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Environmental management of confectionery products: Life cycle impacts and improvement strategies

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ABSTRACT

This paper presents the first environmental life cycle analysis for a range of different confectionery products. A proposed Life Cycle Assessment (LCA) approach and multi-criteria decision analysis (MCDA) was developed to characterise and identify the environmental profiles and hotspots for five different confectionery products; milk chocolate, dark chocolate, sugar, milk chocolate biscuit and milk-based products. The environmental impact categories are based on Nestle's EcodEX LCA tool which includes Global Warming Potential (GWP), Abiotic Depletion Potential (ADP), ecosystems quality, and two new indicators previously not considered such as land use and water depletion. Overall, it was found that sugar confectionery had the lowest aggregated environmental impact compared to dark chocolate confectionery which had the highest, primarily due to ingredients. As such, nine key ingredients were identified across the five confectionery products which are recommended for confectionery manufacturers to prioritise e.g. sugar, glucose, starch, milk powder, cocoa butter, cocoa liquor, milk liquid, wheat flour and palm oil. Furthermore, the general environmental hotspots were found to occur at the following life cycle stages: raw materials, factory, and packaging. An analysis of five improvement strategies (e.g. alternative raw materials, packaging materials, renewable energy, product reformulations, and zero waste to landfill) showed both positive and negative environmental impact reduction is possible from cradle-to-grave, especially renewable energy. Surprisingly, the role of product reformulations was found to achieve moderate-to-low environmental reductions with waste reductions having low impacts. The majority of reductions was found to be achieved by focusing on sourcing raw materials with lower environmental impacts, product reformulations, and reducing waste generating an aggregated environmental reduction of 46%. Overall, this research provides many insights of the environmental impacts for a range of different confectionery products, especially how actors across the confectionery supply chain can improve the environmental sustainability performance. It is expected the findings from this research will serve as a base for future improvements, research and policies for confectionery manufacturers, supply chain actors, policy makers, and research institutes towards an environmentally sustainable confectionery industry.

1. Introduction

Over the past few decades, improving the sustainability of food production and consumption has become a key priority for the food industry, governments and civil society (FAO, 2016; WRAP, 2015; Notarnicola et al., 2011). However, due to the diversity and

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Abbreviations

ADP	Abiotic depletion potential
AHP	Analytical hierarchy process
CED	Cumulative energy demand
D4E	Design for environment
DB	Database
DCC	Dark chocolate confectionery
EQ	Ecosystems quality
FU	Functional unit
GWP	Global warming potential
LCA	Life cycle assessment
LCI	Life cycle inventory
LU	Land use
MAUT	Multi-attribute utility theory
MAVT	Multi-attribute value theory
MCDA	Multi-criteria decision analysis
MCC	Milk Chocolate Confectionery
MCBC	Milk chocolate biscuit confectionery
MBC	Milk-based confectionery
PED	Primary energy demand
RE	Renewable energy
SC	Sugar Confectionery
T	Transport
UBP	Umweltbelastungpunkte
W	Waste
WD	Water depletion
WSM	Weighted sum model

complexity of the food system – from local to global – there are unprecedented challenges to transition towards a food system which is healthy, nutritious and environmentally sustainable (Wolf et al., 2011; Tukker et al., 2011). For example, some of the environmental challenges includes climate change, resource efficiency, water scarcity, and land availability (UN, 2014; FAO, 2009; Ewert et al., 2005).

In the confectionery sector, these challenges are amplified across the nutrition, health and environmental sustainability nexus due to the fast moving nature of consumption and consumer preference for different confectionery products. For example, it is estimated that a person in the UK consumes per day on average 20 g of chocolate, 14 g of sugar confectionery, and 32 g of fine bakery ware (Statista, 2015; CAOBISCO, 2013). Due to the volume of consumption, confectionery products has formed part of the normal diet for many people in the UK and abroad (FSA, 2014). However, they are not regarded as a staple food since they are consumed as a 'treat' given their inherently low nutrition and health benefits due to their high sugar and fat content.

Furthermore, the increasing consumption is exerting unnatural pressures on confectionery supply chains across the globe which have limits to production. For example, the core ingredients such as cocoa and palm oil are only grown in certain parts of world (e.g. Ivory Coast, Nigeria, Brazil and Indonesia). In addition, such commodities are highly sensitive to the growing impacts of climate change e.g. rising temperatures reducing favourable agricultural conditions for high cocoa yields (CIAT, 2011). Overall, due to the changing consumer demand and increasing consumption, there are enormous pressures on the confectionery supply chain, in particular from raw materials acquisition to manufacturing, to be flexible, resilient and environmentally sustainable (Salter, 2017; Pirker and Obersteiner, 2016; CIAT, 2011).

As a sector, the confectionery industry is highly diverse and complex. For example, there are over 12,700 confectionery manufacturers across Europe producing speciality and mass produced products which can be divided into three main product categories (CAOBISCO, 2015); (1) chocolate products, (2) sugar products, and (3) fine bakery ware. The type of chocolate products includes chocolate bars, pralines, white chocolate, and chocolate spreads. Whereas sugar products includes chewing gum, boiled sweets, toffees, caramels, gums, and jelly confectionery. In comparison to both, fine bakery ware products includes chocolate coated biscuits, gingerbreads, crispbreads, rusks, toasted bread, matzos, savoury biscuits and cakes. However, due to the diversity of products there are complex supply chains, ingredients which are grown in specific regions of the world, specialised equipment to process and transform ingredients, different formulation science to create nutritious and tasty recipes, and diverse retailers who have different strategies to sell products (e.g. multi-buy offers). Overall, such diversity and complexity compounds the transition towards environmental sustainability and requires a systems-based approach to analyse and improve the confectionery sector across the full supply chain from raw materials to manufacturing to consumption and disposal i.e. cradle-to-grave.

Currently, there are a range of disparate studies investigating the environmental impacts of different types of confectionery products by an advance systems analysis tool known as Life Cycle Assessment (LCA) (Recanati et al., 2018; Konstantas et al., 2017a; Nilsson et al., 2011). For example, a comparison of the existing studies shown in Table 1 reveals major differences and limitations, such as; (1) single product analysis (primarily chocolate) which only provides a limited representation of the diverse confectionery products found in the confectionery industry (Recanati et al., 2018; Konstantas et al., 2017a; Nilsson et al., 2011), (2) inconsistent system boundaries which omit parts of the supply chain resulting in inaccurate environmental impacts (Wallen et al., 2004), (3) lack of environmental impacts categories which do not provide a balanced overview of impacts, especially the impacts associated across the confectionery production – land – water – and energy nexus (Vesce et al., 2016; Jungbluth and Konig, 2014; Nilsson et al., 2011), (4) outdated data (Recanati et al., 2018; Vesce et al., 2016), and (5) limited-to-none improvement strategies to demonstrate effective improvements to prioritise across the confectionery supply chain (Recanati et al., 2018; Jungbluth and Konig, 2014; Ntiamoah and Afrane, 2008).

Overall, based on the disparity of existing studies, there are inevitably major gaps in developing a full and holistic overview of the environmental sustainability of the confectionery industry. Such analysis is important to critically guide the confectionery industry towards a high performance of environmental sustainability. Some of these gaps in knowledge are defined by the following research questions:

1. What are the environmental impacts of different confectionery products from cradle-to-grave?
2. What are the comparative environmental impacts across the different confectionery product groups?
3. What other environmental impact categories can provide a balanced overview of environmental impacts?
4. Which confectionery product category has the highest environmental impact?

Table 1
Comparison of environmental LCA studies for different confectionery products.

No#	Reference	Confectionery type	Functional Unit	Scope of boundary	Environmental impact category	Environmental hotspots
1	Recanati et al. (2018)	Chocolate	1 kg of dark chocolate	Cradle-to-grave: Agricultural, transportation, manufacturing and disposal	Global Warming Potential Eutrophication potential Ozone layer depletion potential Acidification potential Abiotic depletion Cumulative energy demand Photochemical ozone creation potential	Cocoa bean provisioning and energy supply for manufacturing
2	Vesce et al. (2016)	Chocolate	1 kg of chocolate	Gate-to-gate: Production and packaging, use and disposal	Human health Ecosystem quality Climate change Resources	Energy consumption during manufacturing, transportation, packaging
3	Jungbluth and Konig (2014)	Chocolate	1 kg of chocolate	Cradle-to-grave: Agricultural, manufacturing, retail, use and disposal	Cumulative Energy Demand (CED) non-renewable GWP UBP 2006 UBP 2013	Farming and manufacturing
4	Büsser and Jungbluth (2009)	Chocolate	1 kg of chocolate	Cradle-to-grave: Agricultural, manufacturing, retail, use and disposal	Cumulative Energy Demand (CED) non-renewable Global Warming Potential (GWP) Ozone Layer Depletion Acidification Eutrophication	Farming and manufacturing
5	Ntiamoah and Afrane (2008)	Chocolate (Cocoa based products e.g. cocoa butter, cocoa liquor etc.)	1 kg of cocoa beans processed	Cradle-to-gate: Agricultural and manufacturing	Global Warming Potential Atmospheric acidification Eutrophication Photochemical ozone creation Freshwater aquatic eco-toxicity Terrestrial eco-toxicity Human toxicity Ozone layer depletion Depletion of abiotic resources	Pesticides and fertilizers in cocoa cultivation
6	Wallen et al. (2004)	Sugar and chocolate	12 kg of chocolate/sugar	Manufacturing and packing	CO_2 emissions Total energy Use of fossil fuels Energy use	None provided
7	Nilsson et al. (2011)	Sugar	(1) 125 g of foam sweets (2) 2 kg of jelly sweets	Cradle-to-gate: Agricultural, manufacturing, distribution, retail, and disposal	Global Warming Potential (GWP) Eutrophication Primary energy	Ingredient production and production plant
8	Wiltshire et al. (2009)	Fine bakery ware	165 g of Jaffa Cake	Agricultural, manufacturing and disposal	GHG emissions	Raw materials and factory
9	Konstantas et al. (2017a)	Fine bakery ware	1 kg of packaged biscuits	Cradle-to-grave	Primary Energy Demand (PED) Global Warming Potential (GWP) Water footprint Land use	Raw materials production, manufacturing and transport
10	Konstantas et al. (2017b)	Fine bakery ware	1 kg of packaged cupcake	Cradle-to-grave	Primary Energy Demand (PED) Global Warming Potential (GWP) Water footprint	Raw materials production, manufacturing and transport

5. How do the environmental impacts vary across different impact categories?
6. How do functional units affect the environmental analysis of various confectionery products?
7. What improvement strategies can deliver effective environmental impact reductions across product categories and the confectionery industry?

In this paper, these research questions are addressed by presenting a comprehensive analysis of the environmental impacts and improvement actions from cradle-to-grave for different confectionery products which are sugar, milk chocolate, dark chocolate, chocolate biscuit and milk based. The confectionery products are manufactured by Nestle, a multi-national food company at their confectionery factory in the North East of England. The functional unit is defined as the ‘production of 1 kg of packaged confectionery product'.

The paper starts with a description of the proposed Life Cycle Assessment (LCA) methodology adopted in Section 2. The results and discussions of the environmental impacts, functional units and improvement actions for different confectionery products are presented in Section 3. Lastly, the conclusions and future work are provided in Section 4.

2. Materials and methods

A transdisciplinary process involving both Nestle practitioners and academics from the University of Surrey was adopted for the development and application of the LCA methodology for confectionery products (Miah et al., 2015a). An attributional process Life Cycle Assessment (LCA) was adopted to evaluate the environmental impacts of different confectionery products by following the ISO 14040/14044 methodology (ISO, 2006; Bauman and Tillman, 2004; Sadhukhan et al., 2014). In comparison to previous studies (Recanati et al., 2018; Vesce et al., 2016; Jungbluth and Konig, 2014), the novel features of the proposed LCA methodology adopted are:

(1) LCA of confectionery products representing core product groups found in the CI. This is important because current studies do not provide environmental impacts of all the main confectionery groups;
(2) Full supply chain analysis from cradle-to-grave. By analysing the full system boundary provides a genuine life cycle analysis rather than specific parts of the supply chain;
(3) Inclusion of food waste data. The food waste generated represents inefficiencies where environmental resources are utilised to manufacture;
(4) Inclusion of pre-processing stage of chocolate manufacture e.g. milk crumb and milk chocolate. Due to the high composition of chocolate ingredients, the milk crumb and milk chocolate manufacture can potentially have a considerable impact;
(5) Analysis from multiple functional units to show how environmental impact vary e.g. mass versus nutritional benefits;
(6) Multi-criteria decision analysis (MCDA). A MCDA allows different environmental impact categories to be compared to each other for benchmarking and decision-making;
(7) Assessment of multiple improvement strategies to demonstrate what can be improved and how;
(8) A broader range of environmental impact categories relevant for the confectionery industry e.g. water, land use and ecosystems quality; and
(9) Data sources based on dedicated LCI food databases such as WFLCD. The utilisation of current data ensures the impacts are up-to-date and accurate compared to older studies.

By using Life Cycle Inventories (LCI), the environmental impacts across the confectionery supply chains can be calculated by Eq. (1) as shown below:

$$Environmental\ Impact = \sum_{i=1}^{n} A_{p(i)} \times E_{p(i)} \quad (1)$$

where: A_p is the inputs (i) into a product's supply chain including raw material extraction, energy consumption, material production and manufacturing processes, etc.; n is the total number of process input (i) into the product's supply chain and Ep is the emissions intensity across a number environmental sustainability metrics (e.g. GHG emissions, land use etc.), for each input (i) into a product's supply chain emissions. The methodology and assumptions are described in more detail in the following sections. For specific data, please see supplementary.

2.1. System boundaries and system definition

The life cycle stages considered are shown in Fig. 1 for the various confectionery products from 'cradle-to-grave'. The key differences between the confectionery products are the ingredients and packaging materials, composition and the pre-processing stage. For example, milk chocolate confectionery product contains pre-processed milk crumb[1] and milk chocolate whereas sugar and milk-based confectionery has no pre-processing attributes.

1 = Milk crumb is a crystallised mixture made of milk, sugar and cocoa liquor. The main purpose is to enhance flavour and extend shelf-life (Beckett et al., 2017Beckett).

2.1.1. Raw materials, ingredients and packaging

The ingredients used for the various confectionery products including milk crumb, milk chocolate and dark chocolate are shown in Table S1 in supplementary with country of origin and source of Life Cycle Inventory (LCI) data.

For the packaging, the environmental impacts involve the conversion of raw materials to packaging components and print format which is used for the final packaging material for the confectionery products. All the primary and secondary packaging has only been considered for the final packaged confectionery product where the packaging conversion process has been assumed and selected from the databases of Ecoinvent v.2.2 integrated with GaBi 6.0 (Thinkstep, 2015). The tertiary packaging components (e.g. pallets and stretch wrapping) have not been considered as the %weight from a system's perspective is negligible. Also, the packaging aspects for ingredients, intermediary ingredients and packaging components have not been considered as they are supplied in bulk bags which are reused and from a system's perspective the %weight is negligible. The data for the packaging of the confectionery products are shown in Table S2 in supplementary.

2.1.2. Pre-processing and manufacturing

The pre-processing stage only includes the processing and manufacture of intermediary materials utilised to manufacture a confectionery product. For milk chocolate confectionery and milk chocolate biscuit confectionery product, this includes the manufacture of milk crumb and milk chocolate. For the dark chocolate confectionery product, this includes the manufacture of dark chocolate. The pre-processing stage takes place all in-house by the food company in the UK.

For the manufacturing stage, this involves the manufacture of the final packaged confectionery product utilising a diverse range of food and packaging technology at a confectionery factory in the UK. The confectionery factory is a multi-product confectionery factory which employs a range of technologies to manufacture sugar, chocolate, chocolate biscuit and milk based products (Miah et al., 2015b). For some of the chocolate products, the same technology and/or production lines were used. The LCI data for the confectionery factory is extracted from Miah et al. (2017).

2.1.3. Distribution, retail and consumption

The final packaged confectionery product is transported to a distribution centre located in York and stored at ambient room temperature. The storage time for confectionery products is assumed to be four weeks. From the distribution centre, the packaged product is transported to a retailer where the confectionery product is assumed to be stored in ambient room temperature for four weeks. These assumptions are based on industrial practices (Espinoza-Orias, 2017).

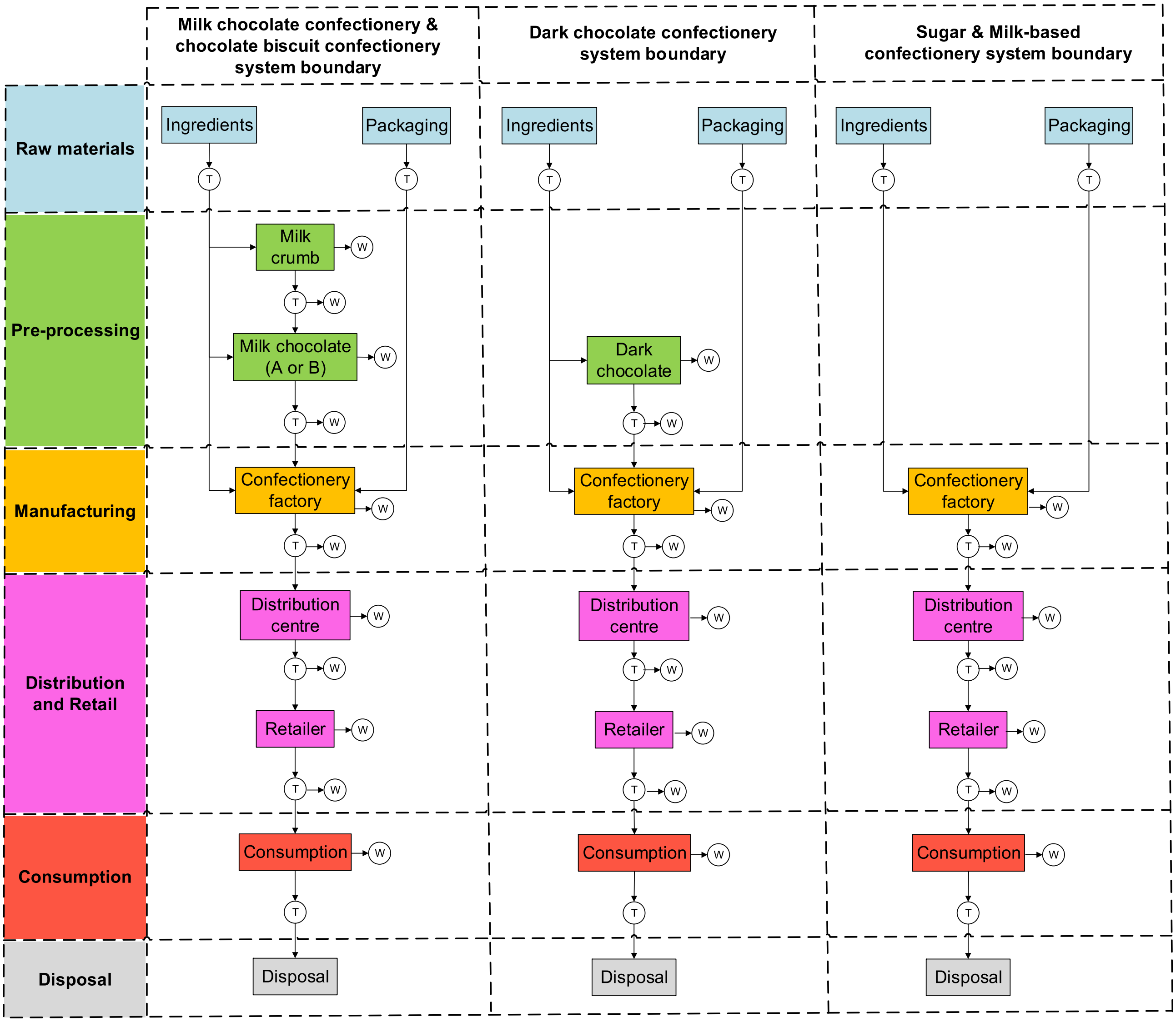

Fig. 1. Life cycle stages for milk chocolate confectionery, milk chocolate biscuit confectionery, dark chocolate confectionery, sugar confectionery and milk-based confectionery products. (T = transport, W = waste, Milk chocolate A & B are two different types of milk chocolate).

For the consumption stage, this involves the consumption of the confectionery product in a home environment. Since confectionery products are packaged in a ready-to-eat format there is no preparation required for consumption. As such, it is assumed that there are no environmental impacts associated with consumption apart from transportation to-and-from the retailer.

2.1.4. Disposal

This stage considers only the waste generated from the factory to the consumption stage. The waste materials generated are from food waste and packaging. For food waste generated, see Table 2.

For the packaging materials, the disposal includes primary and secondary packaging of the confectionery product only which consist of product packaging and the corrugated-board boxes used to pack the final products. The packaging for other parts of the supply chain (e.g. transport, distribution centre, retail) are assumed to be negligible. The disposal routes for the five different confectionery products are assumed to be recycling (packaging materials only) and incineration that occur in the UK. The disposal assumptions are summarised in Table S3 in supplementary which is based on UK recycling rates (PAFA, 2015; CPI, 2013). The LCI data for disposal have been sourced from the databases of Ecoinvent v2.2 integrated with GaBi 6.0 (Thinkstep, 2015).

2.1.5. Transport

The environmental impacts associated with transport at different LCA stages are combined together as the impact from

Table 2
Food waste generated across the confectionery supply chain on a 1 kg basis.

Life Cycle Stage	% waste generated	End-of-Life
Factory	• Sugar products = 4.1%[a] • Chocolate products = 2%[a] • Biscuit products = 5.7%[a]	Energy-from-waste
Transport	0.12%[b]	Landfill
Distribution	0.23%[b]	Landfill
Retail	0.7%[c]	Landfill
Consumer	5%[d]	Landfill

[a] Miah et al., 2017.
[b] Espinoza–Orias, 2017.
[c] WRAP, 2016.
[d] WRAP, 2014.

Table 3
Different life cycle impact assessment methods used to estimate a range of environmental impacts.

Life cycle impact assessment method	Indicator name	Nestle EcodEX definition
CML 2001 (Guinée et al., 2002)	Global warming potential (GWP)	Greenhouse gas emissions
CML 2001 (Guinée et al., 2002)	Abiotic depletion (ADP elements and fossil)	Non-renewable resources & Fuels
ReCiPe (Goedkoop et al., 2009)	Water depletion	Freshwater consumption
ReCiPe (Goedkoop et al., 2009)	Agricultural land occupation	Land use
ReCiPe (Goedkoop et al., 2009)	Urban land occupation	
Impact 2002+ (Humbert et al., 2012)	Aquatic acidification	Ecosystems quality
Impact 2002+ (Humbert et al., 2012)	Aquatic eutrophication	
Impact 2002+ (Humbert et al., 2012)	Terrestrial ecotoxicity	

transportation for some stages is negligible. The transport distances for each ingredient and packaging material have been determined based on existing suppliers to the confectionery factory. For some materials, not all transport distances are disclosed due to confidentiality. The distances between the distribution centre and retailer are assumed to be 100 km. The distances between the retailer and consumer are assumed to be 5 km. The distances between the consumer and disposal routes are assumed to be 30 km. These distances are based on current industrial practices (Espinoza-Orias, 2017). The transport assumptions are summarised in Table S4 in supplementary. The LCI data for transport have been sourced from the databases of Ecoinvent v.2.2 (Frischknecht et al., 2007) integrated with GaBi 6.0 (Thinkstep, 2015).

2.1.6. Environmental impact assessment methodologies

The environmental life cycle impacts of different confectionery products were modelled in Microsoft Excel based on Nestlé's EcodEX LCA tool (Schenker et al., 2014). Currently, five environmental impact indicators are taken into account by EcodEX, shown in Table 3. They are: land occupation and water consumption at the inventory level (Goedkoop et al., 2009); GHG emissions at a 100 year perspective (IPCC, 2006) and Non-renewable minerals and fuels (Guinee et al., 2002) at the midpoint level; and Ecosystems Quality (based on the IMPACT, 2002 + method and modified to exclude land occupation and thus avoid double counting) at the endpoint level (Jolliet et al., 2015). Overall, the indicators adopted in EcodEX are found elsewhere in food LCA applications either on their own or combined (Fusi et al., 2016; Rivera et al., 2014; Roy et al., 2009).

The EcodEX tool contains LCI data sourced from several public LCI databases which are continually uploaded as commercially practical to the latest versions such as Ecoinvent (Frischknecht et al., 2007), the World Food LCA Database (Quantis, 2014), Agribalyse database (Koch and Salou, 2013) and Agrifootprint (Agrifootprint gouda, 2014). In practice, the integration of data from different sources is routinely applied to complete data gaps (Roy et al., 2009). However, a critical perspective must be taken in the interpretation of results due to methodological differences in different LCI DBs.

For gaps in data (e.g. ingredients, packaging etc) and where no datasets are currently available in public databases, datasets are created based on LCA studies done by consultants for Nestlé and/or collected directly from suppliers. For datasets which were collected from suppliers (e.g. Miah et al., 2017), the data were converted to environmental impacts categories defined by EcodEX using Gabi LCA software V6.4 (Thinkstep, 2015), shown in Table 3.

In the Nestle EcodEX tool, the environmental impact categories are presented on their own. There is no feature to aggregate environmental impact categories together as this is a subjective exercise involving multi-criteria decision analysis (MCDA). As such, in this paper, the environmental impacts are presented both on their own and in an aggregated format after the application of MCDA. The application of MCDA allows different environmental impact categories to be compared and combined together, especially when there are conflicting criteria, qualitative and quantitative data and information on different scales. The key benefit is the ease of interpretation in decision making for environmental management. There are many types of MCDA methods which include Weighted Sum Model (WSM), multi-attribute utility theory (MAUT), The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), multi-attribute value theory (MAVT) and analytical hierarchy process (AHP) (Azapagic and Perdan, 2005).

For the purposes of comparing aggregated environmental impacts, the WSM has been used as it allows a simple consideration of all five environmental impact categories by applying weights to criteria. It is assumed each environmental impact category is valued equally since the elicitation of preferences by decision makers and stakeholders was outside the scope of the study. The typical steps involved in WSM include normalisation, weighting and aggregation.

For the normalisation stage, each environmental impact category is rescaled from 0 (best value) to 1 (worse value) to avoid scale affects in the aggregation of parameters inside each environmental impact category. The best value represents the lowest environmental impact. Whereas the worse value represents the highest environmental impact. Normalisation was done using Diaz-Balteiro and Romero (2004) Equation (2).

$$X_n = \frac{X_i - X_{min}}{X_{max} - X_{min}} \quad (2)$$

In Equation (2), X_i is the value of ith parameter in the environmental impact category. X_{max} and X_{min} are the best and worst values of the ith environmental impact category.

For the weighting and aggregation stage, it is assumed each environmental impact has equal importance during the aggregation. The aggregated environmental impacts (AEI) is calculated according to Equation (3).

$$AEI = \sum w_i \cdot X_n \quad (3)$$

In Equation (3), the AEI is the sum of all normalised environmental impacts. The weight (w_i) of each environmental impact category is 1.

3. Results and discussion

3.1. Comparison of environmental impacts for different confectionery products

3.1.1. Global Warming Potential (GWP) impact

A comparison of the Global Warming Potential (GWP) impact for different confectionery products is shown in Fig. 2. In addition, the sensitivity analyses of the contributing ingredients by ±20% of mass weight are carried out to assess the influence on total GWP impact, shown in Fig. 3. The procedure for the sensitivity analysis is to only change one of the key contributing ingredients by ±20% of mass weight whilst keep all other parameters the same. The procedure is repeated for other ingredients to find the most sensitive ingredients.

For the GWP impact, it can be seen that the dark chocolate confectionery has the highest impact whereas the sugar confectionery has the lowest impact, shown in Fig. 2. The milk chocolate confectionery has the second highest followed by the milk chocolate biscuit confectionery and milk-based confectionery, respectively. Overall, the dark chocolate confectionery can cause greater than 395% global warming potential impact compared to the sugar confectionery. The major reason for the difference between the highest and lowest impact confectionery products is due to the raw materials. For example, the sensitivity analysis shown in Fig. 3 shows that cocoa butter, cocoa liquor and milk-based ingredients are largely responsible for the high raw materials stage impact in DCC.

Some of the contributing factors for the different GWP hotspots are related to the types of ingredients used and processing technology. For example, sugar confectionery has a high impact at raw materials stage due to ingredients such as sugar, glucose syrup, and gelatine powder. Such ingredients are intrinsically energy intensive. Whereas for the chocolate based confectionery, the high percentage of cocoa based ingredients increases the GWP impact due to high energy demand to cultivate and process cocoa beans into milk chocolate and associated deforestation. Similarly, for the milk-based confectionery, the high impact at raw materials stage is due to ingredients such as dairy-based products, sugar, and palm oil. Overall, the selection of a few ingredients can considerably contribute to the GWP impact of confectionery products.

The factory stage accounts for the second highest environmental impact area across all five confectionery products. This is primarily due to the energy used for the different processing technology. Further analysis shows that on average, for this particular case study, the direct energy (e.g. natural gas) accounts for 66% of energy utilisation whereas 34% accounts for indirect energy (e.g. grid electricity), shown in Fig. 4. As such, there are opportunities to reduce energy demand, especially the application of heat integration to reduce natural gas consumption.

Furthermore, one of the key differences between the GWP impacts of different confectionery products is the high percentage attributed to manufacturing for sugar confectionery. In comparison to the rest of the confectionery products, the manufacturing stage for sugar confectionery attributes nearly 50% of the total GWP impact. The reasons for the high impact at manufacturing stage is due to energy intensive sugar processing technology which involves batch cooking and long durations of temperature controlled heating. Whereas chocolate confectionery products are produced in a semi-continuous operations involving less energy intensive processing and higher throughput of production to increase overall efficiency.

3.1.2. Water depletion impact

An alternative environmental impact category that is growing in importance in the food industry is water impacts (FDF, 2016). Some of the primary drivers are related to water scarcity, resource efficiency, and environmental stewardship. A comparison of the water depletion impact for different confectionery products is shown in Fig. 5. In addition, the sensitivity analysis (as described in Section 3.1.1) of the contributing ingredients by ±20% of mass weight are carried out to assess the influence on total water depletion impact, shown in Fig. 6.

In comparison to the GWP impact, it can be seen that the sugar confectionery product has the highest water depletion impact whereas the milk chocolate confectionery has the lowest impact, shown in Fig. 5. The milk chocolate biscuit confectionery has the second highest impact followed by the dark chocolate confectionery and milk-based confectionery, respectively. Overall, the sugar confectionery is more than 165% of the milk chocolate confectionery. The major contributor between the highest and lowest impact confectionery products is due to the raw materials. In particular, for the sugar confectionery the high water impacts are attributed to gelatine powder (48% of total water impacts). In comparison to other sugar confectionery ingredients, it was found from the data collected from suppliers, the processing sites for gelatine powder generated energy from different sources (e.g. natural gas, coal, fuel oil and wood) requiring high water consumption (Miah et al., 2017).

Another interesting difference between the seven confectionery products for water depletion impact is the similar percentage attributed by both raw materials and manufacturing stage. Some of the contributing factors for raw materials stage are similar to factors contributing to GWP impact. However, for the manufacturing stage, the energy mix from indirect sources has shown to have a strong role in the water depletion impact. For example, the

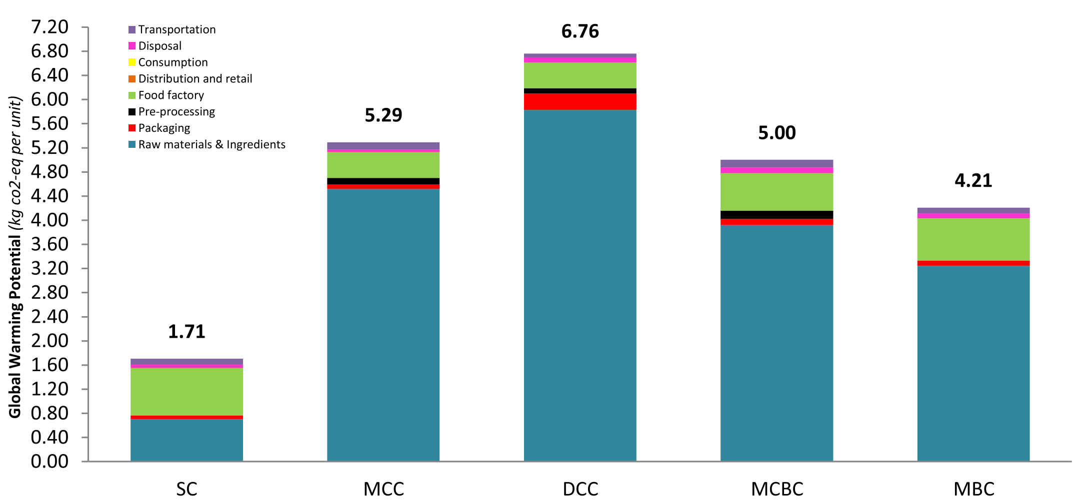

Fig. 2. A comparison of the GWP impact for different confectionery products. (SC = Sugar confectionery, MCC = Milk chocolate confectionery, DCC = Dark chocolate confectionery, MCBC = Milk chocolate biscuit confectionery, and MBC = Milk based confectionery).

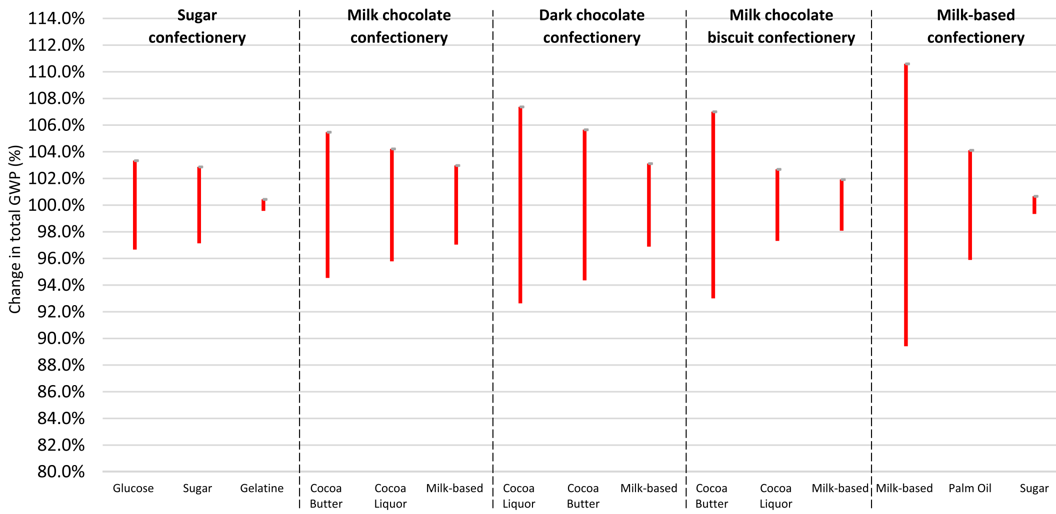

Fig. 3. Sensitivity of key ingredients contributing to GWP impact across five confectionery products.

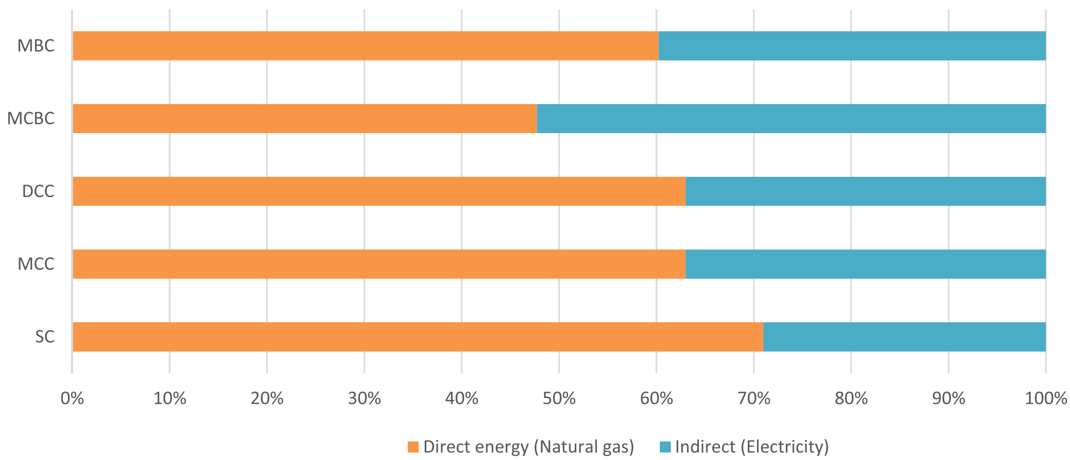

Fig. 4. Comparison of direct and indirect energy percentage for different confectionery products.

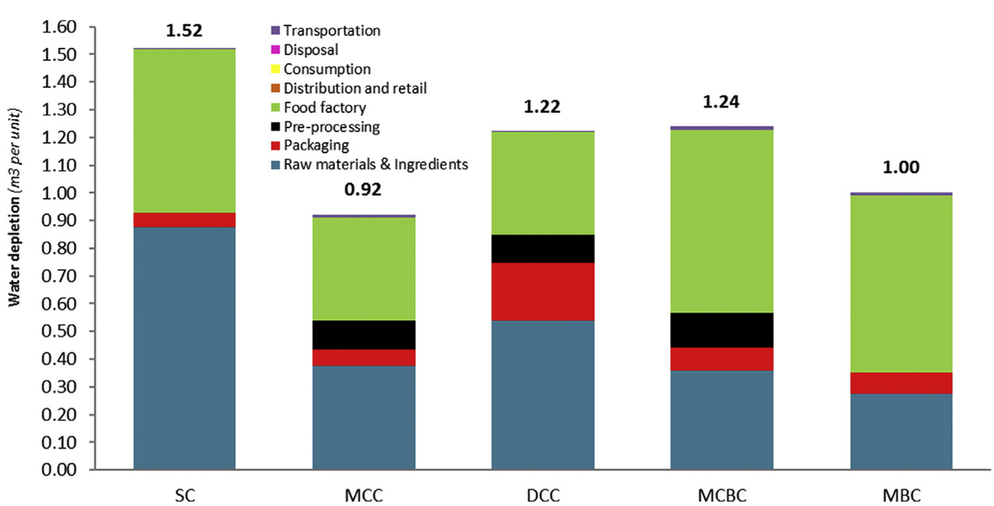

Fig. 5. A comparison of the water depletion impact for different confectionery products.

chocolate biscuit manufacturing stage involves a higher electricity contribution than the other chocolate-based confectionery products. As such, alternative energy sources can potentially reduce water depletion impacts.

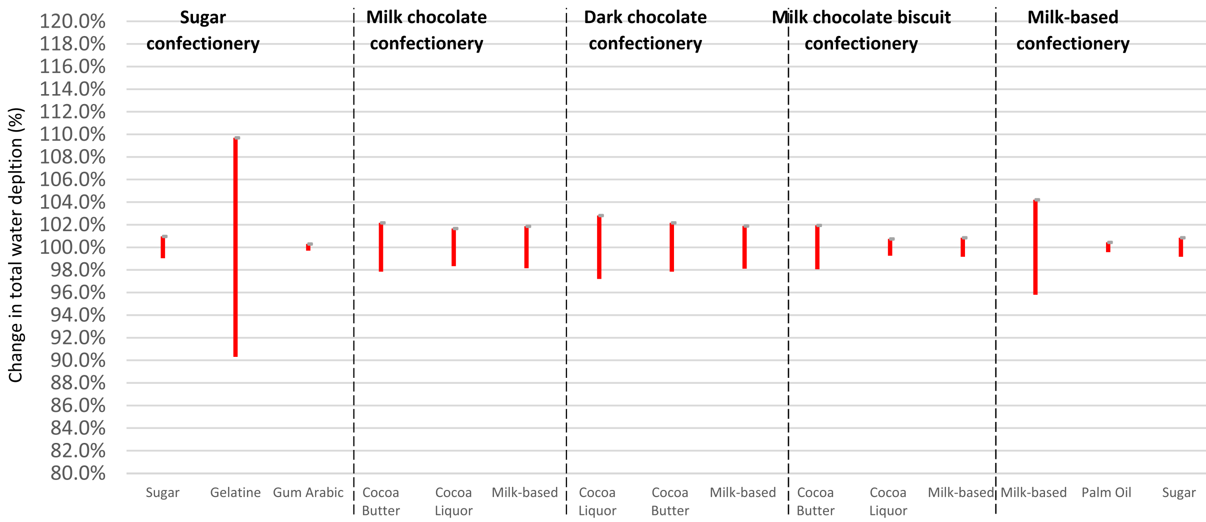

Fig. 6. Sensitivity of key ingredients contributing to water depletion impact across five confectionery products.

Another significant difference is the water depletion impact attributed to packaging stage (inc. packaging conversion) across the five confectionery products. In particular, the packaging stage for dark chocolate confectionery product accounts for nearly 17% of total water depletion impact. The reasons for the high impact at packaging stage are primarily due to the large percentage weight of packaging material compared to other confectionery products. However, further investigation of the LCI data found the following contributing factors: (1) energy mix associated with the manufacture of plastic packaging and cardboard and (2) open loop water systems during plastics and cardboard manufacturing compared to closed-loop where water is recycled. Furthermore, another key difference is that the dark chocolate confectionery product (for this example) is regarded as a seasonal product e.g. sold during the winter period. Due to seasonal nature, these types of products can have a higher packaging weight due to unique packaging formats e.g. different shapes and textures. Overall, packaging weight should be optimised within the constraints of quality parameters and product requirements.

3.1.3. *Abiotic Depletion Potential (ADP) impact*

Another environmental impact category that is widely considered in environmental LCA is Abiotic Depletion Potential (ADP). The ADP is an indication of depletion of non-renewable resources i.e. fossil fuels, metals and minerals (Guinee, 2015). A comparison of the Abiotic Depletion Potential (ADP) impact for different confectionery products is shown in Fig. 7. In addition, the sensitivity analysis (as described in Section 3.1.1) of the contributing ingredients by ±20% of mass weight are carried out to assess the influence on total ADP impact, shown in Fig. 8.

For the five confectionery products, it can be seen the dark chocolate confectionery has the highest ADP impact whereas the sugar confectionery has the lowest impact, shown in Fig. 7. The milk chocolate confectionery has the second highest followed by milk-based confectionery and milk chocolate biscuit confectionery. Overall, the milk chocolate confectionery is more than 196% of the sugar confectionery. Some of the major contributor factors for the difference are due to the raw materials found in chocolate-based products such as cocoa based ingredients, dairy-based products, sugar, and palm oil.

In comparison to GWP impact, the environmental hotspots are primarily due to the raw materials and ingredients, transportation and packaging, respectively. The factors influencing raw materials and ingredients impact are similar to GWP impact. However, the reasons for the high impact at transportation stage is due to the numerous travel journeys made for many different ingredients sourced from different locations both within the UK and internationally. Whereas the reason the packaging stage has a high impact, in particular for dark chocolate confectionery, is due to the PET (Polyethylene Terephthalate) material used in the confectionery product.

Another interesting difference between GWP and ADP impact is the disposal stage. For all five confectionery products, the disposal stage contributes to improving the environmental impact as a large proportion of material is recycled, represented as negative value in Fig. 6. As such, further initiatives to recycle and reuse materials can have positive impact on the environment. However, further environmental and economic analysis is required on the reverse logistics supply chain that is created to facilitate material recovery and re-use.

3.1.4. *Land use impact*

Another environmental impact indicator that has formed part of previous environmental analysis in the food industry is land use (Foresight, 2010). The assessment and reduction of land use is highly important for decision makers given the finite resources available and multiple competitions of land use for different purposes such as human settlements, industry and recreation (Canals et al., 2013). A comparison of the land use impact for different confectionery products is shown in Fig. 9. In addition, the sensitivity analysis (as described in Section 3.1.1) of the contributing ingredients by ±20% of mass weight are carried out to assess the influence on total land use impact, shown in Fig. 10.

For the five confectionery products, it can be seen that the dark chocolate confectionary has highest land use impact whereas the sugar confectionery has the lowest impact, shown in Fig. 9. The milk chocolate confectionery has the second highest followed by milk chocolate biscuit confectionery and milk-based confectionery. Overall, the dark chocolate confectionery impact is more than 1200% of the sugar confectionery. Some of the contributing factors are common for all three chocolate-based confectionery products as the majority of the impact is generated at the raw materials stage, see sensitivity analysis of key ingredients in Fig. 10. Several common ingredients shared in the chocolate-based confectionery

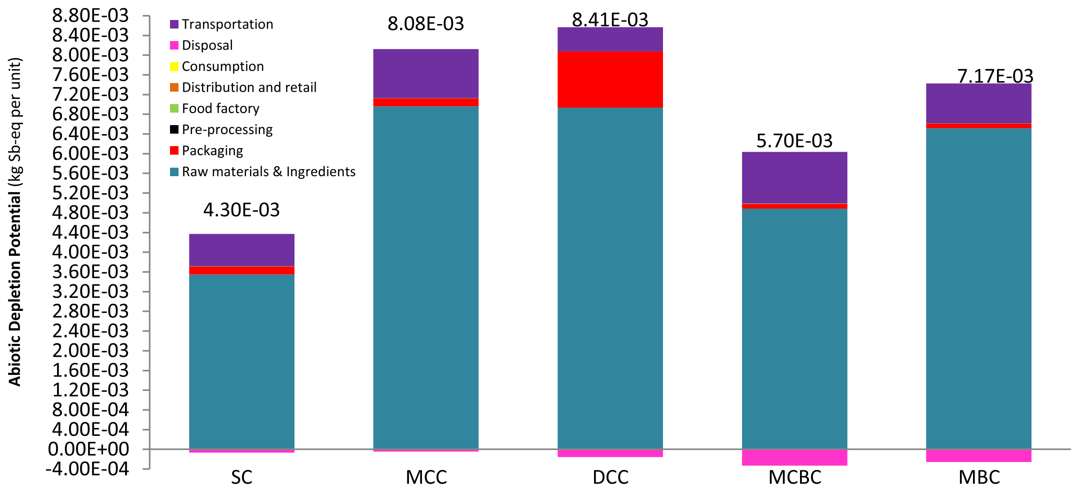

Fig. 7. A comparison of the Abiotic Depletion Potential impact for different confectionery products.

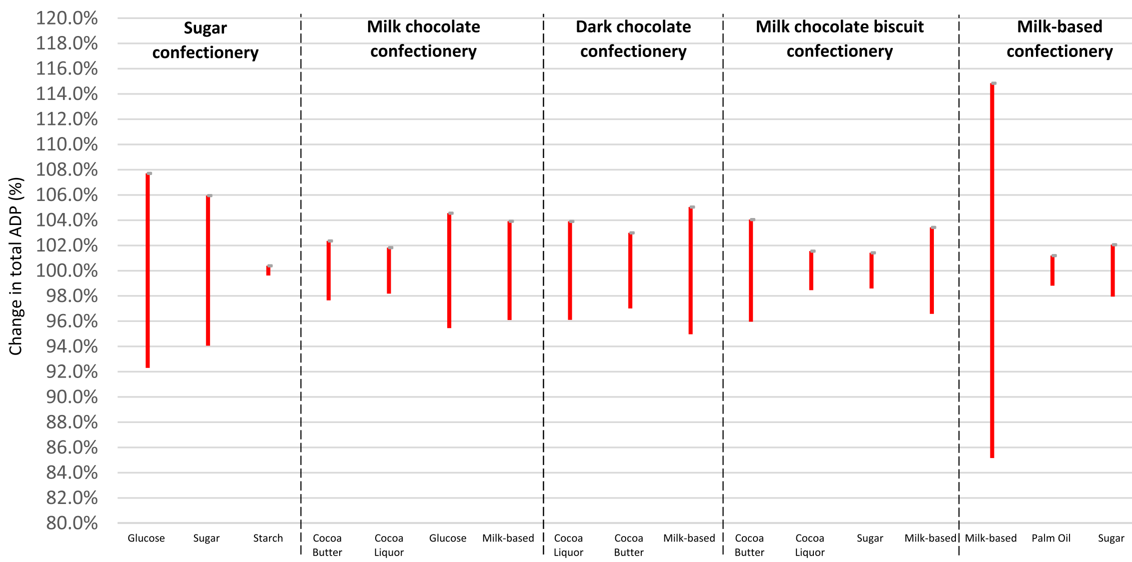

Fig. 8. Sensitivity of key ingredients contributing to ADP impact across five confectionery products.

such as sugar, milk and cocoa-based ingredients which have a relatively high land use requirement. However, the reason dark chocolate confectionery total impact is higher is due to the high percentage of cocoa-based ingredients. For the milk-based confectionery product, the majority of impacts arises from high land use requirements from ingredients such as sugar, dairy-based

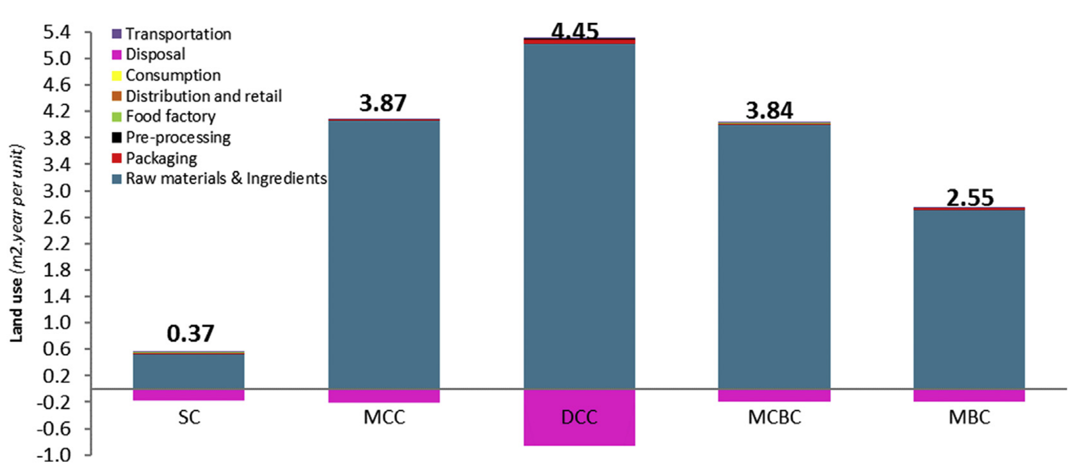

Fig. 9. A comparison of the land use impact for different confectionery products.

ingredients and palm oil. In addition, dairy-based ingredients require land for grazing and/or feed cultivation. As such, initiatives developed as part of a corporate sustainability strategy should seek to work with farmers by providing assistance and technical training to encourage environmental reductions.

A key finding shown in the land use impact is the positive role recycling can have on the environment. Similar to the ADP impact, the five confectionery products have a positive impact on the environment at the disposal stage since a large proportion of material is recycled, represented as a negative value in Fig. 9. Further research should be carried out on developing packaging materials with a high percentage of recycled material and seeking disposal routes higher up the waste hierarchy such as energy from food waste.

3.1.5. Ecosystems quality impact

Another emerging environmental impact indicator which is growing in importance for decision makers in the food industry is related to natural capital and biodiversity, called ‘ecosystems quality’ (FDF, 2016). The consideration of natural capital in its widest sense and protection of biodiversity is primarily driven by the role nature plays in supporting a healthy and functioning ecosystem for food production (Bordt, 2018). A comparison of the Ecosystems Quality (EQ) impact for different confectionery products is shown in Fig. 11. In addition, the sensitivity analysis (as described in Section 3.1.1.) of the contributing ingredients by ±20% of mass weight are carried out to assess the influence on total EQ impact, shown in Fig. 12.

A key finding is the role the factory contributes to the overall EQ environmental impact which is primarily driven by the energy sources such as natural gas and electricity. As such, reducing energy demands and considering alternative energy source may help reduce EQ impact. Overall, the EQ profile for different confectionery products is similar to the water depletion profile. As such, the contributing factors and remediation are similar such as supplier initiatives to reduce environmental impact, reduction in packaging weight, energy reductions and alternative energy sources.

3.1.6. Total environmental impacts of confectionery products

For all five environmental impact categories, a comparison of the aggregated environmental impact is shown in Fig. 13 based on equal weighting. Overall, the confectionery product with the highest aggregated environmental impact is the dark chocolate confectionery due to the high chocolate and dairy-based product content. It was found the dark chocolate confectionery was higher than milk chocolate biscuit confectionery by 21.7%, milk chocolate confectionery by 35.8%, milk-based confectionery by 42.2%, and sugar confectionery by 48.4%.

3.2. Comparison with other food products

A general comparison with other food products is provided to demonstrate how the calculated GWP impact benchmark with other food products. A GWP impact was selected for comparison because this is the most common and advanced environmental indicator amongst LCA studies (Muijica et al., 2016; Stoessel et al., 2012). Despite this, for such comparisons, there are major limitations due to differences in system boundary, life cycle impact assessment methodologies and data quality. Nonetheless, the comparative GWP impact for different food products is shown in Fig. 14.

The calculated GWP for the five confectionery products are generally higher than the environmental impacts of other confectionery products e.g. calculated impacts range from 1.75 to 6.77 kg CO_2-eq per 1 kg of product compared to 1.9–4.1 kg CO_2-eq per 1 kg of product (Jungbluth and Konig, 2014). In particular, the dark chocolate confectionery products and biscuit-based products presented in the work is significantly different from Racanati et al. (2018), Jungbluth and Konig (2014) and Konstantas et al. (2017a). For the dark chocolate confectionery, it was found the difference between Recanati et al. (2018) and the work produced in this research was due to different recipes e.g. higher sugar content and dairy products. However, further analysis of the difference between the values by Jungbluth and Konig (2014) and Konstantas et al. (2017a) was not possible as the information presented is limited on the product recipes. It is expected the difference arises due to the energy mix of manufacturing, data sources and composition of ingredients. As such, the environmental life cycle impacts presented in this paper is the most transparent environmental LCA on confectionery products. Such information will be extremely valuable in the future to researchers working on improving the environmental sustainability of confectionery manufacturing.

Overall, when the five confectionery products are compared to different food products such as bread (Espinoza-orias et al., 2011),

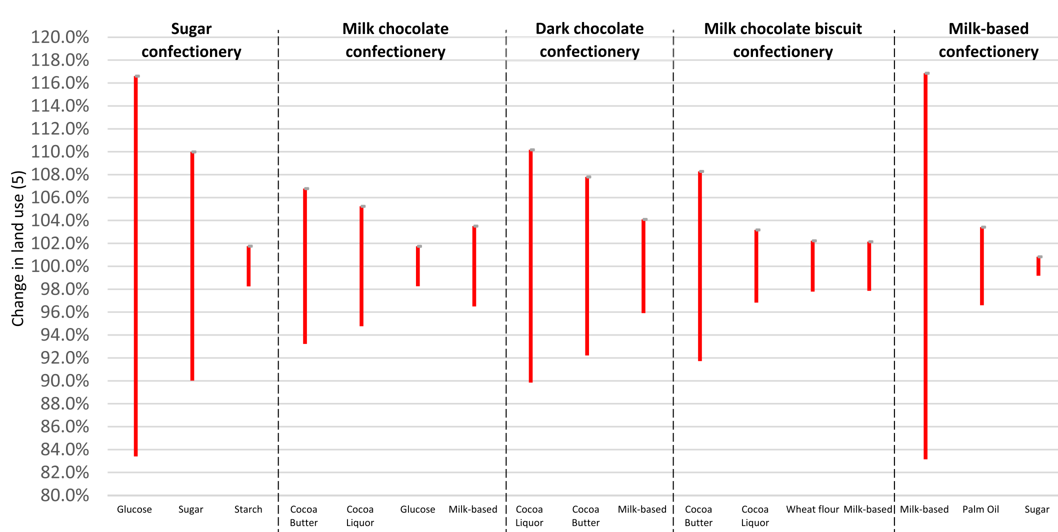

Fig. 10. Sensitivity of key ingredients contributing to land use impact across five confectionery products.

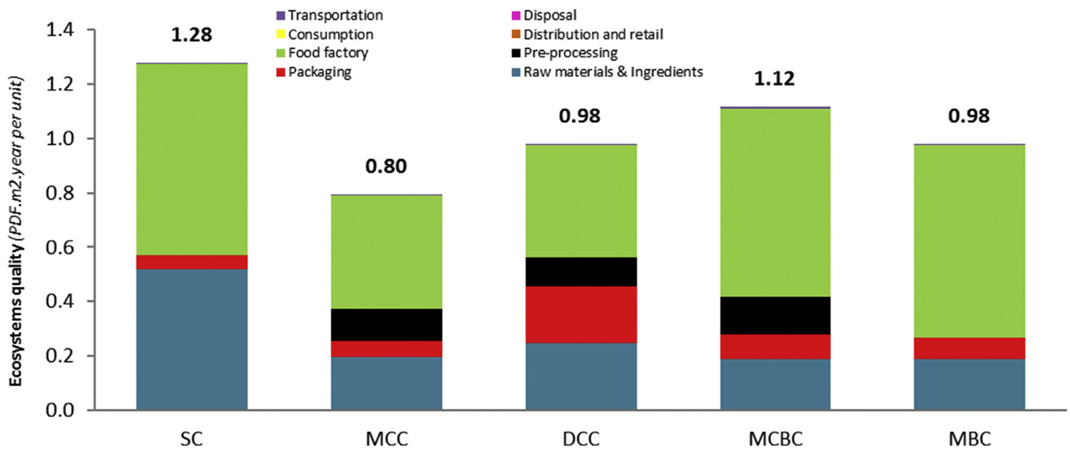

Fig. 11. A comparison of the ecosystems quality impact for different confectionery products.

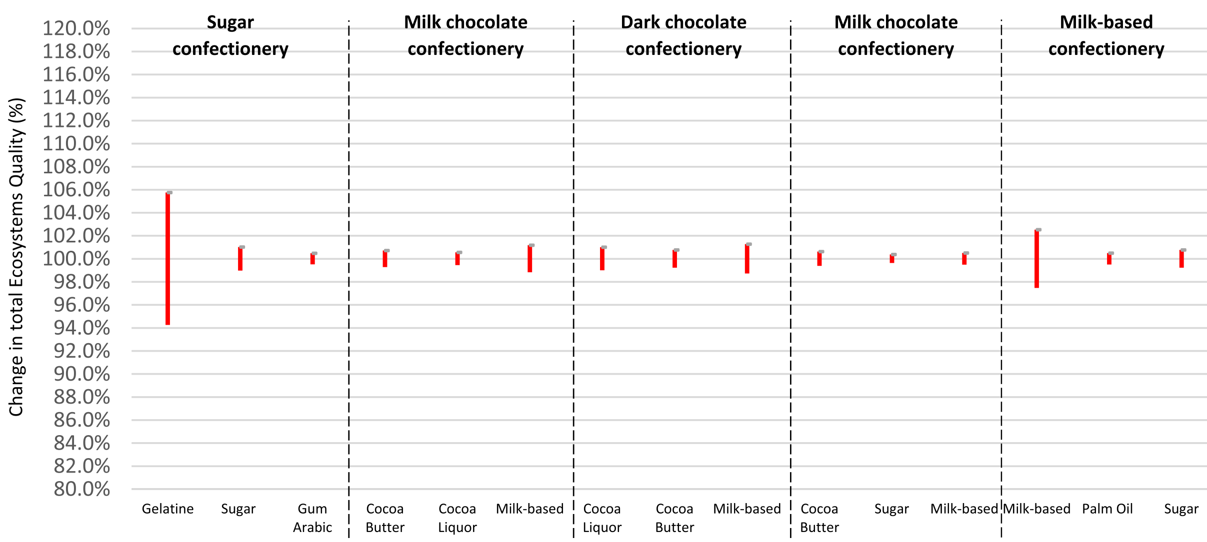

Fig. 12. Sensitivity of key ingredients contributing to ecosystem quality impact across five confectionery products.

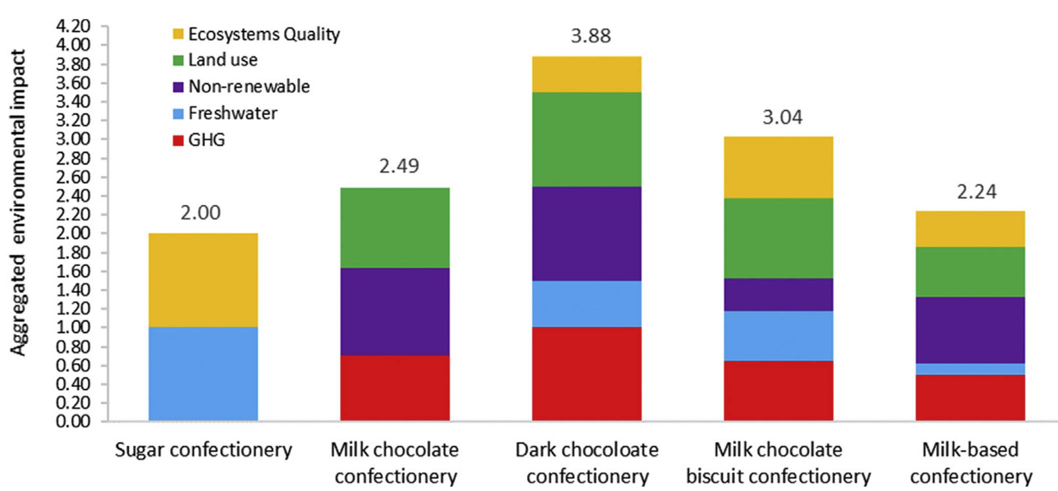

Fig. 13. Aggregated environmental impacts after normalisation for five confectionery products.

ready-made meals (Rivera et al., 2014), dry pasta (Fusi et al., 2016), bananas (Cirad, 2012), and beef (Beauchemin et al., 2010), the GWP impact for the confectionery products is positioned as a medium-to-low environmental impact. For the remaining four

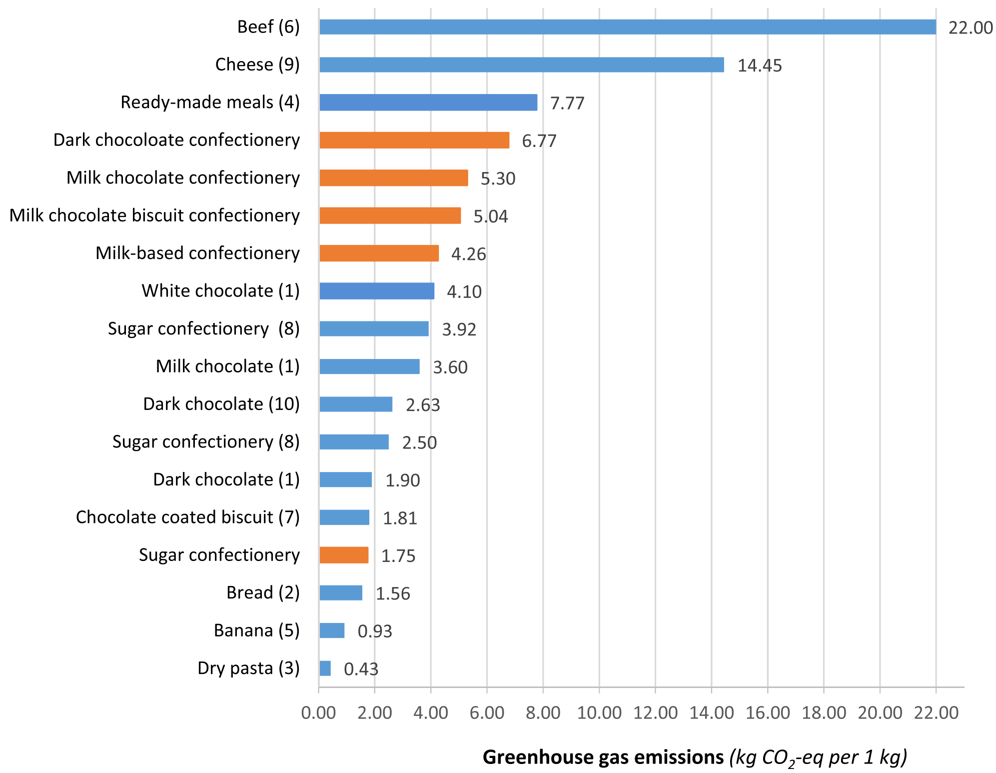

Fig. 14. Comparison of the GWP impacts for confectionery products highlighted in orange with other food products. (1) = Jungbluth and Konig, 2014, (2) = Espinoza-orias et al., 2011, (3) = Fusi et al., 2016, (4) = Rivera et al., 2014, (5) = Cirad, 2012, (6) = Beauchemin et al., 2010, (7) = Konstantas et al., 2017a, (8) = Nilsson et al., 2011, (9) = Santos et al., 2017, and (10) = Recanati et al., 2018. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

environmental impacts, it was not possible to find a diverse range of comparable environmental impacts. As such, future research is required to gauge how these environmental impacts compare with other food products.

3.3. Comparison of functional units

Recently, the consideration of alternative functional units based on nutrition has emerged compared to conventional mass basis (kg CO2-eq/kg of product) to provide a different perspective on the environmental life cycle impacts of food products regarding functionality. For example, kg CO2-eq/kg of protein, kg CO2-eq/1000 calories, kg CO2-eq/mg B12 vitamin, and kg CO2-eq/mg calcium etc (Meija et al., 2017; Saarinen et al., 2017; Sonesson et al., 2017).

In this section, a range of functional units (FU) is explored for the first time in confectionery manufacturing. The aim is to understand the changes in total environmental impact and how this may affect communication strategies for the wider public. Compared to Meija et al. (2017), Saarinen et al. (2017) and Sonesson et al. (2017), three new FU are also considered; serving size, 1 g of fat, and 1 g of sugar. The FU of 100 kcal is also analysed. The 100 kcal is defined as the amount of confectionery product required to deliver 100 kcal. The serving size is defined as the recommended portion of food to be eaten by food manufacturers. They are typically related to nutritional value balanced across daily calorie intake but are not defined by any empirical formula. The 1 g of fat is defined as the amount of product required to consume 1 g of fat. The 1 g of sugar is defined as the amount of product required to consume 1 g of sugar. Overall, a comparison of the total environmental impact after normalisation for the different FUs are shown in Fig. 15.

$\sigma = 0.88$

Across the different FUs considered, it can be seen from Fig. 15 that different FUs result in different total environmental impact. For example, in the original analysis, the 1 kg of packaged product showed the DCC to have the highest total environmental impact. However, when compared with other FUs (e.g. 1 g of sugar and serving size) the dark chocolate confectionery becomes the 2nd or 3rd highest. Such flexibility in selecting alternative functional units can be useful to communicate key messages and/or for internal audiences to reduce sugar and fat content relative to environmental impact reductions.

Furthermore, for each product the variation of environmental impact changes to different degrees. For example, the least variation is generally found in the MCC and SC (standard deviation is 0.70 and 0.88, respectively). Whereas, the largest variation is found in the MCBC and MBC (standard deviation is 1.28 and 1.06, respectively). For the products with a large degree of change, the selection of functional units can have a profound impact on how environmental impacts are communicated, especially in a comparative format. As such, it is recommended that environmental results are presented alongside alternative functional units to provide a fair comparison across different functions.

3.4. Improvement analysis

From the environmental hotspots identified in Section 3.1, the following improvement areas are explored; raw materials sourcing, packaging materials, renewable energy, product reformulations, and zero waste to landfill.

3.4.1. Raw materials sourcing

For the five confectionery products, a total of 17 key ingredients were identified which contribute to the majority of the

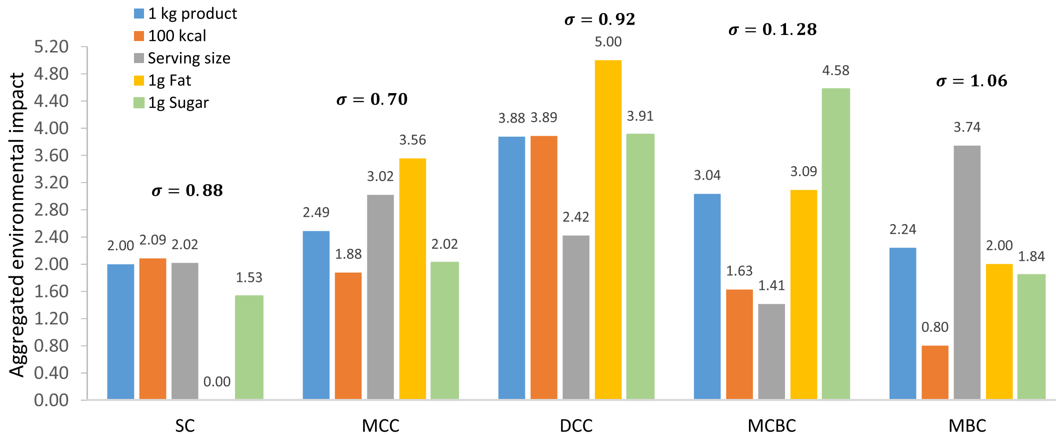

Fig. 15. Comparison of total environmental impacts based on different functional units for five confectionery products, including standard deviations.

environmental impacts e.g. greater than 90%. For the key ingredients identified, several LCI databases were searched for the same materials but with lower environmental impacts such as Agri-footprint LCA database (Agri-Footprint, 2016), and Ecoinvent v 2.2 (Frischknecht et al, 2007). The selection of materials with lower environmental impacts is based on the MCDA process described in Section 3.1.5.

From the 17 key ingredients identified, only 8 ingredients were not changed as alternatives were not available in the LCI databases. Nonetheless, the ingredients which were changed have resulted in a considerable change in total environmental impact across all five confectionery products, shown in Fig. 16 and Table S5.

On average, across all seven confectionery products, the GWP reduction is 49.1%, WD is 13.4%. ADP is 22.2%, LU is 14.8%, and EQ is 9.5%, respectively. The largest reduction was observed for the milk-based confectionery whereas the lowest reduction was seen in sugar confectionery. The majority of the changes are attributed to ingredients with a lower environmental impact resulting from best management practice for crop cultivation/processing. Such practices include: increasing the efficiency and precision of agro-chemical use, reducing waste, soil conversation, pest control, reducing nutrient loading and water pollution (Asare and David, 2011; Donough et al., 2011; Clay, 2003).

In addition, three materials are replaced with a different ingredient belonging to same food category e.g. milk and soya. A comparative example of the environmental reductions for changing milk liquid to soya milk is shown in Fig. 17.

As can be seen in Fig. 17, the environmental reductions from changing milk liquid to soy milk can achieve an environmental reduction across the five environmental categories ranging from 70 to 99%. However, for the materials which have been replaced with different ingredients (e.g. soya-based instead of milk-based), further research is required to understand how ingredient changes impact final products in terms of taste, nutrition, physical appearance, shelf-life, manufacturing, and consumer acceptance etc.

Overall, from the 17 ingredients identified only 9 were changed to lower environmental profiles generating considerable environmental reductions. However, further reductions may be possible if alternative LCI profiles are collected for the remaining 8 materials which includes; buttermilk, whey permeate powder, lactose powder, concentrated milk, gelatine powder, glucose syrup, gum arabic, and natural flavours. Despite this, it is clear from Fig. 16 and previous analysis that the priority ingredients (max number of 5) to focus on should be as follows for the five confectionery products shown in Table 4.

3.4.2. Renewable energy

As part of reducing the environmental impacts from factory operations, the integration of renewable energy (RE) is considered as an intervention. In this paper, the scenario of transitioning to 100% RE is analysed. The 100% RE supply consists of wind energy for all the electricity, biomass for steam heating for the site and biogas for the gas ovens such as biscuit ovens, see Table S6 for LCI profiles. The change in total environmental impacts before and after renewable energy application for the different confectionery products is shown from Table S7.

The integration of 100% RE at factories was found to demonstrate both positive and negative environmental impacts, shown in Fig. 18. For all five confectionery products, the ADP, LU and EQ did not improve, while the impact categories, GWP and WD are improved. The negative environmental impact, especially the large increase observed in EQ, arises from the different inventory flows found for natural gas and biomass. A contribution analysis of EQ impact via GaBi LCA software found the release of heavy metals, in particular Zinc to be considerably higher for biomass than natural gas, see Tables S8 and S9. The source was found to be the fly ash resulting from biomass combustion (Zhang et al., 2014; Wiinikka et al., 2013; Demibras, 2005). In this case, the consideration of biomass energy would require changes in fuel types, modifications to the combustion technology and particle removal technologies to ensure environmental pollutants are reduced e.g. improving combustion efficiency, pyrolysis, scrubbers, Electrostatic Precipitators (ESP) (Sikarwar et al., 2016; Kovacs and Szemmelveisz, 2016; Sadhukhan et al., 2014). However, further research is required to ensure any improvements are across all five environmental categories and not just in one area such as GWP by adopting a systems analysis approach such as LCA.

Alternatively, the adjustment of weights for each environmental impact category can be applied to change the importance of different environmental impact category by a rank preference system (Ren et al., 2015; Kim et al., 2013). For example reducing the significance of EQ. However, such attributions are open to debate since the importance varies from across different stakeholders (Azapagic et al., 2016).

Another approach can be to accept the environmental damage but to allocate a cost for the environmental pollution to be remediated in the future e.g. carbon tax. However, in this case study, the development of the cost for EQ damage resonates with valuing natural capital. Such assessment tools are based on a Willingness-

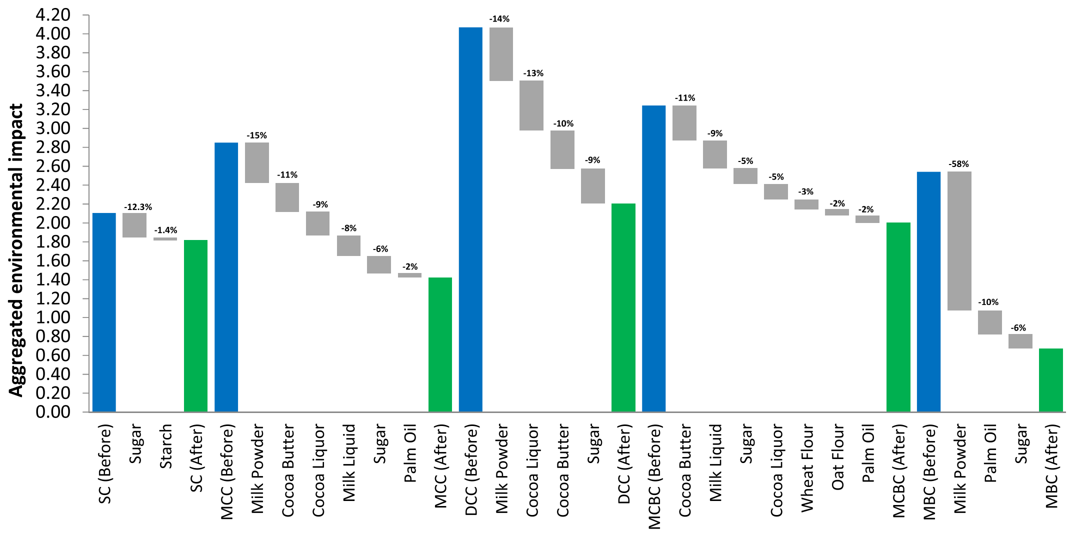

Fig. 16. Contribution of key ingredients in reducing aggregated environmental impacts of different confectionery products.

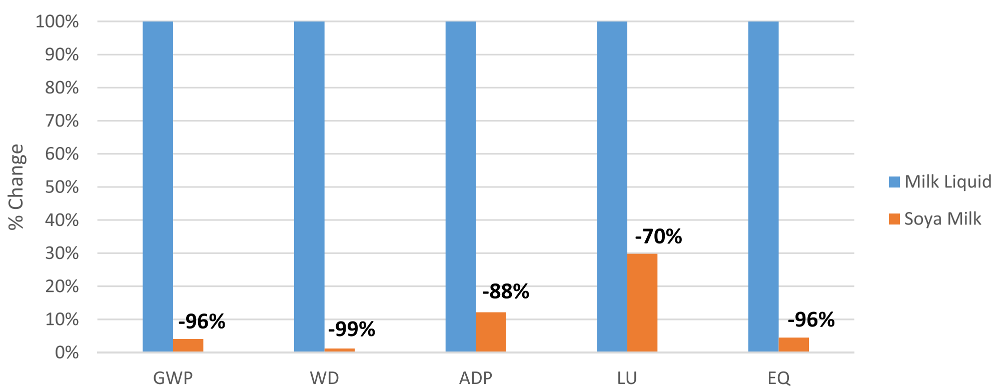

Fig. 17. A comparative example of the environmental benefits of changing milk liquid to soya milk.

Table 4
Priority ingredients to reduce environmental impacts at raw materials stage.

	Sugar confectionery	Milk chocolate confectionery	Dark chocolate confectionery	Milk chocolate biscuit confectionery	Milk-based confectionery
Priority ingredients	1. Sugar 2. Glucose 3. Starch	1. Milk powder 2. Cocoa butter 3. Cocoa liquor 4. Milk liquid 5. Sugar	1. Milk powder 2. Cocoa liquor 3. Cocoa butter 4. Sugar	1. Cocoa butter 2. Milk liquid 3. Sugar 4. Cocoa liquor 5. Wheat flour	1. Milk powder 2. Palm oil 3. Sugar

To-Pay principle and are still under development (Bordt, 2018; World Forum Natural Capital, 2016; Nomura and Akai, 2004).

3.4.3. Packaging materials

Similar to raw materials sourcing, the packaging materials have been changed to materials with a lower aggregated environmental impacts where available in the same LCI databases. From the 5 packaging materials identified, only one material was kept the same, see Table S10. Nonetheless, the packaging materials that were changed has resulted in a mix change in total environmental impact across all five confectionery products, shown in Table S11. On average, across all seven confectionery products, the GWP is increased by 0.7%, water depletion decreased by 7.9%, ADP increased by 12.3%, land use increased by 3.6%, and ecosystems quality decreased by 9.2%, respectively. As an example, a contribution analysis of ADP for the alternative corrugated board found copper and gold elements to be responsible for the increased ADP, see Table S12. The main sources for heavy metals can be found from the use of colorants (e.g. paints and pigments) (Metoglu-Elmas, 2017).

Alternatively, packaging materials based on biomaterials could potentially reduce environmental impacts but requires a systems analysis approach to ensure reductions are made across all five environmental impact categories (Saraiva et al., 2016; McDevitt and Grigsby, 2014; Yates and Barlow, 2013). As such, further research is required to develop packaging materials that have a lower concentration of heavy metals and reduce the overall environmental impact. Such materials can be achieved by designing packaging materials based on 'Design for the Environment' principles in collaboration with packaging manufacturers and research

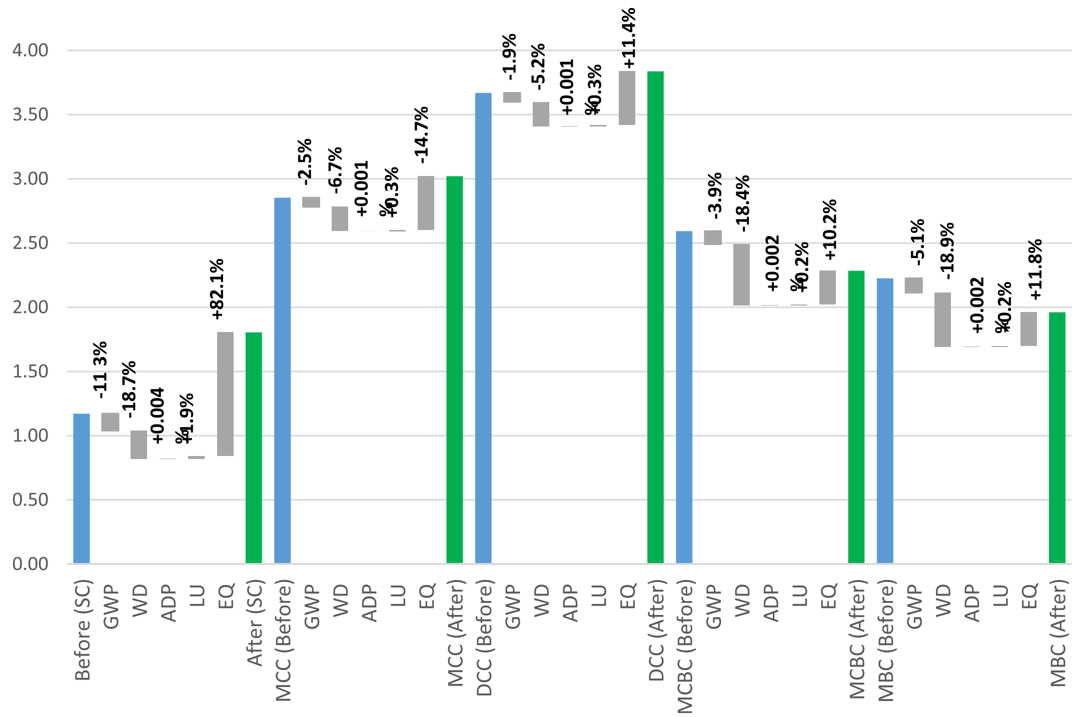

Fig. 18. Contribution of different environmental impact categories on total change from the transition to 100% RE.

institutes (D4E) (UNEP, 2009).

3.4.4. Product reformulations

From the sensitivity analysis of key ingredients, it can be seen that changing the %weight of different ingredients may or may not increase the environmental impact i.e. zero-sum. This is because other ingredients will need to be compensated by increasing to ensure the functional unit is satisfied. However, in reality, the reformulation of a product would involve multiple dimension not just related to environmental impacts but other factors related to product quality, taste, and processing conditions. Despite this, a simple analysis is performed to illustrate the impact of product reformulations on environmental impacts. For the five confectionery products, the ingredient which showed the largest sensitivity is considered; glucose for sugar confectionery, milk crumb for milk chocolate confectionery and milk chocolate biscuit confectionery, sugar for dark chocolate confectionery and palm oil for the milk-based confectionery. For example, if the %weight of the selected ingredient (xf) is reduced by 20%, then, the %weight for other ingredients can be readjusted. For the other ingredients (x_1, x_2, x_3, etc), the %weight is readjusted by the factor (R_F) calculated in Equation (4).

$$R_F = \frac{1 - \left(1.2x_{ingredient\ selected}\right)}{(x_1 + x_2 + x_3 + \ldots)} \tag{4}$$

The change in total environmental impacts before and after product reformulation application for the different confectionery products is shown in Table S13. It can be seen that the application of product reformulation has resulted in medium-to-low reductions. On average, across all five confectionery products, the GWP has reduced by 4.7%, water depletion reduced by 0.7%, ADP reduced by 4.2%, land use reduced by 8.9%, and negligible change for ecosystems quality, respectively. The largest reduction was observed for the milk-based confectionery whereas the lowest reduction was seen from milk chocolate confectionery (e.g. the summation of % change of all environmental impacts as listed in Table S13). Overall, further research is required to investigate the implications of

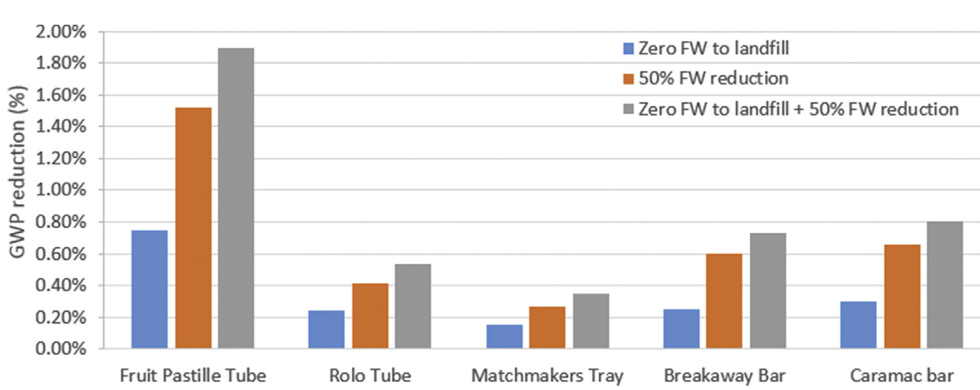

Fig. 19. Comparison of food reduction options on reducing total GWP for different confectionery products.

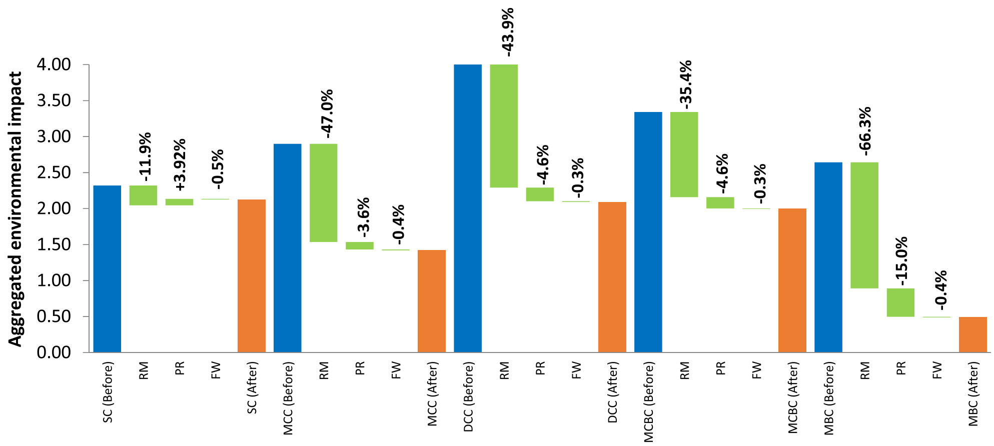

Fig. 20. Comparison of aggregated environmental impact before and after improvement strategies.

product reformulations across multiple dimensions as part of an integrated product design process.

3.4.5. Food waste reduction from factory to consumer boundary

Across the confectionery supply chain, there are several stages where food waste is generated and sent to landfill and incineration. In this section, three scenarios are investigated to analyse the environmental benefits of different food waste reduction strategies which are aligned with the food waste target by the UK Food and Drink Federation (FDF, 2016). These are: (1) zero food waste sent to landfill, (2) 50% food waste reduction, and (3) combined 50% food waste reduction with zero food waste sent to landfill. It is assumed, the alternative route to divert food waste from landfill is waste incineration with energy recovery. A comparison of the GWP benefits is shown in Fig. 19 as reductions in the four environmental categories were negligible, see Table S14.

Overall, it can be seen that the application of a zero waste to landfill strategy involving different scenarios has resulted in very low reductions. For example, scenario 3 offers the highest reductions with an average of 0.86% across the five confectionery products. Clearly, a food waste reduction strategy involving the different scenarios does not yield the highest environmental reductions compared to other interventions such as raw material changes and integration of renewable energy. Even more so, the environmental reductions are not expected to increase considerably even if the food waste from farms and agricultural processing was included. Despite this, food waste is a major problem in society (Kummu et al., 2012). There are many economic and social reasons to pursue reductions irrespective of the environmental benefits such as food security, reduced costs, resource efficiency, and consumer behaviour change.

3.4.6. Comparison of before and after improvements

The combined impact of the five improvement strategies shows mixed environmental reduction across all five environmental impact categories due to the RE and packaging materials having a negative impact for SC, MCC and DCC. As such, the benefits of strategies demonstrating an aggregated environmental impact reduction only is shown in Fig. 20. Overall, the aggregated environmental impact before and after improvement strategies shows an average reduction of 46% is possible across the five confectionery products (Fig. 20). The major interventions to achieve this is from sourcing raw materials with lower environmental impact, product reformulations and combined zero food waste to landfill and 50% food waste reduction. The role of RE and packaging materials are still important but requires further research to investigate alternative energy and materials with lower environmental impact across all five environmental impact categories. For the five confectionery products the recommended strategies based on their scope for environmental reductions are shown in Table 5.

4. Conclusions and future work

An environmental life cycle analysis has been presented for first time for a range of different confectionery products produced by the same factory, such as: sugar confectionery, milk chocolate confectionery, dark chocolate confectionery, milk chocolate biscuit confectionery, and milk-based confectionery. In comparison to previous studies (Recanati et al., 2018; Vesce et al., 2016; Jungbluth and Konig, 2014), there are several key methodological differences which improves our understanding of the environmental sustainability of confectionery products. These are: (1) a range of products representing the core product categories found in the confectionery sector, (2) full confectionery supply chain analysis from cradle-to-grave, (3) inclusion of pre-processing stages for chocolate pre-

Table 5
Recommended improvement strategies to reduce environmental impact across all seven confectionery products.

Improvement strategy	Confectionery product				
	SC	MCC	DCC	MCBC	MBC
Raw materials sourcing	YES	YES	YES	YES	YES
50% food waste reduction + Zero food waste to landfill	YES	YES	YES	YES	YES
Product reformulations	STFA	YES	YES	YES	YES
Renewable energy integration at manufacturing	STFA	STFA	STFA	STFA	STFA
Packaging materials	STFA	STFA	STFA	STFA	STFA

STFA = Subject to further analysis.

cursors, (4) inclusion of food and packaging waste, (5) five environmental impact categories (GWP, water depletion, ADP, land use and ecosystems quality) which are more aligned with metrics used in the food industry, and (6) multi-criteria decision analysis (MCDA) to aggregate environmental impacts to aid decision-making.

The analysis of five confectionery products at a confectionery factory in the UK found that sugar confectionery had the lowest aggregated environmental impact compared to dark chocolate confectionery which had the highest. It was found the dark chocolate confectionery was higher than milk chocolate biscuit confectionery by 21.7%, milk chocolate confectionery by 35.8%, milk-based confectionery by 42.2%, and sugar confectionery by 48.4%. Some of the key factors contributing to the difference was primarily due to the ingredients such as cocoa liquor, milk powder, and cocoa butter for dark chocolate confectionery. In comparison, sugar, glucose and starch were major contributing factors for sugar confectionery. Overall, a range of key ingredients were identified which are recommended for confectionery manufacturers to focus on as part of their sustainability strategy.

In addition, an investigation of different functional units has shown the selection of functional units can have a profound impact on how environmental impacts are communicated, especially in a comparative format. As such, it is recommended that food manufacturers should explore different functional units to understand the wider implications on public communications and consumer understanding.

The general environmental hotspots across all five confectionery products were found to occur at the following life cycle stages: raw materials, factory, and packaging. An analysis of five improvement strategies (alternative raw materials and packaging materials, renewable energy, product reformulations, and zero food waste to landfill) showed a range of mixed improvements were possible as interventions. Some of the key findings are:

(1) Transitioning to 100% renewable energy at the factory stage has both positive and negative environmental impact. On average, GWP reduced by 17.3%, WD reduced by 23.5%, negligible change for ADP, LU increased by 5.8%, and EQ increased by 550.8%;
(2) Raw material changes to alternative ingredients and/or lower environmental impact ingredients can reduce on average: GWP by 49.1%, WD by 13.4%. ADP by 22.2%, LU by 14.8%, and EQ by 9.5%;
(3) Product reformulations can generate medium-to-low environmental life cycle impact reductions. On average, GWP reduced by 4.7%, WD reduced by 0.7%, ADP reduced by 4.2%, LU reduced by 8.9%, and negligible change for EQ;
(4) Reducing food waste across the confectionery supply chain from gate-to consumer by 50% and sending zero food waste to landfill generates low-to-negligible environmental life cycle impact. On average, GWP reduced by 0.9%, negligible change for WD, ADP, LU, and EQ;
(5) The combined improvement strategies of raw materials changes, product reformulations and zero food waste to landfill (including 50% food waste reduction) can on average reduce: GWP by 54.6%, WD by 14.1%, ADP by 26.6%, LU by 23.7%, and EQ by 9.6%.

Overall, future research should seek to: (1) understand how changes to recipe formulations affect final products, (2) collaborate with suppliers, research institutes and relevant actors to develop raw materials and packaging materials with lower environmental impact, and (3) investigate alternative renewable energy which can reduce environmental impacts across all five environmental impact categories.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jclepro.2017.12.073.

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