denote that data for thee respective unit processed has been obtained from primary sources via means such as questionnaires and direct industrial consultation. The dotted lines and boxes denote unit processes that have been derived from tertiary sources such as from literature or recognised LCA databases (please see 2.2 Life cycle Inventory).

Fig. 2. Crunchy Garlic Chicken Breasts scope visualisation.

- Some of the ingredients present in the selected products, including paprika, spices (except for salt), antioxidants, aroma, fat powder, yeast extract, modified starch glucose and artificial colours and flavours, were not included in the study due to a systemic lack of data within the global LCA body of knowledge. Another reason was that these ingredients accounted for only1.48% of the Crunchy Garlic Chicken Breast and 0.33% of the Swedish Meatballs.
- The emissions and embodied energy consumption from the production of capital equipment, including building, pipe infrastructure and machinery, are excluded from the system boundary of the LCA analysis due to their long term spans (Biswas, 2009; Frischknecht et al., 2007).

2.2. Life cycle inventory

Life cycle inventory (LCI) is a pre-requisite for carrying out environmental impact assessments. The LCI consisted of inputs in the form of chemicals and energy and was developed after multiple site visits and surveys into the production processes for the Canon Foods products 'Swedish Meatballs' and 'Crunchy Garlic Chicken Breast'.

2.2.1. Swedish Meatballs

The Swedish Meatballs consist of beef mince mixed with herbs and spices consisting chiefly of salt, pepper, soy protein, onion and garlic. This mixture is formed into small ball-shaped patties and the patties are flash fired in vegetable oil and then fully cooked in a heating tunnel. The completed product is then precooled using a liquid cooled precooler and then snap-frozen in a spiral freezer. Finally, the products are packaged in 750 g portions. The packages are then packed into reusable crates and loaded onto a refrigerated truck and shipped to their final destination, which for the purpose of this study is the remote mining community of Barrow Island. The quantitative values of all of the inputs required to produce a 885 g of Swedish Meatballs including constituents transported by rigid trucks, constituents, cardboard packet and energy data are listed in Table 2. This table also shows the inputs associated with the transportation of 1 kJ equivalent of Swedish Meatballs where the nutritional value (i.e. 10,557 kJ/kg) was sourced from My Fitness Pal (2015).

2.2.2. Crunchy Garlic Chicken Breast

The 'Crunchy Garlic Chicken Breast' consists of chicken mince mixed with chicken skin emulsion and seasoned with herbs and spices consisting chiefly of salt, pepper, soy protein and onion. The mixture is firmed with the addition of CO_2 gas and formed into a breast shaped patty. The patty is then coated in a light dusting of wheat flour followed by a liquid coating of flour, after which it is coated with spiced breadcrumbs consisting primarily of garlic, salt and breadcrumbs. The crumbed patty is then flash fired in vegetable oil, then fully cooked in a heating tunnel. The completed product is

Table 2
Swedish Meatballs inventory.

Particulars	Units	Quantity per 885g	Per nutrition unit (kJ)
Materials inputs:			
Beef meat	Grams	619.98	7.83E-02
Spices and soy products (total)	Grams	77.40	9.78E-03
(a) Salt	Grams	5.05	6.38E-04
(b) Black pepper*	Grams	2.52	3.19E-04
(d) Soy protein	Grams	42.07	5.31E-03
(e) Onion	Grams	25.24	3.19E-03
(f) Garlic	Grams	2.52	3.19E-04
Vegetable oil	Grams	75.00	9.47E-03
Water (process)	Grams	75.00	9.47E-03
Water (lubricant)	Litres	0.02	2.33E-06
Packaging	Grams	135.00	1.71E-02
Electricity (machinery)	Energy input kWh	0.244	3.080E-05
Transportation inputs			
Constituents			
Beef from the Boyup Brook cattle farm (257 km)	tkm	0.16	2.0E-05
Salt from salt mining site (795 km)	tkm	4.01E-03	5.1E-07
Soy protein from Fremantle port (33 km)	tkm	1.39E-03	1.8E-07
Onion from a farm in Mangimup (288 km)	tkm	7.27E-03	9.2E-07
Garlic from a farm in Bawang (462 km)	tkm	1.17E-03	1.5E-07
Vegetable oil from local canola belt (341 km)	tkm	2.56E-02	3.2E-06
Product			
Swedish Meatballs transported to Barrow island (1,833 km)	tkm	1.36	1.5E-04

Table 3
Crunchy Garlic Chicken Breasts inventory.

Particulars	Unit	Quantity per package (602 g)	Per nutrition unit (kJ)
Material inputs			
Chicken meat	Grams	369.00	7.42E-02
Spices and soy products (total)	Grams	42.12	8.47E-03
(a) Salt	Grams	5.40	1.09E-03
(b) Pepper	Grams	7.56	1.52E-03
(d) Soy protein	Grams	7.56	1.52E-03
(e) Onion	Grams	21.60	4.35E-03
Wheat flour	Grams	44.26	8.90E-03
Spiced breadcrumbs (total)	Grams	51.61	1.04E-02
(a) Garlic	Grams	2.58	5.19E-04
(b) Salt	Grams	2.58	5.19E-04
(c) Breadcrumbs	Grams	46.45	9.35E-03
Vegetable oil	Grams	51.00	1.03E-02
CO_2	Grams	350.00	6.86E-05
Water (process)	Grams	51.00	1.03E-02
Water (lubricant)	Litres	0.17	3.46E-05
Packaging	Grams	92.00	1.85E-02
Electricity (machinery)	kWh	0.23	4.62E-05
Transportation inputs			
Constituents			
Chicken meat from Wingfield (2697 km)	tkm	1.00	2.00E-04
Breadcrumbs from Cannington industrial area (1 km)	tkm	5.16E-05	1.04E-08
Wheat flour from Western Australian wheatbelt (262 km)	tkm	0.01	2.05E-06
Polyethylene packaging: Breadcrumbs from Cannington industrial area (1 km)	tkm	9.20E-05	1.85E-08
Product			
Crunchy Garlic Chicken Breasts transported to Barrow island (1,833 km)	tkm	0.931	1.59E-04

then precooled using a liquid cooled precooler and then snap-frozen in a spiral freezer. Lastly the final products are packaged in 510 g portions. The packages (92 g) are then packed into reusable crates and loaded onto a refrigerated truck and shipped to their final destination which for the purpose of this study is the remote mining community of Barrow Island. The quantitative values of all of the inputs required to produce a 602 g packet as well as 1 kJ equivalent nutritional value of Crunchy Garlic Chicken Breasts are listed in Table 3. The conversion factor for converting 1 kg of Crunchy Garlic Chicken Breasts to 1 kJ nutritional value is 9746 kJ/kg (My Fitness Pal, 2015). The packet chicken product is made of thermoplastic LDPE (i.e. low-density polyethylene) material.

From an investigation into Australian growing regions, estimations were made of the distances that each sub-product had to travel from the point where they were most likely to have been grown to Canon Foods. All measures of travel were calculated in tkm (tonne of input × km travelled) using the emission factor for ‘Transport, rigid truck, 3.5–16t, fleet average/t’ obtained from the Australasian unit process LCI database.

2.3. Impact assessment

Impact values of global warming are expressed over 20-, 100- and 500-year time horizons to enable policy-makers to make

Table 4
Carbon footprint emission factor sourcing.

Emission factor description	Source	Value and unit
Beef meat	Biswas 2015; Wiedemann et al., 2015	15 kg CO_2-e/kg
Chicken meat	Wiedemann et al., 2012; Wiedemann et al., 2015	2.64 kg CO_2-e/kg
Salt	Database (Australasian unit process LCI)	0.0138 kg CO_2-e/kg
Soy protein	LCA Food DK (Nielsen et al., 2003)	0.161 kg CO_2-e/kg
Onion	Marasenia et al., 2010	0.0312 kg CO_2-e/kg
Garlic	Samavatean et al., 2011 Database (Australasian unit process LCI)	1.13 kg CO_2-e/kg
Vegetable oil	Beer et al., 2007	1.18 kg CO_2-e/kg
Wheat flour	Eady et al., 2010	0.9 kg CO_2-e/kg
Breadcrumbs	Eady et al., 2010	0.942 kg CO_2-e/kg
Water	Database (Australasian unit process LCI)	6.0E-4 kg CO_2-e/kg
Transport	Database (Australasian unit process LCI)	0.289 kg CO_2-e/tkm
Swedish meatballs packaging	LCAFood DK; (Nielsen et al., 2003)	1.23 kg CO_2-e/kg
Chicken breasts packaging	Database (Australasian unit process LCI)	2.18 kg CO_2-e/kg

Table 5
Embodied energy emission factor sourcing.

Emission factor description	Source	Value and unit
Beef meat	Peters et al. 2010; Wiedemann et al., 2015	29.6 MJ/kg
Chicken meat	Wiedemann et al., 2012; Wiedemann et al., 2015	22.2 MJ/kg
Salt	Database (Australasian unit process LCI)	0.144 MJ/kg
Soy protein	LCA Food DK (Nielsen et al., 2003)	0.408 MJ/kg
Onion	LCA Food DK (Nielsen et al., 2003)	0.379 MJ/kg
Garlic	Samavatean et al., 2011; Database (Australasian unit process LCI)	17 MJ/kg
Vegetable oil	Ecoinvent system processes database; Weidema et al., 2008	20.55 MJ/kg
Wheat flour	LCA Food DK (Nielsen et al., 2003)	2.32 MJ/kg
Breadcrumbs	LCA Food DK (Nielsen et al., 2003)	1.83 MJ/kg
Water	Database (Australasian unit process LCI)	9.2E-3 MJ/kg
Transport	Database (Australasian unit process LCI)	2.41 MJ/tkm
Swedish meatballs packaging	LCA Food DK; (Nielsen et al., 2003)	28.1 MJ/kg
Chicken breasts packaging	Database (Australasian unit process LCI)	21.5 MJ/kg

relevant climate change decisions. Accordingly, individual greenhouse gas emissions (CO_2, CH_4 and N_2O) from each production stage were converted to CO_2-equivalent (CO_2 −e) using established conversion factors for 20-, 100- and 500-year time horizons (IPCC, 2013). We only discuss the 100-year horizon as it is considered to be the reference. According to Department of Climate Change [3], N_2O is 298 more powerful than CO_2, while CH_4 is 25 more powerful than CO_2. Following IPCC's second assessment report (SER) (IPCC, 2006), it was considered that the CH_4 is 21 times and N_2O is 310 times more effective at trapping heat in the atmosphere compared to CO2 over a 100-year time.

The inputs/outputs have been linked to the relevant emission factor databases of the Simapro software where the GHG emissions were calculated by converting each selected GHG to CO_2 equivalent for a 100-year time horizon. The program sorted GHG from the selected emission databases and then converted each selected GHG to CO_2 equivalent (or gram CO_2 equivalent). Lastly, all CO_2 equivalent GHG emissions for all life cycle inventory items were added to determine the full life cycle GHG emissions associated with production and transportation of beef and chicken products to Barrow Island.

The cumulative energy demand method was used to determine the embodied energy of these meat products.

The amount of inputs in the LCIs (Tables 2 and 3) were multiplied by the corresponding emission factors to determine the emissions of the inputs associated with the manufacture of meat products. The emission factor of a product or service is the summation of all emission until end of a product life cycle. Most of the GHG emission and embodied energy consumption factors databases were sourced mainly from local databases except for a few which were derived from international databases and refereed literature (Tables 4 and 5).

For electricity use in Western Australia, this study uses the data for the Western Australian energy mix for high voltage supplies. The 'Western Australian energy mix' is based upon data from the Australasian unit process LCI database entry. In the case of the carbon footprint for beef meat, the initial carbon footprint for live weight cattle (LWC) was taken from Biswas (2015) and was then converted into 'hot standard carcass weight' (HSCW) according to Wiedemann et al. (2015). Similarly, the embodied energy value was obtained from Peters et al. (2010). This was then modified using the slaughter values provided by Wiedemann et al. (2015) for Western Australian beef.

The emission factor for both the carbon footprint and the embodied energy of onions that have been 'cleaned, dried, refrigerated and packaged' was sourced from local (Marasenia et al., 2010) and European databases (Nielsen et al., 2003). The amount of energy required for mixing and chopping the mix into a composite form was determined by conducting a primary experiment on blending on a small scale using equipment very similar to that used by Canon's suppliers to mix and chop the 'spice and soy product' mix.

In the absence of an emission factor for soy protein, the emission factor for soy meal, a by-product of the production of soy-oil based biofuels (Nielsen et al., 2003), was used. It was taken into account that the soy meal was produced in South America and then it was shipped to Fremantle and finally trucked to Canon Foods. Since soy is a crop that is not readily grown in Australia, the Danish LCA food database emission factor was modified by utilising this transportation factor.

There is no Australian emission factor for garlic due to it being a specialist crop grown in certain limited areas of Australia. The study therefore used the inventory from the research which focused on garlic production in Iran (Samavatean et al., 2011) and used local emission factors from the Australian databases for these inputs in the inventory to calculate emission factors.

The carbon footprint for refined canola oil used by Canon Foods was sourced from a local study by Beer et al. (2007). The embodied energy of this product has not been assessed by an Australian study, so the Ecoinvent System Processes Database was used instead (Weidema et al., 2013).

The emission factor for the Swedish Meatballs packaging (a single wall cardboard carton) was unavailable in both local and other databases. Therefore, emission factors for the closest product category, which was 'packaging, corrugated board, mixed fibre, single wall', was sourced from the Ecoinvent System Processes Database (Weidema et al., 2013).

The initial carbon footprint for carcass weight (CW) was sourced from a study carried out in South Australia and Queensland (Wiedemann et al., 2012). This was then modified by incorporating the carbon footprint associated with slaughter under Australian conditions (Wiedemann et al., 2015). Similarly, the emission factor for the embodied energy value up until the slaughter stage was sourced from Australian studies (Wiedemann et al., 2012; Wiedemann et al., 2015). The packaging of Canon Foods' 'Crunchy Garlic Chicken Breast' is a plastic thermoplastic LDPE material, therefore the emission factor for 'polyethylene, LDPE, film, at plant' was selected from the Australasian unit process (LCI) (Life Cycle Strategies Pty Ltd n.d.).

The emission factor for the carbon footprint of breadcrumbs and wheat flour was based upon Western Australian data on the production of flour from wheat production (Eady et al., 2010). Due to the lack of Western Australian data on the embodied energy for the production of wheat flour and breadcrumbs, the embodied energy value from the Danish LCA food database was substituted (Nielsen et al., 2003).

2.4. Uncertainty analysis

There are uncertainties associated with the quality of the inputs and emission factors used from different sources for estimating environmental impacts. Monte Carlo simulation (MCS) would estimate this uncertainty in each of these input variables and predict the influence on that variable on the environmental impacts (Hung and Ma, 2009; McCleese and LaPuma, 2002). MCS is basically a reiterative process of analysis and uses repeated samples from probability distributions as the inputs for models and produces distribution of possible outcome values for 1000 iterations (Huijbregts et al., 2006; Goedkoop et al., 2013). This method provides the decision maker with a range of potential outcomes along with the predicted chance of their occurrence. Therefore, MCS has been used to carry out an uncertainty analysis of LCA results of this research.

The mean, standard deviation and standard error of the mean from each meat product was calculated using the MCS (1000 runs, 95% confidence interval) using Simapro LCA software (Goedkoop et al., 2013). The ratio between the standard deviation and the mean is coefficient of variability or CV. It is a useful parameter for assessing the quality of data by the relative magnitude of the uncertainty. The 95% confidence interval has been chosen as this is typically used in Applied Science practices (e.g. LCA analysis) (Zar, 1984; Goedkoop et al., 2013).

Table 6
Carbon footprint and embodied energy of Swedish Meatballs per kJ of nutritional value.

Ingredient/activity	gCO_2-eq/kJ		kJ of embodied energy/kJ	
Beef meat	1.00	91.4%	1.99	47.9%
Packaging	0.02	1.7%	0.48	11.4%
Vegetable oil	0.01	0.9%	0.47	11.4%
Processing electricity	0.02	2.1%	0.29	6.9%
Transport	0.04	3.9%	0.92	22.1%
Spice soy mix and process water	0.00	0.1%	0.01	0.3%
Total	1.09	100%	4.15	100%

Table 7
Swedish Meatballs Monte Carlo simulation analysis (1000 runs).

	Unit	Mean	SD	Std. err. of mean
CF of Swedish Meatballs	kg CO_2 eq	1.09E+00	8.23E-04	2.56E-06
EE of Swedish Meatballs	kJ LHV	4.14E+00	6.91E-02	5.64E-05

3. Results and discussion

3.1. Carbon footprint and embodied energy consumption assessment for Swedish meatballs

The global warming impact of 1 kJ equivalent of Swedish Meatballs produced by Canon Foods and transported to Barrow Island has been estimated to be 1.09 g of CO_2 -e and 4.15 kJ respectively (Table 6). There may be uncertainties for these LCA results due to use of secondary data and variability between sources and inventory data. Therefore, an uncertainty analysis has been carried out using a Monte Carlo Simulation (MCS) where the inventory results were transformed from a concrete value into a probability distribution around a mean value (Sundberg and Hansson 2010). This probability distributions provides a better understanding of the magnitude of the uncertainties in LCA results (Röös et al., 2010).

Accordingly, a MCS was run to determine the mean, standard deviation and standard error for the carbon footprint and embodied energy results for the Swedish Meatball product at a confidence level of 95% (Table 7). The standard deviations for these two indicators are both less than 2% of the mean, confirming the validity of this LCA analysis following Biswas (2013) and Mohammad et al. (2016). It appears that beef accounts for 91% of the total carbon footprint, followed by transportation (4%), electricity (2%), packaging (2%) and vegetable oil (<1%). The remainder of the carbon footprint value can be attributed to the production of spice and soy mix and process water.

In the production of value added processed food, the usual public perception is that food processing industries have a significant environmental impact, including GHG emissions (Chukwu, 2009). However the results reflected in this study suggest that pre-food processing is the main contributor of GHG emissions, whereas the food processing industries have very limited control over the reduction of supply chain GHG emissions.

Whilst beef accounts for 70% of the meatballs by weight, it accounts for 91.4% of the total carbon footprint. This is due to the fact that a significant amount of CH_4, which is 25 times more powerful than CO_2 (Biswas et al., 2010), is emitted during the life cycle of beef. Enteric metho-genesis GHG emissions account for approximately 85–96% of the GHG emissions associated with the production of 1 kg of live weight (Biswas, 2015). This is supported by other contemporary studies (Wiedemann et al., 2014; Peters et al., 2010). The Australian studies draw the same conclusions as international studies (Mogensen et al., 2012; Ogino et al., 2007 as well as Roy et al., 2012).

The next hotspot is transportation, which accounts for 4% of the overall carbon footprint of the final product. The majority of this impact can be attributed to the final transportation of Swedish Meatballs by truck to Barrow Island, which is 1546 km from Canon Foods. Its primary point of access is by sea and is via Dampier, WA. The emissions associated with the transportation of inputs to Canon Foods are negligible due to the company's strategy of sourcing the majority of inputs from nearby producers, thus minimising pre-farm transportation.

Lastly, the remaining components of the total carbon footprint include packaging, vegetable oil, spice and soy products, process electricity and process water. These inputs altogether constitute 2% of the total carbon footprint of the Swedish Meatballs product and as such can be deemed 'of least concern' in the mitigation of the carbon footprint of this processed food. The minimal impact of vegetable oil and spice and soy mix is due to the fact that these products are derived from vegetables or plant based products which primarily require water to grow, along with minimal application of fertilisers and processing. Lastly, the low emissions associated with the process energy required for the production of Swedish Meatballs is due to Canon's automated batch process which integrates each production sub-process in the overall process with the use of interlinking conveyor belts. This not only ensures the most efficient conveyance of intermediate products between the sub-processes, it also allows for the bypassing of various sub-processes when they are not required for a specific final product. This can be seen in action with the elimination of the bowel chopper for the Swedish Meatball production process. The strength of this level of automation and technology is that it offers flexibility in batch process food production along with the efficiency and minimal human interaction that comes with integrated and automated processing strategies usually associated with continuous operation plants.

Similarly to the results for GHG emissions, beef meat accounts for approximately 48% of the total embodied energy, followed by transportation (22%), packaging (11.4%) and vegetable oil (11.4%) and process electricity (7%). The remaining inputs make up a very small portion, with spice and soy mix and process water having a negligible impact on the overall carbon footprint of the product.

The effect of beef meat is extensive, contributing 48% of the total embodied energy consumption. However, embodied energy impact of beef is not as overwhelming as its carbon footprint because the GHG emissions happened is not only due to CH_4 ruminant emissions, but also from denitrifying bacteria of soil which transform the N of fertilisers into N_2O emissions. The difference is due to the fact that additional methane emissions from the digestion process in ruminant livestock increase the carbon footprint value of beef meat. Secondly, the embodied energy of beef is also linked with the long life cycle of cows. The embodied energy of the feed required to sustain the animals over their three year life span has a large impact, as corroborated by the findings of Peters et al. (2010) as well as Roy et al., 2012. Feed growth requires energy inputs for reticulation, fertilisation, soil preparation, operation of farm equipment and harvesting equipment and medication. This on-farm embodied energy, like the carbon footprint of beef, is further exacerbated by the slaughter process. During the slaughter process, the reduction in weight and increase in energy through the application of energy inputs and heavy machinery increases the embodied energy consumption of beef on a kilogramme basis.

Transportation accounts for 22% of the total embodied energy of Swedish Meatballs. The long transportation distance between Canon Foods and Barrow Island is still the biggest energy consumer, while Canon Foods' sourcing of ingredients from the most local suppliers shows minimal embodied energy consumption. It can also be observed that the embodied energy pattern for packaging, vegetable oil and electricity is same as the carbon footprint.

Although the cardboard packaging in makes up only approximately 6% of the product's overall weight, it accounts for approximately 11.4% of the overall embodied energy. The high embodied energy of corrugated cardboard packaging observed cannot be attributed to its primary inputs as it is made chiefly of non-petroleum sources, instead favouring wood pulp. This means that the embodied energy of this portion of the product remains high. However, relative to some of the industrial alternatives such LDPE or PET packaging, it is one of the preferable options with a real prospect of being reused or recycled at the end of its life cycle (Toniolo et al., 2013).

The percentage of the overall embodied energy that can be derived from vegetable oils has been determined to be 11.4%. This relatively large secondary impact is due to the fact that vegetable oil requires processing and refining in order to be converted from raw seed to seed oil. The refining and conversion of this oil requires crushing, heating and processing, all of which involve an energy input as well as the raw ingredients (Beer et al., 2007).

Processing electricity is shown to make up 7% of overall embodied energy. Relative to similar food production processes, Canon Foods' process is relatively efficient as it is operated in batches with process runs undertaken to fulfil a set demand as opposed to running the process continuously. Additionally their process utilises precision equipment with low voltage requirements as well as close proximity between process units that minimises the electrical losses per process unit as well as minimising the electrical power required to transport intermediate products between the process units. Lastly, the inputs of spice and soy mix and process water, which constituted all vegetable and spice products, made up 9% of the product by weight and were all primary products with a very low level of processing attached to them. The spice and soy products particularly were vegetables, salt or soy protein all simply chopped and packaged in bulk with the only secondary processing being cleaning and chopping into an emulsion-like mix. The water was simply scheme water taken from Perth's reticulated metre mains and as such had a very low impact.

3.2. Carbon footprint and embodied energy consumption assessment for Swedish crunchy garlic chicken breasts

The GHG emissions and embodied energy consumption associated with 1 kJ equivalent of Crunchy Garlic Chicken Breasts produced by Canon Foods and then transported to Barrow Island have been estimated to be 0.38 gCO_2 -e and 5.08 kJ respectively (Table 8). A Monte Carlo simulation was run to determine the mean, standard deviation and standard error for the carbon footprint and embodied energy results for the Crunchy Garlic Chicken Breasts product at a confidence level of 95%. The standard deviations for these two indicators are both less than 2% of the mean, confirming the validity of this LCA analysis (Table 9). It appears that chicken

Table 8
Carbon footprint and embodied energy of Crunchy Chicken Garlic Breast per kJ of nutritional value.

Ingredient/activity	gCO_2-eq/kJ		kJ of embodied energy/kJ	
Chicken meat	0.17	45.3%	1.43	28.1%
Packaging	0.03	9.1%	1.52	30.0%
Processing electricity	0.03	8.6%	0.43	8.5%
Process CO_2 emission	0.06	15.4%		
Vegetable oil	0.01	2.7%	0.50	10.0%
Spiced breadcrumbs	0.01	2.3%	0.06	1.1%
Wheat flour	0.01	1.8%	0.04	0.7%
Transport	0.06	14.9%	1.08	21.3%
Spices, soy products and process water	0.00	0.45%	0.02	0.4%
Total	0.38	100%	5.08	100%

Table 9
Crunchy Garlic Chicken Breast Monte Carlo simulation analysis (1000 runs).

	Unit	Mean	SD	Std. err. of mean
CF of crunchy garlic chicken breast	g CO_2 eq/kJ	3.68E+00	1.39E-02	2.05E-04
EE of crunchy garlic chicken breast	kJ LHV/kJ	4.91E+01	6.27E-01	6.89E-04

meat accounts for 45.3% of the total carbon footprint, followed by process CO_2 (15.4%), transportation (14.9%), packaging (9.1%), electricity (8.6%) and vegetable oil (3%). The remainder of the carbon footprint can be attributed to the production of the spice and soy mix, wheat flour, spiced breadcrumbs and process water.

It can be seen that the Crunchy Garlic Chicken Breast has a carbon footprint about three times lower than that of the Swedish Meatballs. The share of GHG emissions from chicken meat (45.3%) is lower than that of the beef in the Swedish Meatballs (91%) due to the fact that chickens, by virtue of their biology, do not produce enteric emissions. In addition, the rearing time of a chicken is approximately 40–50 days (Vamilson Prudêncio da Silva et al., 2014), which is 3% of the time required to raise cattle. Thirdly, as smaller animals they require less feed, space and resources to move them from one location to another. Fourthly, most industrial chicken farms house chickens in enclosed hen houses ((Wiedemann et al., 2012). This segregation of the animals from the environment helps to control their interaction with the environment, minimising the feeding requirements and the emissions due to manure which can be effectively collected and disposed of in the enclosed environments. This segregation also offers protection from the spread of disease among the chicken population, resulting in further minimisation of veterinary, transportation and herding requirements.

The second largest hotspot is the process CO_2 (15.3%) that is used for firming Crunchy Garlic Chicken Breasts so that they hold their shape. As a result, the Crunchy Garlic Chicken Breast processing stage produces 2.5 times more emissions than that of the Swedish Meatballs. The next largest contributors to the carbon footprint of Canon Foods' Crunchy Garlic Chicken Breasts are transport (14.9%) and packaging (9.1%).

The packaging uses material, which is made of carbon and energy intensive LPDE plastic. LPDE is a derivative of petroleum based resources that requires a complex combination of steam, natural gas, electricity and natural hydrocarbons (all high impact high energy content inputs), and these factors all contribute to LPDE's high embodied energy value (Harding et al., 2007). Lastly, the remaining inputs of wheat flour, spice and soy products and spiced breadcrumbs all have a negligible impact on the carbon footprint of this product, for reasons similar to those for the Swedish Meatballs.

By contrast with the carbon footprint, embodied energy consumption of Crunchy Garlic Chicken Breasts is 1.2 times higher than Swedish meatballs due to fact that the latter involved the use of energy intensive packaging materials. The embodied energy consumption of packaging material LDPE, which is used for packing chicken breast product, is 1.04 kJ higher than the card board packaging materials used for Swedish meat ball. The packaging accounts for the highest portion (30%) of the total embodied energy consumption of Crunchy Garlic Chicken Breasts transported to Barrow island (Table 8), followed by chicken meat (28.1%), transportation (21.3%) and vegetable oil (10%). The remainder of the embodied energy can be attributed to the production of spice and soy mix, wheat flour, spicy breadcrumbs and process water. As mentioned earlier, LDPE is a very energy intensive material which requires energy inputs associated with the extraction, purification and refining of raw petroleum products. This high impact petroleum input then undergoes further processing by the addition of high embodied energy chemicals such as acids, peroxides and sulphates, which add their embodied energy to the final LDPE product (Harding et al., 2007). In addition to this, the production of LDPE requires heat via steam, electricity and natural gas, thus increasing the total GHG emissions as well as the embodied energy consumption.

The corrugated cardboard packaging that was used for Swedish Meatballs has a lower carbon footprint and embodied energy consumption than LDPE packaging due to the fact that the production process of cardboard primarily involves wood pulp products which are relatively low impact with little to no chemicals added during production. This is coupled with the fact that LDPE is synthesised chemically, while cardboard is simply wood pulp converted from one form to another.

The second largest hotspot in this system is chicken meat, which makes up 28% of the embodied energy of the Crunchy Garlic Chicken Breast. The next largest contributors to the embodied energy of this product are vegetable oil and transport. These inputs make up 21% and 10% of the embodied energy of this product and the justification for this remains the same as discussed in the embodied energy discussion for Swedish Meatballs. The impact of transport is primarily due to the final transportation of the goods to their extremely rural destination, and the impact of vegetable oil is due to the energy intensive production process required for its conversion from seed to seed oil. These inputs can be considered to be of lesser concern due to the fact that their impact is inherent to their nature and cannot be substituted a more environmentally friendly input such as transportation by shipping in bulk or the substitution of butter for oil, which all have cost considerations greater than the potential environmental impact they would mitigate.

The next largest contributor to the embodied energy of this product is the process electricity consumed in order to create the final good. Relative to the Swedish Meatballs, the chicken has a higher process electricity usage attributable to the four additional process steps required for the production of this product. This extra energy requirement is exacerbated by WA's electrical supply mix which has a less than ideal percentage of renewable sources as discussed previously.

The inputs of wheat flour, spiced breadcrumbs, spice and soy mix and process water can be considered negligible in their embodied energy impact. Each constitutes less than 1% of the total embodied energy of the product, which is a result of these products being comprised of primarily 'raw' plant based products with low levels of secondary processing, as explored in earlier discussions.

3.3. Comparison with similar Australian and international LCAs

Comparison of the Swedish Meatballs with other products is difficult due to the lack of national and international research on processed food where the percentage of beef in the product is same as in these Swedish Meatballs (i.e. 70%). As such, in order to compare this product to confirm its validity nationally, the results of the current research were compared with the carbon footprint of the closest available product, 'beef, fresh boned meat' (Eady et al., 2010). On a kilogramme basis, it was found that beef, fresh boned meat (25.2 kg of CO_2-e) produces 1.5 times more GHG emissions than the Swedish Meatballs (16.89 kg of CO_2-e). When only packaging, transport and processing stages are considered for both products, it can be seen that these products are somewhat comparable, however the primary difference is that the Swedish Meatballs are only 70% beef whereas the fresh meat product is 90% beef, making the beef, fresh boned meat more carbon intensive than the Swedish Meatballs. This is also supported by the fact that beef is the main component responsible for the increase in the footprint of meat products.

Renouf and Fujita-Dimas (2013) found that around 80% of Australia's key agricultural commodities have been subject to some level of LCA investigation, with the most coverage being achieved for the livestock sector (beef, dairy, sheep and poultry), wheat and sugarcane, with very little comparative coverage of the processed food industry nationally. Furthermore, the unique nature of the Canon Foods product makes it hard to find a similar product nationally or even internationally for comparison.

In most of the cases, the comparison of this study has been made with other studies per kg basis as other studies have functional units as kilogramme. For the comparison of Crunchy Garlic Chicken Breast products from a national perspective, the closest product that has been subjected to an LCA assessment is ‘conventional roast chicken’ (Jonas and Julia, 2013), in which the product was found to have a carbon footprint of 3.71 kg CO_2 equivalent. By comparison, the values obtained from this study were 3.58 kg CO_2 equivalent. These values show a high level of correlation and, considering the differences between the products, it can be said that this data is well within the range of being considered highly comparable. From an international perspective, a study conducted by the Swedish Institute of Food and Biotechnology (2009) found that a highly similar ‘coated chicken meal’ was found to have a carbon footprint of 5.38 kg CO_2 -e, which is 50% greater than that seen in the Australian cases. However, this difference can be accounted for by removing the impact associated with the transport of ingredients as this product is manufactured in Greece using almost entirely imported goods. Australia saves on this cost as it is an agricultural nation which can supply many of the ingredients for its processed food. Once this has been taken into account, it can be seen that this result is also within the range of the international situation.

Since there is no local study estimating the embodied energy consumption of even closely related products, the embodied energy measured in the current research was compared with the SIK (The Swedish Institute for Food and Biotechnology) chicken product (85.71 MJ per kg), which is 1.7 times more than the value found in this study (49.5 MJ per kg). This discrepancy once again can be accounted for by the amount of transport to and from the production facility in Sweden, requiring more high impact fossil fuel inputs. In addition, retail and wholesale do not exist in the supply chain of current study although they account for only 5% of the embodied energy consumption (SIK, 2009). When the transport impact and the slight differences in make-up and production processes for these two goods are taken into account, the results are comparable, but not to the high level observed when comparing between studies conducted locally.

When the processed meat products examined in the current research were compared with other processed non-meat products per kg basis such as Australian-produced maize corn chips (Grant and Beer, 2006) the latter (1.3 kgCO_2-e) were found to have a lower carbon footprint than the former (3.67 kg CO_2-e/kg of Swedish Meatballs and 11.5 kg CO_2-e/kg of Crunchy Chicken Breasts), indicating that the impact of processed food production is highly dependent on the inputs into the process while they have same system boundary (i.e. pre-processing to finished product).

Lastly, when highly calorific processed meat products were compared with Australian grown, low calorific fresh produce such as strawberries, lettuce and mushrooms by (Gunady et al., 2012) it was observed that while these vegetables had a carbon footprint of 2.46 g CO_2-e/kJ, 5.18 CO_2-e/kJ and 3.00 CO_2-e/kJ respectively, the Canon Foods products had a much lower carbon impact per kilojoule energy provided, with the chicken product having a carbon footprint of 0.38 g CO_2-e/kJ and the beef product having an impact of 1.08 g CO_2-e/kJ. This is mainly because of the fact that meat products are more nutrient dense than vegetable products.

4. Conclusions

The operations of processed meat value adders such as Canon Foods have an impact of less than 10% of the total carbon footprint and embodied energy of their goods. The real culprits in the environmental impact of processed food are the primary producers, particularly the producers of beef meat, chicken meat and packaging producers. Chicken based value added processed meat products are environmentally superior to beef based products.

The meat input accounts for the significant portion of the total carbon footprints for both products. In the case of embodied energy of Swedish Meatballs, beef meat is the primary contributor (48%), with the secondary contributor being transport of the product and its pre-farm inputs. When evaluating the embodied energy of the chicken product, the largest contributor was found to be the LDPE packaging.

The primary recommendations for only processed meat industries require certain process substitutions as listed below:

- The elimination of CO_2 firming in the Canon Foods process, either replacing it with traditional chilling or recovering the CO_2 using a fume hood as it is applied would go a long way towards the mitigation of this impact.
- From the data it would seem that replacing LDPE with corrugated cardboard packaging would yield a positive environmental outcome.
- Regarding long distance transport to a rural location, sending the products to Barrow Island by sea as part of a larger consignment of various mining related goods is a potential alternative if the volume of the products required is sufficient.

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