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Economic sustainability of food supply chains: life cycle costs and value added in the confectionary and frozen desserts sectors

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Abstract

The confectionary and frozen desserts sectors are important parts of the food industry but have received relatively little attention from a life cycle cost perspective. Thus, the purpose of the current study is to evaluate the life cycle costs (LCC) and value added (VA) in these sectors in the UK, focusing on four major product categories: biscuits, cakes (ambient and frozen), chocolates and ice cream. In total, 18 products are considered along their life cycles, including the raw materials, manufacturing, packaging, distribution, retail, consumption and waste management stages. The results suggest that cakes have the highest LCC (£1.52–2.64/kg) and the biscuits the lowest (£0.72–0.91/kg). The LCC of chocolates and ice cream fall within a similar range (£1.16–1.46/kg and £1.03–1.30/kg, respectively). Divergent trends are noted between LCC and VA: for instance, ‘premium’ ice creams have only 18% higher costs than their ‘regular’ counterparts, but a four-fold higher VA. For all the products, raw materials contribute most to the costs (43%–95%), followed by packaging (1%–29%) and manufacturing (1%–14%). The annual LCC at the sectoral level are estimated at £3.455 billion, to which biscuits contribute 42%. The share of chocolates and cakes is 24% and 19%, respectively, with ice cream contributing the remaining 15%. By contrast, chocolates contribute more than 50% of the total sectoral VA, which is five-fold higher than that of ice cream. The study also demonstrates how LCC can be used to evaluate the eco-efficiency of products and sectors. With respect to global warming potential, whole cakes are the most eco-efficient and vanilla regular ice cream the least efficient products. Overall, the confectionary sector is nearly 60% more eco-efficient than the frozen desserts sector. These results can be used for benchmarking and to drive innovation towards more economically-sustainable and eco-efficient confectionary and frozen desserts supply chains.

Keywords: Biscuits; Cakes; Chocolates; Ice cream; Economic assessment; Eco-efficiency.

Nomenclature

$C_{CL(CO)}$	cost of washing the dishes at consumer
C_{CO}	costs associated with product consumption
C_{DC}	costs of operating distribution centre
C_{EOL}	costs of post-consumer waste management
C_{MA}	costs of product manufacturing
$C_{PA(CO)}$	cost of consumer shopping bag
C_{PA}	costs of packaging
C_{RE}	costs associated with the retail
C_{RM}	costs of raw materials (ingredients)
$C_{ST(CO)}$	cost of refrigerated storage at consumer
$C_{TR(CiG)}$	transport costs from cradle to grave
$C_{TR(CiMA)}$	transport costs from cradle to manufacturer
$C_{TR(MAiRE)}$	transport costs from manufacturer to retailer
$C_{TR(REiCO)}$	transport costs from retailer to consumer's home
LCC_{CiG}	total life cycle costs of a product from cradle to grave
LCC_{MA}	manufacturer's life cycle costs
LCC_{RE}	retailer's life cycle costs
P	product selling price
S	savings (system credits) related to end-of-life waste management
VA	value added

1 Introduction

The food sector is an important part of the global economy and a significant contributor to costs of living. In developing countries, it accounts for 38.6% of household expenditure (World Bank, 2010). In developed countries, this share is lower but still substantial. For example, in Japan, 23% of household income is spent on food, in the US 14% and in the UK 11% (FAO, 2015). However, despite its importance, relatively little work exists within the scientific literature related to the life cycle economic sustainability in the food sector. Only a handful of studies have assessed the costs of food products or specific sub-sectors across their entire life cycle. For instance, Schmidt Rivera & Azapagic (2014) analysed the life cycle costs (LCC) of chilled and frozen ready-made meals in comparison with their home-made equivalents. Other studies include that by Settani et al. (2010) who considered the LCC of pasta and by Nguyen et al. (2012) who evaluated the cost of environmental impacts of meat production. Furthermore, Sonye-Mengual et al. (2018) reported the LCC of fresh vegetables at the consumption point. A similar approach was also adopted by Laso et al. (2018) in the evaluation of fresh anchovies.

Aside from the above studies, no other life cycle costing work related to food products is available in the literature. Specifically, there is a notable lack of studies of confectionary, ice cream and other frozen desserts, despite the omnipresence and popularity of these products worldwide. The current study seeks to fill this research gap by estimating LCC and value added (VA) of the production and consumption of confectionary and frozen desserts. The study is based in the UK, which is the second highest consumer of these products in Europe after Germany (Statista, 2018a; 2018b). Four major product categories are considered within these two sectors – biscuits, chocolates, cakes (ambient and frozen) and ice cream – focusing on the leading products identified through a market analysis. In addition to LCC and VA, their eco-efficiency is also considered based on their life cycle global warming potential and the LCC. The analysis is carried out at the product and sectoral levels and is aimed at manufacturers and consumers. This is detailed in the next section, together with the methods used in the study. Although the study focuses on UK market conditions, the methods described below are generic and can be applied to estimating the LCC and VA of these sectors in other countries.

2 Methods

The methodology applied in this work comprises the following steps:

1. market analysis of the confectionary and frozen desserts sectors to select market-leading products to be considered;
2. LCC, VA and eco-efficiency estimation at the product and sectoral levels; and
3. sensitivity and uncertainty analysis to ensure the robustness of the results.

These are described in turn below.

2.1 Market analysis and selection of products

The confectionary and frozen desserts sectors are very diverse and can be divided in many different sub-sectors and product categories. In this work, the focus is on the aforementioned four major product categories consumed widely worldwide, including in the UK. Each product category is also very diverse and considering the whole range of products is not feasible. Therefore, to focus the study, a market analysis has been carried out to identify and select products with the highest market share. These are listed in Table 1, which also shows the annual sales by value of the four product categories selected for consideration.

As indicated in Table 1, the annual UK sales of biscuits amount to £2.608 billion (Key Note 2015a), with a total volume sold estimated in this study at 1.7 Mt/yr; for the estimates, see Table S1a in the Supplementary Information (SI). Fig. 1a shows that the greatest market share by volume is occupied by low fat & sugar biscuits (23.5%), followed by crackers (13.9%), semi-sweet (10.8%) and chocolate cream biscuits (10.8%). Therefore, these have been selected for consideration in this study. In addition, vanilla cream sandwich and chocolate-coated biscuits are also considered (8% each). The remaining 25.1% of the sales

volume are other biscuits involving a great variety of products with small individual contributions (Key Note 2015a). Hence, they are not considered at the product level but are included in the assessment at the sectoral level.

The cakes sector is worth £1.646 billion per year, of which ambient storage cakes are valued at £1.37 billion (Key Note, 2015a) and frozen cakes at £0.272 billion (Key Note, 2015c). An estimated total 360 Mt of cakes are consumed annually in the UK (Table S1b in the SI). As indicated in Fig. 1b, the leading product types by volume are apple pies (50.4%), cheesecake (17.6%); cake slices (12.6%), whole cakes (11.7%) and cupcakes (7.7%). Therefore, these have been chosen for evaluation, assuming that apple pies represent all pies and Victoria sponge all cakes. Strawberry cheesecake is presumed representative of all other types of cheesecake while vanilla flavoured cake slices with sugar icing represent all types of cake slice.

Table 1 Market-leading products in the biscuits, cakes, chocolates and ice creams sectors.

Biscuits (£2.608 billion/yr)^a	Cakes (£1.646 billion/yr)^a	Chocolates (£4.344 billion/yr)^a	Ice cream (£1.133 billion/yr)^a
Crackers	Whole cakes	Moulded chocolate	Vanilla regular
Low fat/low sugar	Cake slices	Chocolate countlines	Vanilla premium
Semi-sweet	Pies	Chocolates in bags	Chocolate regular
Chocolate-coated	Cupcakes		Chocolate premium
Chocolate cream	Cheesecake		
Vanilla cream			

^a Total annual sales by sector (Key Note, 2015a; Key Note, 2015b&c).

Fig. 1 Market share by volume of leading products in the biscuits, cakes, chocolates and ice cream sectors [Estimates based on data for annual share of different products by value sourced from the literature as follows: Biscuits & cakes: Key Note (2015a); Chocolates: Key Note (2015b); Frozen desserts (including ice cream): Key Note (2015c). For details, see Table S1 in the SI. CC: Chocolate-coated biscuits].

The chocolates sector is the market leader by value among the four sectors considered, with an estimated £4.344 billion/yr (Key Note, 2015b). As indicated in Fig. 1c, the leading products by volume are chocolate countlines (47.6%), chocolates in bags (24.7%), moulded chocolates (17.7%) and other chocolate confectionaries (9.9%) (Konstantas et al., 2018). For these estimates, see Table S1c in the SI. Hence, these products have been selected for further consideration.

Finally, the ice cream market has annual sales of £1.133 billion (Key Note, 2015c). Vanilla and chocolate ice cream are the leading flavours, occupying nearly 36% of the total market volume, with around 18% each (see Fig. 1d and Table S1d). The other ice cream products are wrapped ‘impulse’ ice cream and multipacks (Key Note, 2015c). The latter refers to individual wrapped impulse products sold together.

2.2 Life cycle costing, value added and eco-efficiency

The methodology for life cycle costing adopted in this study is that based on Hunkeler et al. (2008). The value-added and eco-efficiency estimates are based on LCC as described in more detail further below. Prior to that, the next section gives an overview of the goal and scope of the study.

2.2.1 *Goal and scope of the study*

The goals of the study are:

- to estimate total LCC and VA in the life cycle of biscuits, cakes, chocolate and ice cream at the product level, based on a basket of 18 individual market-leading products (Table 1);
- to estimate costs of these products to different stakeholders: manufacturers, retailers and consumers;
- to identify the economic hotspots in the life cycles of these products;
- to evaluate the annual LCC and VA at the sectoral level based on the annual consumption of confectionary products and frozen desserts in the UK; and
- to determine the eco-efficiency at the product and sectoral levels.

To achieve these goals, two functional units are defined, as follows:

- 1 kg of product consumed at home (study goals i-iii); and
- annual consumption of each product in the UK (study goal iv).

The system boundary spans cradle to grave, comprising production of raw materials and products, their packaging, distribution, retail, consumption, end-of-life waste management and all life cycle transport steps. This is depicted in Fig. 2, which also shows the system boundaries used to estimate the costs to manufacturers, retailers and consumers.

Fig. 2 Life cycle stages considered for life cycle costing and the system boundaries for the costs to manufacturers, retailers and consumers [TR: transport].

2.2.2 Estimation of life cycle costs and value added

The total life cycle costs of individual products have been calculated as follows:

$$LCC_{CtG} = C_{RM} + C_{MA} + C_{PA} + C_{DC} + C_{RE} + C_{CO} + C_{EOL} + C_{TR(CtG)} - S \quad (1)$$

where:

LCC_{CtG} : total life cycle costs of a product from cradle to grave

C_{RM} : costs of raw materials (ingredients)

C_{MA} : costs of product manufacturing

C_{PA} : costs of packaging

C_{DC} : costs of operating distribution centre

C_{RE} : costs associated with the retail

C_{CO} : costs associated with product consumption

C_{EOL} : costs of post-consumer waste management

$C_{TR(CtG)}$: transport costs from cradle to grave

S : savings (system credits) related to end-of-life waste management (recycling and energy recovery).

Considering costs to different stakeholders, the manufacturer's life cycle costs comprise costs of raw materials, manufacturing, packaging and all transport up to the manufacturing facility, as illustrated in Fig. 2 and defined by eqn. (2):

$$LCC_{MA} = C_{RM} + C_{MA} + C_{PA} + C_{TR(CtMA)} \quad (2)$$

where:

LCC_{MA} : manufacturer's life cycle costs

$C_{TR(CtMA)}$: transport costs from cradle to manufacturer.

Costs to the retailer incorporate the manufacturer's costs, costs of operating distribution centres and retail space as well as transport costs from the manufacturing gate to the retailer (Fig. 2):

$$LCC_{RE} = C_{MA} + C_{DC} + C_{RE} + C_{TR(MAtRE)} \quad (3)$$

where:

LCC_{RE} : retailer's life cycle costs

$C_{TR(MAtRE)}$: transport costs from manufacturer to retailer.

Finally, from the consumer's perspective, life cycle costs include the retailer's costs, costs of transport to purchase the product and a (plastic) shopping bag, as well as the cost of electricity for refrigerated storage and energy and water for cleaning the dishes:

$$LCC_{CO} = C_{RE} + C_{TR(REtCO)} + C_{PA(CO)} + C_{ST(CO)} + C_{CL(CO)} \quad (4)$$

where:

$C_{TR(REtCO)}$: transport costs from retailer to consumer's home

$C_{PA(CO)}$: cost of consumer shopping bag (allocated to the functional unit on volume basis)

$C_{ST(CO)}$: cost of refrigerated storage at consumer (ice cream and frozen cakes)

$C_{CL(CO)}$: cost of cleaning the dishes.

In addition to LCC, VA has also been estimated at both the product and sectoral levels. VA is defined as the sales price minus the costs of goods sold (Sutherland & Canwell, 2004), reflecting the increase in economic value due to the production of the final goods. Therefore, the VA is calculated considering the life cycle costs incurred up to the retail point where the product is sold, as follows:

$$VA = P - LCC_{RE} \quad (5)$$

where:

VA : value added

P: product selling price.

2.2.3 Estimation of eco-efficiency

Following the definition by the World Business Council for Sustainable Development (Lehni, 2000), the eco-efficiency can be estimated as a ratio of an environmental impact to the economic value of a product or service. LCC can be used as an indicator of a product system value (ISO, 2012) as any cost variation alters the economic value added and consequently the corresponding system value. Different environmental impacts can be considered for the estimation of eco-efficiency. Here, global warming potential is selected as one of the key impacts of interest to manufacturers, policy makers and consumers. Therefore, the eco-efficiency is estimated as a ratio of GWP and LCC, both at the product and sectoral levels, with the lower values representing a higher efficiency. The GWP values for the products and sectors have been sourced from Konstantas (2018), Konstantas et al. (2018) and Konstantas et al. (2019). These have been estimated based on the same system boundary as for the LCC and are summarised in Table 2 and Table 3, respectively.

Table 2 Global warming potential (GWP) of confectionary products and frozen desserts (Konstantas, 2018, Konstantas et al., 2018, Konstantas et al., 2019)

Product	GWP (kg CO ₂ eq./kg)
Biscuits	
Crackers	1.31
Low fat/sugar	1.27
Semi-sweet	1.28
Chocolate coated	1.81
Vanilla cream	1.29
Chocolate cream	1.36
Cakes	
Whole cakes	2.04
Cake slices	1.78
Pies	1.58
Cupcakes	2.18
Cheesecakes	4.83
Chocolates	
Moulded chocolate	3.39
Chocolate countlines	2.91
Chocolates in bags	4.15
Ice cream	
Vanilla regular	3.75
Chocolate regular	3.66
Vanilla premium	3.94
Chocolate premium	3.91

Table 3 Global warming potential (GWP) of the confectionaries and frozen sectors based on the annual consumption in the UK (Konstantas, 2018)

Sub-sectors and sectors	GWP (kt CO ₂ eq./yr)
Biscuits sub-sector	2573
Cakes sub-sector	820
Chocolates sub-sector	2176
Ice cream sub-sector	1573
Confectionary sector	5263
Frozen desserts sector	1879

Table 4 Cost data along the life cycle of the products considered in the study

Life cycle stage	Cost [£/unit]	Source
<i>Raw materials (ingredients)</i>		
Acetic acid	0.46 [£/kg]	ICIS (2015)
Apples	0.61 [£/kg]	Office for National Statistics UK (2015)
Butter	1.94 [£/kg]	DEFRA (2015)
Citric acid	0.79 [£/kg]	ICIS (2015)
Cocoa butter	2.11 [£/kg]	Niagara – Atlantic (2015)
Cocoa liquor	2.65 [£/kg]	Niagara Atlantic Industries (2015)
Cocoa powder	2.85 [£/kg]	Niagara Atlantic Industries (2015)
Eggs pasteurised	5.99 [£/kg]	Bulk Powders (2015)
Egg-yolk pasteurised	10.95 [£/kg]	Fine Food Specialist (2015)
Flour white	0.94 [£/kg]	Marriage's Master Millers (2015)
Flour wholemeal	1 [£/kg]	Marriage's Master Millers (2015)
Fructose – glucose	3 [£/kg]	RealFoods (2015)
Glycerine (vegetable)	2.4 [£/kg]	Darrant Chemicals (2015)
Milk cream	0.98 [£/kg]	DairyCO (2015)
Milk powder	2.19 [£/kg]	Index Mundi (2015)
Palm kernel oil	0.595 [£/kg]	Index Mundi (2015)
Palm oil	0.37 [£/kg]	Index Mundi (2015)
Raw milk	0.24 [£/kg]	DairyCo (2015)
Salt	0.13 [£/kg]	Credit Chem Group (2015)
Soda	0.33 [£/kg]	ICIS (2015)
Soft cheese	2.28 [£/kg]	DEFRA (2015)
Sorbic acid	79.19 [£/kg]	ICIS (2015)
Starch	1.12 [£/kg]	RealFoods (2015)
Strawberries	2.26 [£/kg]	Office for National Statistics UK (2015)
Sugar	0.37 [£/kg]	Index Mundi (2015)
Vanilla extract	155 [£/kg]	Vanilla Mart (2015)
Vanillin	11.97 [£/kg]	ICIS (2015)
Whey powder	1.064 [£/kg]	Index Mundi (2015)
Yeast	9.36 [£/kg]	RealFoods (2015)
<i>Manufacturing</i>		
Electricity	0.079 [£/kWh]	DECC (2015)
Liquid ammonia ^a	0.33 [£/kg]	Technicold Services (2015), ICIS (2015)
Lubricant	0.664 [£/kg]	ICIS (2015)
Natural gas	0.019 [£/kWh]	DECC (2015)
Nitric acid	0.141 [£/kg]	ICIS (2015)
Sodium hydroxide	0.416 [£/kg]	ICIS (2015)
Steam	0.034 [£/MJ]	DECC (2015)
Water	0.0016 [£/l]	United Utilities (2015)
<i>Packaging</i>		
Aluminium	1.22 [£/kg]	LME (2015)
Corrugated board	0.14 [£/kg]	LetsRecycle (2015)
Folding box	0.14 [£/kg]	LetsRecycle (2015)
Low density polyethylene	1.57 [£/kg]	Plastic Informat (2015)
Paper	0.14 [£/kg]	LetsRecycle (2015)
Plastic bags (retailer price)	0.05 [£/piece]	UK retailers
Polypropylene	1.69 [£/kg]	Plastic Informat (2015)
<i>Distribution centre, retail and consumption</i>		
Electricity	0.079 [£/kWh]	DECC (2015)
Water	0.0016 [£/l]	United Utilities (2015)
Refrigerant (R134a) ^b	12.8 [£/kg]	Schmidt & Azapagic (2014)
Electricity (domestic)	0.152 [£/kWh]	Ofgem (2015)
Detergent	6.65 [£/kg]	Tesco (2015)
<i>Transport</i>		
Fuel for passenger car ^c	1.208 [£/l]	Global Petrol Prices (2014)
Transoceanic tanker	0.0025 [£/km]	VTT (2010), Global Petrol Prices (2014)
Transport (16 t lorry)	0.00003 [£/kg km]	DECC (2015), VTT (2010)
<i>Waste management</i>		
Wastewater treatment	0.0013 [£/l]	United Utilities (2015)
Landfilling	0.1 [£/l]	WRAP (2015)
Energy recovery	0.99 [£/kg]	WRAP (2015)
Recycling	0.06 [£/kg]	WRAP (2015)
Organic waste	0.046 [£/kg]	WRAP (2015)

^a Refrigerant used for deep-freezing of ice cream. Frozen storage at manufacturer: 30 days (Konstantas et al., 2019).

^b Frozen storage of ice cream: 7 days at retailer and 30 days at consumer (Konstantas et al., 2019). Frozen storage of cheesecake: 30 days at distribution centre, 15 days at retailer and 5 days at consumer (Konstantas, 2018).

^c Average fuel consumption assumed at 10 l/100 km.

2.2.4 Life cycle cost data

Life cycle cost data for individual products have been collected from manufacturers, literature and other publicly available sources. These are summarised in Table 4, which lists costs of all flows and activities across the 18 products considered in the study, together with the data sources. A detailed breakdown of ingredients and costs by product can be found in Table S2 in the SI. Where possible, all cost data are representative of UK conditions in 2015. In the case of multi-function or multi-output systems, the costs have been allocated on an economic basis. The savings (system credits) correspond to the market prices of recycled materials (see Table S2).

To estimate the LCC and VA at the sectoral level, it has been necessary to define sales volumes and typical retail prices. Due to a lack of data on the sales volumes, these have been estimated based on the annual monetary value (Key Note 2015a-c). These values have been divided by the typical retail prices of each product in the UK at three major UK supermarkets (Tesco, 2015; Sainsbury's, 2015; Morrison, 2015) to obtain an estimated sales volume for each product in mass terms (Table S1). The retail prices and the derived annual sales volumes are given in Table 5. In the case of different retail prices for the same product, the lowest price has been adopted. Thus, following a conservative approach, the highest possible sales volumes have been considered.

In the estimation of the sales volumes, it has been assumed that cupcakes, pies and cake slices have equal sales value as their individual share of the market is not known. In a similar fashion, semi-sweet and vanilla cream biscuits are also presumed to have the same sales values. The same assumption applies for chocolate-coated and chocolate cream biscuits as only the total sales of chocolate-containing biscuits are available but not their individual shares. For ice cream, the same sales of vanilla and chocolate flavour are considered. Any other products that could not be assigned to the existing product categories have been allocated to the 'other' category. Taking a conservative approach, their LCC are assumed to be equal to the highest cost to the retailer in each product category.

Table 5 Product sales prices and estimated annual sales volumes

Category	Products	Retail price [£/kg]	Sales value [£m/yr]	Sales volume [t/yr]
Biscuits	Crackers	1.3	362	278,462
	Low fat/sugar	1.5	612	408,000
	Semi-sweet	1.1	281.5	255,909
	Chocolate coated	2	208.5	104,250
	Vanilla cream	6.4	281.5	43,984
	Chocolate cream	6.5	208.5	32,077
	Other biscuit products ^a	1.1	654	594,545
	<i>Total</i>		<i>2608</i>	<i>1,717,227</i>
Cakes	Whole cakes	6.8	287	42,206
	Cake slices	8	362.3	45,288
	Pies	2	362.3	181,150
	Cupcakes	13	362.3	27,869
	Cheesecakes	4.3	272	63,256
	<i>Total</i>		<i>1646</i>	<i>359,769</i>
Chocolates	Moulded chocolate	7.5	845	112,667
	Chocolate countlines	6	1817	302,833
	Chocolates in bags	8.3	1304	157,108
	Other chocolate products ^b	6	378	63,000
	<i>Total</i>		<i>4344</i>	<i>635,608</i>
Ice cream	Vanilla regular	2	55	27,500
	Chocolate regular	2	55	27,500
	Vanilla premium	5	221.5	44,300
	Chocolate premium	5	221.5	44,300
	Other ice cream products ^c	2.225	580	260,674
	<i>Total</i>		<i>1133</i>	<i>404,274</i>

^a Seasonal, savoury, children and special treats (Key Note 2015a) report.

^b Seasonal products and novelties (Key Note, 2015b).

^c Other than take-home ice creams (Key Note 2015c).

3 Results and discussion

This section first presents the LCC and VA estimates by product type, followed by sensitivity and uncertainty analyses. The latter part of the section discusses the LCC and VA estimates at the sectoral level.

3.1 Economic sustainability at the product level

Among the product categories considered, cakes are found to have the highest LCC, followed by ice cream, chocolates and finally biscuits (Fig. 3–Fig. 6). These findings are discussed below by product category.

3.1.1 *Life cycle costs of biscuits*

The total life cycle costs of biscuits and the contribution of different stages are shown in Fig. 3. The most costly product is crackers (£0.91/kg) while the vanilla cream biscuits are the least expensive (£0.72/kg). The costs of all other biscuits are within approximately 15% of each other. The raw materials have the highest contribution to the total costs, ranging between 79% and 86%. This is mainly due to flour, milk and cocoa powder, palm oil and sugar, with flour alone contributing on average 50% of the total (see Table S2). While the unit cost of flour is quite low (£0.94/kg), it makes up the majority of the mass of the biscuits which explains its high overall contribution to the total cost.

Manufacturing contributes 6%–7%, mainly due to energy consumption in the production process. This is followed by packaging with 4%–6%, except for crackers where it accounts for 11%. The latter is due to the use of more packaging material per mass of product compared to the other types of biscuit, leading to their highest overall LCC in this product category. The rest of the costs (3%–4%) are due to transport. Crediting the system for end-of-life packaging recycling and energy recovery reduces the costs by only 1%–3% (Table S3).

3.1.2 *Life cycle costs of cakes*

The results in Fig. 4 indicate that whole cakes are the most costly products (£2.64/kg) with a total LCC 42% higher than the lowest cost, estimated for pies (£1.52/kg).

More than any of the other product categories, cakes are dominated by the raw material costs, which account for 80%–94% of the total LCC. Pasteurised eggs, fructose/glucose sweetener, butter, flour, strawberry, milk powder and palm oil contribute most to the costs of ingredients (Table S3). Eggs are the biggest individual cost component, accounting for an average of 43% across the products. The only exception is cheesecake which does not include eggs, where milk powder and soft cheese together account for 53% of the total LCC.

The second most contributing stage is packaging, with noteworthy contributions to the costs of cupcakes (12.8%) and pies (7%). Cupcakes benefit from some cost savings (3%) due to a greater amount of energy recovered from the incinerated packaging, related to a higher amount of packaging used for these products.

3.1.3 *Life cycle costs of chocolates*

The LCC of chocolate products are presented in Fig. 5 which reveals that chocolates in bags are the most expensive product type (£1.46/kg), followed closely by moulded chocolates (£1.41/kg). By comparison, chocolate countlines cost £1.16/kg.

Raw materials again dominate the LCC, accounting for 89%–94% of the total, with milk powder, cocoa butter and liquor as well as sugar being the most relevant ingredients (see Table S2). Milk powder is the greatest single contributor, accounting for an average of 35% of the LCC. It can also be noted in Fig. 5 that the cost of packaging is over three times higher for chocolates in bags than for the moulded chocolates, despite their packaging materials being very similar. This is due to the bagged chocolates requiring more packaging per unit of product. However, in comparison with raw materials, packaging and other stages have

insignificant contributions to the LCC. Further details on the contribution analysis can be found in Table S3.

Fig. 3 Life cycle costs (LCC) of biscuits [RM: raw materials; MA: manufacturing; PA: packaging; RE: retail; CO: consumption; EoL: end-of-life waste management; TR: transport; S: savings (system credit for EoL)].

Fig. 4 Life cycle costs (LCC) of cakes [For the legend, see Fig. 3.].

Fig. 5 Life cycle costs (LCC) of chocolates [For the legend, see Fig. 3.].

Fig. 6 Life cycle costs (LCC) of ice cream [For the legend, see Fig. 3.].

3.1.4 Life cycle costs of ice cream

As indicated in Fig. 6, chocolate premium ice cream has the highest LCC (£1.30/kg) while vanilla regular is the least costly (£1.03/kg). This difference is entirely attributable to the raw materials: premium chocolate ice cream contains egg yolk and cocoa, which are expensive ingredients (Table S2) and not used in the regular varieties. It also has a 27% higher amount of sugar compared to the vanilla regular product.

Across all four types of ice cream, production of raw materials is the most expensive life cycle stage (43%–55% of the total), mainly due to milk (30%–37%). Packaging is the next significant stage, with contributions ranging from 23%–29%, largely due to the polypropylene tub. Manufacturing is the third biggest contributor (11%–14%) with energy consumption accounting for 10%–13% of the total costs, the vast majority of which is related to electricity usage. The retail stage contributes 4%–5% of the total LCC, mostly caused by energy consumption for refrigeration. The contribution of the consumption stage is similar to retail (4%–6%), mainly due to energy consumed by the freezer and hot water used to wash the used dishes. Crediting the system for packaging recycling and energy recovery saves £0.020–0.022/kg ice cream, reducing the total LCC by 2%. For further details on the contribution of different life cycle stages to the costs, see Table S3.

3.1.5 Costs to different stakeholders and value added

The LCC to manufacturers, retailers and consumers are shown for each product in Fig. 7. These have been estimated using eqns. (2)–(4), based on the system boundaries outlined in Fig. 2. Fig. 7 also provides the VA by product type, obtained via eqn. (5), using the LCC discussed in the previous sections and the sales prices of the products in Table S2. Further details on the costs to different stakeholders and VA can be found in Table S4.

As can be inferred from Fig. 7, the costs to the biscuit manufacturers are 4.7%–7.3% lower than their respective total LCC. A similar difference is found for cakes (4%–8.5%), while for chocolates the differential is only 2%. By contrast, the costs of ice cream manufacture are 23%–30% lower than the total LCC, largely due to the additional refrigeration beyond the manufacturer's gate.

Costs to retailers are higher with respect to manufacturers' costs on average by 1.5% for all product categories but the ice cream (7%); the latter is again due to refrigeration. Finally, costs to consumers relative to retailers are on average 20% higher for ice cream and, for the other products, they are greater by 1% to 6%.

The highest VA is found for the cupcakes, estimated at £11.28/kg (Fig. 7a). This is due to the low costs of ingredients and high retail price per kg relative to the other cake types. The next highest VA is for chocolates in bags with £6.84/kg and moulded chocolates with £6.11/kg

(Fig. 7b). They both command high retail prices (£8.3 and £7.5 per kg) and have low retailer's LCC (£1.46 and £1.39/kg), hence the high VA. At the other end of the scale, the lowest VA, found for semi-sweet biscuits, is 30 times lower than that of the cupcakes. This type of biscuit has a low retail price (£1.10/kg) and, despite only a moderate retailer's LCC (£0.75/kg), generates only £0.35/kg in VA. The other products with a relatively low VA are crackers (£0.44/kg) and pies (£0.55/kg). Among the biscuits, the highest VA is found for the vanilla and chocolate cream varieties (~£5.75/kg) and, among the ice cream, for the premium products (~£4/kg).

a) Biscuits and cakes

b) Chocolates and ice cream

Fig. 7 Life cycle costs to different stakeholders and value added by product

3.1.6 Sensitivity analysis

Given the high contribution of raw materials across the products, and the packaging for ice cream, these two life cycle stages are the focus of the sensitivity analysis as discussed below. The effect on the LCC of energy consumption in the manufacturing, retail and use stages is explored.

3.1.6.1 Raw materials

Loss of raw materials in manufacturing can be highly variable. In the base case presented above, manufacturing losses have been assumed at 2%. In the sensitivity analysis, two cases are examined, one assuming 5% and another 10% losses of raw materials. The results are shown in Fig. 8, expressed relative to the base case costs.

If the manufacturing losses increase from 2% to 5%, the overall LCC increase by around 1% for ice cream and up to 3% for the remaining products. When losses are assumed to be 10%, the costs go up by 3%–4% for ice cream, 4%–8% for biscuits and 6%–8% for chocolates and cakes. Hence, a five-fold increase in raw material losses increases the overall LCC by only 3%-8%. Nevertheless, production losses have an obvious adverse effect on both the economic and environmental sustainability and should be minimised as much as possible.

3.1.6.2 Packaging losses in ice cream manufacturing

To examine how manufacturing losses in ice cream packaging influence the LCC, it is assumed that 5% and 10% of packaging is lost in manufacturing instead of 2% assumed in the base case. The results in Fig. 9 suggest very low influence of packaging losses on the total LCC. An increase in the packaging losses from 2% to 5% increases the LCC at most by 1.5%, while an increase to 10% changes the total by 3%. Therefore, the total costs are not sensitive to packaging wastage. However, generation of waste is undesirable and should be kept as low as possible.

3.1.6.3 Energy

The effect on the LCC of energy used in the manufacturing, retail and use stages is explored by varying the total energy consumption by $\pm 20\%$. As Fig. 10 indicates, the relationship between energy and life cycle costing is stronger in the case of ice cream than for the other products. This is attributable to the refrigeration energy used in the life cycle of ice cream. However, the total LCC of ice cream only changes by $\pm 3\%$. The LCC of the other products is altered by ± 0.2 -1.4%, with the latter referring to chocolate-coated biscuits. Nevertheless, despite this low variation in the overall LCC with energy consumption, the cost reductions are likely to be significant on an annual basis.

Fig. 8 The effect on the life cycle costs (LCC) of increasing raw materials losses in manufacturing relative to the base case losses (2%).

Fig. 9 The effect on the life cycle costs (LCC) of increasing packaging losses for ice cream relative to the base case losses (2%).

Fig. 10 The effect on the life cycle costs (LCC) of the variation in energy consumption in manufacturing and distribution.

3.1.7 Uncertainty analysis

In addition to the uncertainties explored in the sensitivity analysis, the uncertainty analysis also considers potential price changes across the life cycle. A variation of $\pm 25\%$ over a three-year period is considered to capture sizeable year-on-year price swings.

The uncertainty analysis has been carried out through Monte Carlo simulation using @RISK7 software (Palisade, 2017). A total of 20,000 iterations have been performed for each product using the PERT distribution for each distinct parameter and considering a 95% confidence interval. This type of distribution has been selected because it places equal emphasis on the minimum and maximum values in the range, which are normally less well-known than the most likely value.

The results in Fig. 11 and Table S5 reveal that the LCC could vary by $\pm 12\%$ (chocolates in bags and chocolate premium ice cream) to 19% (low fat/sugar biscuits). However, their ranking in terms of costs remains unchanged: cakes maintain their position as the most costly product category, followed by ice cream, chocolates and finally biscuits.

3.2 Economic sustainability at the sectoral level

This section presents the LCC and VA at the sectoral level, estimated using the LCC and VA of the individual products discussed in sections 3.1.1–3.1.4 and their annual sales volumes given in Table 5. The total LCC at the sectoral level are estimated at £3.455 billion/yr (Fig. 12 and Table S6). Biscuits contribute most to the total costs (41%) due to their high sales volumes (1.72 million t/yr). They are followed by chocolates, accounting for 23% of the total – although their sales volume is much lower (636 kt/yr), they have a higher average cost per kg (see previous sections). Cakes and ice cream contribute 19% and 15% to the total costs, respectively.

a) Biscuits and cakes

b) Chocolates and ice cream

Fig. 11 Uncertainty analysis for the four product categories considered in the study [Parameters varied: raw material and packaging losses in manufacturing, energy consumption and costs across the life cycle of products].

Fig. 12 Annual life cycle costs (LCC) and value added (VA) at the sectoral level.

The total VA per year is equivalent to £6.483 billion, of which chocolates account for 54% (Fig. 12 and Table S6). Within this product category, chocolate countlines generate the most value (£1.47 billion/yr) due to the combination of high sales volumes, high retail prices and relatively low costs (see section 3.1.5). Overall, chocolates have a five-fold higher VA than ice cream (which accounts for 11% of the total sectoral VA), three times higher than biscuits (19%) and more than three times greater than cakes (16%). Although ice cream creates the lowest total VA at the sectoral level, it is notable that the premium versions generate four times the value of their respective regular counterparts as they command a 150% higher retail price despite their similar costs per unit.

The above results are contextualised in Fig. 13 against the sales values (Key Note, 2015a-c) of the four product categories considered. As indicated in the figure, the annual LCC of biscuits contribute around 55% to their total sales value, with the rest representing the VA. The share of the LCC in the sales value of cakes is lower, estimated at 38%, and thus the contribution of VA to the total is somewhat higher than for biscuits. The split between the LCC and the VA for ice cream is similar to that of cakes, with the former accounting for 41% of the sales value and the VA for 59%.

Fig. 13 Annual sales of products by value, showing contributions of the life cycle costs and value added to the total.

Chocolates, on the other hand, have a much lower LCC contribution (19%) than the other products; therefore, their VA is considerably higher (81%), making chocolates economically the most efficient sector.

The total sales value in these four sectors estimated in this work is £9.938 billion – this differs only by 2% from the value of £9.731 billion reported by Key Note (2015a-c), instilling further confidence in the results. Overall, the estimated LCC of £3.455 billion account for 35% of the total sales and VA the remaining 65%.

3.3 Eco-efficiency at the product and sectoral levels

To put the economic performance in context, this section considers eco-efficiency of the products and sectors relative to their environmental performance. As explained in Section 2.2.3, global warming potential is considered for these purposes.

The estimated eco-efficiencies of the different products considered in the study are illustrated in Fig. 14. As can be seen, whole cakes are the most eco-efficient product type with an eco-efficiency of 0.77 kg CO₂ eq./£, while vanilla regular ice cream has the lowest eco-efficiency of 3.64 kg CO₂ eq./£. The cakes are generally most eco-efficient: although they have high LCC, their GWP is relatively low, leading to a lower score and, therefore, higher eco-efficiency. The exception to this is cheesecake which is ranked 13th out of 18 products due to its high GWP – more than two times higher than that of whole cakes (Table 2).

Biscuits are the second most eco-efficient products with respect to GWP, with the crackers being the best and chocolate-coated biscuits the worst in this category (1.44 and 2.06 kg CO₂ eq./£, respectively). Chocolates are ranked third overall, with the eco-efficiency values in the range of 2.4 and 2.84 kg CO₂ eq./£. The ice cream is the least efficient product category due to the high GWP, leading to 2.5–4.7 times worse eco-efficiency than the cakes (3.01–3.64 kg CO₂ eq./£).

The above results are also reflected at the sectoral level, with the cakes sub-sector being the most eco-efficient at 1.3 kg CO₂ eq./£ and the ice cream the least efficient with 3.1 kg CO₂ eq./£ (Fig. 15). Biscuits and chocolates are ranked 2nd and 3rd, respectively. Overall, as indicated in Fig. 15, the confectionary sector is around 60% more eco-efficient than the frozen desserts sector (1.9 vs 3 kg CO₂ eq./£).

Fig. 14 Product eco-efficiency with respect to the global warming potential (GWP) and life cycle costs (left) and the ranking of products based on their eco-efficiency (right). [The values on top of the bars in the graph on the right represent the eco-efficiency scores of the products obtained by dividing their respective GWP values by their life cycle costs (kg CO₂ eq./£). The lower the score, the higher the eco-efficiency.]

Fig. 15: Eco-efficiency at the sub-sectoral (left) and sectoral levels (right) based on the annual global warming potential (GWP) and life cycle costs. [The ordinal numbers in the graphs indicate the ranking of the sectors and the values in brackets are their respective eco-efficiency scores obtained by dividing the GWP by the LCC values (kg CO₂ eq./£). The lower the score, the higher the eco-efficiency.]

4 Conclusions

This study has estimated life cycle costs and value added of biscuits, cakes, chocolates and ice cream, both at the level of individual products and for the whole sector. For the 18 product types assessed, the life cycle costs range from £0.72 to £2.64/kg, with vanilla cream biscuits having the lowest and whole cakes the highest costs.

In the biscuits category, crackers have the highest life cycle costs, followed by chocolate-coated; vanilla cream biscuits are the least costly. Raw materials are the main hotspot, with flour, milk and cocoa powder being the main contributors.

In the cakes sector, whole cakes have the highest costs. Like the other product categories, the majority of costs within the life cycle of cakes are related to raw materials.

Chocolates show a similar pattern in terms of the contribution analysis: raw materials production is by far the most costly stage, accounting for 89%–94% of the total life cycle costs. Milk powder, cocoa butter and liquor as well as sugar production are the most cost-relevant activities.

Within the ice cream sector, the premium versions have up to 18% higher life cycle costs than their regular counterparts, primarily because they contain egg yolk and more sugar. Chocolate premium ice cream has the highest overall costs. The majority of costs are due to raw materials, followed by manufacturing, packaging and retail. Within these, the key activities are milk production, energy consumption for ice cream refrigeration and packaging.

The estimated value added across the products ranges from £0.35/kg for semi-sweet biscuits to £11.28/kg for cupcakes. Chocolates in bags, moulded chocolates, cake slices and cream biscuits also have a high value added (£5.71-6.84/kg) which is four to six times higher than their overall costs. It is also notable that premium ice cream products create four times higher value added than their regular counterparts (~£4/kg vs ~£1/kg), despite a much smaller difference in their costs (18%).

The total annual life cycle costs in the four sectors considered are estimated at £3.455 billion, of which 42% is contributed by the biscuits due to their high sales volume. The total value added is nearly £6.5 billion per year, half of which is created by chocolates because of their high retail prices.

The study has also demonstrated how LCC can be used to evaluate the eco-efficiency of products and sectors. Using global warming potential as an environmental indicator, the results suggest that whole cakes are the most eco-efficient and vanilla regular ice cream the least efficient products. The same trend is found at the sectoral level, with cakes being the best and ice cream the worst sub-sectors for the eco-efficiency. Overall, the confectionary sector is around 60% more eco-efficient than the frozen desserts sector. However, these

results are based on one environmental indicator so the ranking of products and sectors could change if other life cycle impacts are also taken into account. This should be considered as part of future work. Multi-criteria decision analysis could be used to rank the products and sectors on their eco-efficiency.

The results of this study can be used for benchmarking of different products and to drive innovation towards economically-sustainable and eco-efficient confectionary and frozen desserts supply chains. They can also be used to stimulate closer collaboration between different players in the supply chain, helping to make more informed procurement and purchasing decisions. Although the focus here has been on the UK market, the methods developed are generic and can be applied to estimate life cycle costs, value added, and eco-efficiency of these sectors in other countries and regions.

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Economic sustainability of food supply chains: life cycle costs and value added in the confectionary and frozen desserts sectors

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Supporting information

Table S1a. Estimates of the volume of biscuits sold annually

1. Sales volume (Key Note 2015a)	2. Biscuit categories – consumer perspective	3. Biscuits categories – manufacturer perspective	4. Alignment of consumer and manufacturer classification	5. Assumptions	6. Average market prices	7. Estimated total sales volume
Crackers: £362 million/yr	Crackers		Similar from both perspectives		Crackers: £1.3/kg	Crackers: 278,462 t
Healthier biscuits: £612 m/yr	Healthier biscuits	Low fat/sugar	Healthier biscuits equal low fat/sugar		Low fat/sugar: £1.5/kg	Low fat/sugar: 408,000 t
Chocolate biscuits: £417 m/yr	Chocolate biscuits	Chocolate-coated/chocolate cream	Chocolate biscuits equal chocolate-coated plus chocolate cream sandwich			
Everyday biscuits: £563 m/yr	Everyday biscuits	Semi-sweet	Everyday biscuits equal semi-sweet plus vanilla cream sandwich	Equal share of vanilla cream and semi-sweet biscuits	Semi-sweet: £1.1/kg	Semi-sweet: 255,909 t
		Chocolate-coated	Chocolate biscuits equal chocolate-coated plus chocolate cream sandwich	Equal share of chocolate-coated and chocolate cream biscuits	Chocolate-coated: £2/kg	Chocolate-coated: 104,250 t
		Chocolate cream sandwich	Chocolate biscuits equal chocolate-coated plus chocolate cream sandwich	Equal share of chocolate-coated and chocolate cream biscuits	Chocolate cream: £6.5/kg	Chocolate cream: 32,077 t
		Vanilla cream sandwich	Everyday biscuits equal semi-sweet plus vanilla cream sandwich	Equal share of vanilla cream and semi-sweet biscuits	Vanilla cream: £6.4/kg	Vanilla cream: 43,984 t
Other types (seasonal, special, children's, etc.): £563 m/yr Total: £2,608 m/yr	Other types	Other types	Similar from both perspectives		Other: £1.1/kg	Other: 594,545 t

Table S1b. Estimates of the volume of cakes sold annually

1. Sales volume (Key Note 2015a & c)	2. Assumptions	3. Average market prices	4. Estimated total sales volume
Whole cakes: £287 million/yr Individual cakes: 1,087m/yr Cake slices: £362.3 m/yr Pies: £362.3 m/yr Cupcakes: £362.3 m/yr Cheesecake: £272 m/yr Total: 1,645.9 m/yr	Assumed to be Victoria sponge cake Equal share of slices, pies and cupcakes	Whole cakes: £6.8/kg Cake slices: £8/kg Pies: £2/kg Cupcakes: £2/kg Cheesecake: £4.3/kg	Whole cakes: 42,206 t Cake slices: 45,288 t Pies: 181,150 t Cupcakes: 27,869 t Cheesecake: 63,256 t

Table S1c. Estimates of the volume of chocolates sold annually

1. Sales volume (Key Note 2015b)	2. Chocolates categories – consumer perspective	3. Chocolate categories – manufacturer perspective	4. Average market prices	5. Estimated total sales volume
Moulded chocolates: £845 million/yr Chocolate countlines: £1,817 m/yr Chocolates in bag: £1,304 m/yr Other chocolates: £378 m/yr Total: 4,344 m/yr	Moulded chocolates Chocolate countlines Chocolates in bag Other chocolates	Moulded chocolates Chocolate countlines Chocolates in bag Other chocolates	Moulded: £7.5/kg Countlines: £6/kg In bag: £8.3/kg Other: £6/kg	Moulded: 112,667 t Countlines: 302,833 t In bag: 157,108 t Other: 63,000 t

Table S1d. Estimates of the volume of ice cream sold annually

1. Sales volume (Key Note 2015c)	2. Sales share in the take-home sector	3. Product categories considered	4. Assumptions	5. Average market prices	6. Estimated total sales volume
Take-home ice cream: £899 million/yr	Regular ice cream 12.2%	Regular ice cream	Vanilla and chocolate occupy 100% of the regular and premium ice cream market in equal shares (no actual data available)	Regular: £2/kg	Vanilla regular: 27,500 t Chocolate regular: 27,500 t
	Premium ice cream 49.3%	Premium ice cream		Premium: £5/kg	Vanilla premium: 44,300 t Chocolate premium: 44,300 t
Wrapped impulse ice cream: £234 m/yr	Multipacks 38.5%	Other (wrapped impulse & multipacks)		Other (wrapped impulse & multipacks) £2.225/kg	Other ice cream: 260,674 t
Total: 1,133 m/yr					

Table S2: Life cycle cost inventory for the 18 products considered in the study

Crackers	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
Raw materials (RM)	Flour white	0.653	kg	0.936	0.611208
RM	Palm oil	0.103	kg	0.3698	0.0380894
RM	Sugar	0.0115	kg	0.37	0.004255
RM	Ammonium bicarbonate	0.0013	kg	0.33	0.000429
RM	Salt	0.0064	kg	0.13	0.000832
RM	Yeast	0.0064	kg	9.36	0.059904
RM	Water	0.28	kg	0.0016	0.000448
Transport (TR)	Transport lorry (raw materials to manufacturer)	184.48	kg*km	0.00003	0.0055344
TR	Transport ship (raw materials to manufacturer)	1630	kg*km	5.00E-08	0.0000815
Manufacturing (MA)	Electricity	1.259	MJ	0.022	0.027698
MA	Gas	4.16	MJ	0.0054	0.022464
MA	Lubricants	0.00001	kg	0.664	0.00000664
MA	Wastewater	0.5	L	0.0013	0.00065
MA	Water	0.5	L	0.0016	0.0008
Packaging (PA)	Polypropylene primary packaging	0.0104	kg	1.69	0.017576
PA	Cardboard secondary packaging	0.382	kg	0.14	0.05348
TR	Transport lorry	7.29	kg*km	0.00003	0.0002187
Distribution centre (DC)	Water	0.00693	L	0.0016	0.000011088
TR	Transport lorry	150	kg*km	0.00003	0.0045
DC	Electricity	0.00000205	MJ	0.022	4.51E-08
DC	Wastewater	0.00693	L	0.0013	0.000009009
DC	LDPE tertiary packaging	0.00047	kg*km	1.57	0.0007379
TR	Transport lorry	50	kg*km	0.00003	0.0015
PA	Plastic bags 1 bag weight 0.0075 kg and costs 5p	0.0047	kg	6.6	0.03102
Retailer (RE)	Water	2.09	L	0.0016	0.003344
RE	Electricity	0.000824	MJ	0.022	0.000018128
RE	Wastewater	2.09	L	0.0013	0.002717
RE	Waste to recycling (secondary packaging)	0.033043	kg	0.06	0.00198258
Savings (S)	Recycled corrugated board savings	-0.0297387	kg	0.14	-0.004163418
RE	Waste to landfill (secondary packaging)	0.005157	kg	0.1	0.0005157
RE	Waste to energy (tertiary packaging)	-0.03207654	MJ	0.022	-0.000705684
RE	Waste to landfill (tertiary packaging)	0.00047	kg	0.99	0.0004653
S	Energy from thermal treatment	-0.0106596	MJ	0.022	-0.000234511
TR	Passenger car	0.135	km	0.12	0.0162

Table S2: continued

Crackers	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
Consumer (CO)	Waste to landfill [plastic bags]	0.002726	kg	0.1	0.0002726
CO	Waste to thermal treatment (plastic bags)	0.001974	kg	0.99	0.00195426
S	Energy from thermal treatment	-0.03624264	MJ	0.022	-0.000797338
End of life (EOL)	Waste to thermal treatment (primary packaging)	0.004368	kg	0.99	0.00432432
EOL	Waste to landfill (primary packaging)	0.006032	kg	0.1	0.0006032
S	Energy from thermal treatment	-0.08019648	MJ	0.022	-0.001764323
Low fat/sugar biscuits	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
RM	Flour white	0.658	kg	0.936	0.615888
RM	Palm oil	0.057	kg	0.3698	0.0210786
RM	Sugar	0.105	kg	0.37	0.03885
RM	Ammonium bicarbonate	0.01	kg	0.33	0.0033
RM	Salt	0.006	kg	0.13	0.00078
RM	Water	0.196	L	0.0016	0.0003136
TR	Transport lorry [tkm] while price is in kg*km	163.7	kg*km	0.00003	0.004911
TR	Transport ship	94	kg*km	5.00E-08	0.0000047
MA	Electricity	1.259	MJ	0.022	0.027698
MA	Gas	4.16	MJ	0.0054	0.022464
MA	Lubricants	0.00001	kg	0.664	0.00000664
MA	Wastewater	0.5	L	0.0013	0.00065
MA	Water	0.5	L	0.0016	0.0008
PA	Polypropylene primary packaging	0.0107	kg	1.69	0.018083
PA	Cardboard secondary packaging	0.0382	kg	0.14	0.005348
TR	Transport lorry	7.34	kg*km	0.00003	0.0002202
DC	Water	0.00487	L	0.0016	0.000007792
TR	Transport lorry	150	kg*km	0.00003	0.0045
DC	Electricity	1.44E-06	MJ	0.022	3.168E-08
DC	Wastewater	0.00487	L	0.0013	0.000006331
DC	LDPE tertiary packaging	0.00047	kg	1.57	0.0007379
TR	Transport, lorry (distribution centre to retailer)	50	kg*km	0.00003	0.0015
PA	Plastic bags 1 bag weight 0.0075 kg and costs 5p	0.00325	kg	6.6	0.02145
RE	Water	1.46	L	0.0016	0.002336

Table S2: continued

Low fat/sugar biscuits	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
RE	Electricity	0.000576	MJ	0.022	0.000012672
RE	Wastewater	1.46	L	0.0013	0.001898
RE	Waste to recycling (secondary packaging)	0.033043	kg	0.06	0.00198258
RE	Waste to thermal treatment (secondary packaging)	0.005157	kg	0.1	0.0005157
S	Recycled corrugated board savings (secondary packaging)	-0.0297387	kg	0.14	-0.004163418
S	Energy from thermal treatment (secondary packaging)	-0.20552746	MJ	0.022	-0.004521604
RE	Waste to energy (tertiary packaging)	0.0001974	kg	0.99	0.000195426
RE	Waste to thermal treatment (tertiary packaging)	0.00047	kg	0.1	0.000047
S	Energy from thermal treatment (tertiary packaging)	-0.0106596	MJ	0.022	-0.000234511
TR	Passenger car	0.135	km	0.12	0.0162
CO	Waste to landfill (plastic bags)	0.001885	kg	0.1	0.0001885
CO	Waste to thermal treatment (plastic bags)	0.001365	kg	0.99	0.00135135
S	Energy from thermal treatment (plastic bags)	-0.0250614	MJ	0.022	-0.000551351
EOL	Waste to thermal treatment (primary packaging)	0.004494	kg	0.99	0.00444906
EOL	Waste to landfill (primary packaging)	0.006206	kg	0.1	0.0006206
S	Energy from thermal treatment (primary packaging)	-0.08250984	MJ	0.022	-0.001815216
Semi-sweet Biscuits	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
RM	Flour white	0.588	kg	0.936	0.550368
RM	Palm oil	0.117	kg	0.3698	0.0432666
RM	Sugar	0.161	kg	0.37	0.05957
RM	Ammonium bicarbonate	0.0008	kg	0.33	0.000264
RM	Salt	0.006	kg	0.13	0.00078
RM	Water	0.136	L	0.0016	0.0002176
TR	Transport lorry (raw materials to manufacturer)	179.3	kg*km	0.00003	0.005379
TR	Transport ship (raw materials to manufacturer)	1860	kg*km	5.00E-08	0.000093
MA	Electricity	1.259	MJ	0.022	0.027698
MA	Gas	4.16	MJ	0.0054	0.022464
MA	Lubricants	0.00001	kg	0.664	0.00000664
MA	Wastewater	0.5	L	0.0013	0.00065
MA	Water	0.5	L	0.0016	0.0008
PA	Polypropylene primary packaging	0.0107	kg	1.69	0.018083

Table S2: continued

Semi-sweet Biscuits	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
PA	Cardboard secondary packaging	0.0382	kg	0.14	0.005348
TR	Transport, lorry (packaging to manufacturer)	7.34	kg*km	0.00003	0.0002202
DC	Water	0.00487	L	0.0016	0.000007792
TR	Transport lorry (manufacturer to distribution centre)	150	kg*km	0.00003	0.0045
DC	Electricity	0.00000144	MJ	0.022	3.168E-08
DC	Wastewater	0.00487	L	0.0013	0.000006331
DC	LDPE film (tertiary packaging)	0.00047	kg	1.57	0.0007379
TR	Transport, lorry (packaging to distribution centre)	0.0705	kg*km	0.00003	0.000002115
PA	Plastic bags (1 bag weighs 7.5 g and costs 5p)	0.00325	kg	6.6	0.02145
RE	Water	1.46	L	0.0016	0.002336
RE	Electricity	0.000576	MJ	0.022	0.000012672
RE	Wastewater	1.46	L	0.0013	0.001898
TR	Transport, lorry (distribution centre to retailer)	50	kg*km	0.00003	0.0015
RE	Waste to recycling (secondary packaging)	0.033043	kg	0.06	0.00198258
S	Recycled corrugated board savings	-0.0297387	kg	0.14	-0.004163418
RE	Waste to landfill (secondary packaging)	0.005157	kg	0.1	0.0005157
S	Energy from thermal treatment (secondary packaging)	-0.03207654	MJ	0.022	-0.000705684
RE	Waste to energy (tertiary packaging)	0.00047	kg	0.99	0.0004653
S	Energy from thermal treatment (tertiary packaging)	-0.0106596	MJ	0.022	-0.000234511
TR	Passenger car	0.135	km	0.12	0.0162
CO	Waste to landfill (plastic bags)	0.001885	kg	0.1	0.0001885
CO	Waste to thermal treatment (plastic bags)	0.001365	kg	0.99	0.00135135
S	Energy from thermal treatment (plastic bags)	-0.0250614	MJ	0.022	-0.000551351
EOL	Waste to thermal treatment (primary packaging)	0.004494	kg	0.99	0.00444906
EOL	Waste to landfill (primary packaging)	0.006206	kg	0.1	0.0006206
S	Energy from thermal treatment (primary packaging)	-0.08250984	MJ	0.022	-0.001815216
Chocolate-coated biscuits	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
RM	Flour white	0.3431	kg	0.936	0.3211416
RM	Flour wholemeal	0.0803	kg	1	0.0803
RM	Palm oil	0.146	kg	0.3698	0.0539908
RM	Sugar	0.1022	kg	0.37	0.037814
RM	Ammonium bicarbonate	0.0146	kg	0.33	0.004818

Table S2: continued

Chocolate-coated biscuits	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
RM	Salt	0.0073	kg	0.13	0.000949
RM	Water	0.028032	L	0.0016	4.48512E-05
TR	Transport lorry (raw materials to manufacturer)	162.06	kg*km	0.00003	0.0048618
TR	Transport ship (raw materials to manufacturer)	2314.1	kg*km	0.00000005	0.000115705
RM	Sugar	0.1242	kg	0.3698	0.04592916
RM	Cocoa powder	0.0135	kg	2.8471	0.03843585
RM	Palm kernel oil	0.0783	kg	0.595	0.0465885
RM	Milk powder	0.054	kg	2.185	0.11799
TR	Transport lorry (raw materials to manufacturer)	56.7	kg*km	0.00003	0.001701
TR	Transport ship (raw materials to manufacturer)	99.63	kg*km	0.00000005	4.9815E-06
MA	Electricity	2.136	MJ	0.022	0.046992
MA	Gas	3.04	MJ	0.0054	0.016416
MA	Lubricants	0.0000073	kg	0.664	4.8472E-06
MA	Wastewater	0.365	L	0.0013	0.0004745
MA	Water	0.365	L	0.0016	0.000584
PA	Polypropylene primary packaging	0.0081	kg	1.69	0.013689
PA	Cardboard secondary packaging	0.0382	kg	0.14	0.005348
TR	Transport lorry (packaging to manufacturer)	6.95	kg*km	0.00003	0.0002085
DC	Water	0.00318	L	0.0016	0.000005088
TR	Transport lorry (manufacturer to distribution centre)	150	kg*km	0.00003	0.0045
DC	Electricity	0.000000942	MJ	0.022	2.0724E-08
DC	Wastewater	0.00318	L	0.0013	0.000004134
DC	LDPE tertiary packaging	0.00047	kg	1.57	0.0007379
TR	Transport lorry (packaging to distribution centre)	0.0705	kg*km	0.00003	0.000002115
PA	Plastic bags 1 bag weight 0.0075 kg and costs 5p	0.00213	kg	6.6	0.014058
RE	Water	0.955	L	0.0016	0.001528
RE	Electricity	0.000377	MJ	0.022	0.000008294
RE	Wastewater	0.955	L	0.0013	0.0012415
TR	Transport lorry (distribution centre to retailer)	50	kg*km	0.00003	0.0015
RE	Waste to recycling (secondary packaging)	0.033043	kg	0.06	0.00198258
S	Recycled corrugated board savings	-0.0297387	MJ	0.14	-0.004163418
RE	Waste to landfill (secondary packaging)	0.005157	kg	0.1	0.0005157
RE	Waste to energy (tertiary packaging)	-0.03207654	kg	0.0793	-0.00254367
RE	Waste to landfill (tertiary packaging)	0.00047	kg	0.99	0.0004653
S	Energy from thermal treatment (tertiary packaging)	-0.0106596	MJ	0.022	-0.000234511
TR	Consumer's car	0.135	km	0.12	0.0162

Table S2 continued

Chocolate-coated biscuits	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
CO	Waste to landfill (plastic bags)	0.0012354	kg	0.1	0.00012354
CO	Waste to thermal treatment (plastic bags)	0.0008946	kg	0.99	0.000885654
S	Energy from thermal treatment (plastic bags)	-0.016424856	MJ	0.022	-0.000361347
EOL	Waste to thermal treatment (primary packaging)	0.003402	kg	0.99	0.00336798
EOL	Waste to Landfill (primary packaging)	0.004698	kg	0.1	0.0004698
S	Energy from thermal treatment (primary packaging)	-0.06246072	MJ	0.022	-0.001374136
Chocolate cream biscuits	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
RM	Flour white	0.38908	kg	0.936	0.36417888
RM	Palm oil	0.08591	kg	0.3698	0.031769518
RM	Sugar	0.15975	kg	0.37	0.0591075
RM	Ammonium bicarbonate	0.00142	kg	0.33	0.0004686
RM	Salt	0.00142	kg	0.13	0.0001846
RM	Cocoa powder	0.01775	kg	2.8471	0.050536025
RM	Water	0.042032	L	0.0016	6.72512E-05
TR	Transport lorry (raw materials to manufacturer)	121.623	kg*km	0.00003	0.00364869
TR	Transport ship (raw materials to manufacturer)	1363.2	kg*km	5.00E-08	0.00006816
RM	Sugar	0.1624	kg	0.3698	0.06005552
RM	Cocoa powder	0.0145	kg	2.8471	0.04128295
RM	Palm kernel oil	0.1102	kg	0.595	0.065569
TR	Transport lorry (raw materials to manufacturer)	58	kg	0.00003	0.00174
TR	Transport ship (raw materials to manufacturer)	1748.7	kg	5.00E-08	0.000087435
MA	Electricity	1.2795	MJ	0.022	0.028149
MA	Gas	2.95	MJ	0.0054	0.01593
MA	Lubricants	0.0000071	kg	0.664	4.7144E-06
MA	Wastewater	0.355	L	0.0013	0.0004615
MA	Water	0.355	L	0.0016	0.000568
PA	Polypropylene primary packaging	0.00365	kg	1.69	0.0061685
PA	Aluminium	0.00365	kg	1.22	0.004453
PA	Cardboard secondary packaging	0.0325	kg	0.14	0.00455
TR	Transport lorry (packaging to manufacturer)	5.976	kg*km	0.00003	0.00017928
DC	Water	0.00356	L	0.0016	0.000005696

Table S2 continued

Chocolate cream biscuits	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
TR	Transport lorry (manufacturer to distribution centre)	150	kg*km	0.00003	0.0045
DC	Electricity	0.00000105	MJ	0.022	2.31E-08
DC	Wastewater	0.00356	L	0.0013	0.000004628
DC	LDPE tertiary packaging	0.00047	kg	1.57	0.0007379
TR	Transport lorry (packaging to distribution centre)	0.0705	kg*km	0.00003	0.000002115
PA	Plastic bags 1 bag weight 0.0075 kg and costs 5p	0.00238	kg	6.6	0.015708
RE	Water	1.07	L	0.0016	0.001712
RE	Electricity	0.000421	MJ	0.022	0.000009262
RE	Wastewater	1.07	L	0.0013	0.001391
TR	Transport lorry (distribution centre to retailer)	50	kg*km	0.00003	0.0015
RE	Waste to recycling (secondary packaging)	0.0281125	kg	0.06	0.00168675
S	Recycled corrugated board savings	-0.02530125	MJ	0.14	-0.003542175
RE	Waste to thermal treatment (secondary packaging)	0.0043875	kg	0.1	0.00043875
S	Energy from thermal treatment (secondary packaging]	-0.02729025	MJ	0.022	-0.000600386
RE	Waste to energy (tertiary packaging)	0.00047	kg	0.99	0.0004653
S	Energy from thermal treatment (tertiary packaging)	-0.0106596	MJ	0.022	-0.000234511
TR	Consumer's car	0.135	km	0.12	0.0162
CO	Waste to landfill (plastic bags)	0.0013804	kg	0.1	0.00013804
CO	Waste to thermal treatment (plastic bags)	0.0009996	kg	0.99	0.000989604
S	Energy from thermal treatment (plastic bags)	-0.018352656	MJ	0.022	-0.000403758
EOL	Waste to thermal treatment (primary packaging)	0.003066	kg	0.99	0.00303534
EOL	Waste to Landfill (primary packaging)	0.004234	kg	0.1	0.0004234
S	Energy from thermal treatment (primary packaging)	-0.05629176	MJ	0.022	-0.001238419
Vanilla cream biscuits	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
RM	Flour white	0.39547	kg	0.936	0.37015992
RM	Palm oil	0.14413	kg	0.3698	0.053299274
RM	Sugar	0.12993	kg	0.37	0.0480741
RM	Ammonium bicarbonate	0.00213	kg	0.33	0.0007029
RM	Salt	0.00213	kg	0.13	0.0002769
RM	Water	0.031879	L	0.0016	5.10064E-05
TR	Transport lorry (raw materials to manufacturer)	152.082	kg*km	0.00003	0.00456246

Table S2 continued

Vanilla cream biscuits	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
TR	Transport ship (raw materials to manufacturer)	2286.2	kg*km	5.00E-08	0.00011431
RM	Sugar	0.19053	kg	0.3698	0.070457994
RM	Vanilla flavour	0.00058	kg	11.97	0.0069426
RM	Palm oil	0.08671	kg	0.3698	0.032065358
RM	Milk powder	0.01218	kg	2.185	0.0266133
TR	Transport lorry (raw materials to manufacturer)	2.436	kg*km	0.00003	0.00007308
TR	Transport ship (raw materials to manufacturer)	1374.6	kg*km	5.00E-08	0.00006873
MA	Electricity	1.2795	MJ	0.022	0.028149
MA	Gas	2.95	MJ	0.0054	0.01593
MA	Lubricants	0.0000071	kg	0.664	4.7144E-06
MA	Wastewater	0.355	L	0.0013	0.0004615
MA	Water	0.355	L	0.0016	0.000568
PA	Polypropylene primary packaging	0.00365	kg	1.69	0.0061685
PA	Aluminium	0.00365	kg	1.22	0.004453
PA	Cardboard secondary packaging	0.0325	kg	0.14	0.00455
TR	Transport lorry (packaging to manufacturer)	5.976	kg*km	0.00003	0.00017928
DC	Water	0.00356	L	0.0016	0.000005696
TR	Transport lorry (manufacturer to distribution centre)	150	kg*km	0.00003	0.0045
DC	Electricity	0.00000105	MJ	0.022	2.31E-08
DC	Wastewater	0.00356	L	0.0013	0.000004628
DC	LDPE tertiary packaging	0.00047	kg	1.57	0.0007379
TR	Transport lorry (packaging to distribution centre)	0.0705	kg*km	0.00003	0.000002115
PA	Plastic bags 1 bag weight 0.0075 kg and costs 5p	0.00238	kg	6.6	0.015708
RE	Water	1.07	L	0.0016	0.001712
RE	Electricity	0.000421	MJ	0.022	0.000009262
RE	Wastewater	1.07	L	0.0013	0.001391
TR	Transport lorry (distribution centre to retailer)	50	kg*km	0.00003	0.0015
RE	Waste to recycling (secondary packaging)	0.0281125	kg	0.06	0.00168675
S	Recycled corrugated board savings	-0.02530125	MJ	0.14	-0.003542175
RE	Waste to thermal treatment (secondary packaging)	0.0043875	kg	0.1	0.00043875
S	Energy from thermal treatment (secondary packaging)	-0.02729025	MJ	0.022	-0.000600386
RE	Waste to energy (tertiary packaging)	0.00047	kg	0.99	0.0004653
S	Energy from thermal treatment (tertiary packaging)	-0.0106596	MJ	0.022	-0.000234511

Table S2 continued

Vanilla cream biscuits	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
TR	Consumer's car	0.135	km	0.12	0.0162
CO	Waste to landfill (plastic bags)	0.0013804	kg	0.1	0.00013804
CO	Waste to thermal treatment (plastic bags)	0.0009996	kg	0.99	0.000989604
S	Energy from thermal treatment (plastic bags)	-0.018352656	MJ	0.022	-0.000403758
EOL	Waste to thermal treatment (primary packaging)	0.003066	kg	0.99	0.00303534
EOL	Waste to Landfill (primary packaging)	0.004234	kg	0.1	0.0004234
S	Energy from thermal treatment (primary packaging)	-0.018352656	MJ	0.022	-0.000403758
Whole cakes	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
RM	Strawberry	0.15	kg	2.26	0.339
TR	Transport lorry (raw materials to manufacturer)	30	kg*km	0.00003	0.0009
RM	Vanilla flavour	0.0027	kg	11.97	0.032319
RM	Sugar	0.15606	kg	0.37	0.0577422
RM	Butter	0.11124	kg	1.9437	0.216217188
TR	Transport lorry (raw materials to manufacturer)	22.788	kg*km	0.00003	0.00068364
RM	Flour white	0.1392	kg	0.936	0.1302912
RM	Palm oil	0.0232	kg	0.3698	0.00857936
RM	Sugar	0.116	kg	0.37	0.04292
RM	Soda	0.0203	kg	0.33	0.006699
RM	Salt	0.000928	kg	0.13	0.00012064
RM	Starch	0.0174	kg	1.12	0.019488
RM	Sorbic acid/sorbates	0.001392	kg	79.19	0.11023248
RM	Eggs pasteurised	0.2436	kg	5.99	1.459164
RM	Glycerine	0.0174	kg	2.4	0.04176
RM	Acetic acid	0.0058	kg	0.46	0.002668
TR	Transport lorry (raw materials to manufacturer)	47.444	kg*km	0.00003	0.00142332
TR	Transport ship (raw materials to manufacturer)	368.3	kg*km	5.00E-08	0.000018415
MA	Electricity	0.5475	MJ	0.022	0.012045
MA	Gas	0.543	MJ	0.0054	0.0029322
MA	Steam	0.501	MJ	0.034	0.017034
MA	Lubricants	0.0000058	kg	0.664	3.8512E-06

Table S2 continued

Whole cakes	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
MA	Wastewater	0.29	L	0.0013	0.000377
MA	Water	0.29	L	0.0016	0.000464
PA	Polypropylene primary packaging	0.006	kg	1.69	0.01014
PA	Folding box	0.087	kg	0.14	0.01218
PA	Cardboard secondary packaging	0.054	kg	0.14	0.00756
TR	Transport lorry (packaging to manufacturer)	22.1	kg*km	0.00003	0.000663
DC	Water	0.00636	L	0.0016	0.000010176
TR	Transport lorry	150	kg*km	0.00003	0.0045
DC	Electricity	0.00000188	MJ	0.022	4.136E-08
DC	Wastewater	0.00636	L	0.0013	0.000008268
DC	LDPE tertiary packaging	0.00047	kg	1.57	0.0007379
TR	Transport lorry (packaging to distribution centre)	0.0705	kg*km	0.00003	0.000002115
RE	Water	1.91	L	0.0016	0.003056
RE	Electricity	0.000753	MJ	0.022	0.000016566
RE	Wastewater	1.91	L	0.0013	0.002483
RE	Waste to recycling (secondary packaging)	0.04671	kg	0.06	0.0028026
S	Recycled corrugated board savings	-0.042039	MJ	0.14	-0.00588546
RE	Waste to landfill (secondary packaging)	0.00729	kg	0.99	0.0072171
RE	Waste to energy (tertiary packaging)	-0.0453438	MJ	0.022	-0.000997564
RE	Waste to landfill (tertiary packaging)	0.00047	kg	0.99	0.0004653
S	Energy from thermal treatment	-0.0106596	MJ	0.022	-0.000234511
TR	Transport lorry	50	kg*km	0.00003	0.0015
PA	Plastic bags 1 bag weight 0.0075 kg and costs 5p	0.0043	kg	6.6	0.02838
TR	Consumer's car	0.135	km	0.12	0.0162
CO	Waste to landfill (plastic bags)	0.002494	kg	0.1	0.0002494
CO	Waste to thermal treatment (plastic bags)	0.001806	kg	0.99	0.00178794
S	Energy from thermal treatment	-0.03315816	MJ	0.022	-0.00072948
CO	Electricity	0.0524	MJ	0.022	0.0011528
CO	Detergent	0.0016	kg	6.65	0.01064
CO	Water	0.187	L	0.0016	0.0002992
CO	Wastewater	0.187	L	0.0013	0.0002431
EOL	Waste to thermal treatment (primary packaging folding box)	0.00696	kg	0.99	0.0068904
EOL	Waste to Landfill (primary packaging folding box)	0.00783	kg	0.1	0.000783

Table S2 continued

Whole cakes	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
EOL	Waster to recycling plant (primary packaging folding box)	0.07221	kg	0.06	0.0043326
S	Recycled folding box savings	-0.017226	kg	0.14	-0.00241164
S	Energy from thermal treatment	-0.0324684	MJ	0.022	-0.000714305
EOL	Waste to thermal treatment (primary packaging, plastic)	0.00252	kg	0.99	0.0024948
EOL	Waste to landfill (primary packaging, plastic)	0.00348	kg	0.1	0.000348
S	Energy from thermal treatment	-0.0462672	MJ	0.022	-0.001017878
EOL	Bio-waste to composting plant	0.024	kg	0.06	0.00144
S	Savings compost	-0.00144	kg	0.125	-0.00018
EOL	Bio-waste to landfill	0.176	kg	0.1	0.0176
Cake slices	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
RM	Sugar - icing	0.23218	kg	0.37	0.0859066
RM	Starch	0.00442	kg	1.12	0.0049504
RM	Water	0.0234	L	0.0016	0.00003744
TR	Transport lorry (raw materials to manufacturer)	0.884	kg*km	0.00003	0.00002652
RM	Vanilla flavour	0.0012	kg	11.97	0.014364
RM	Sugar	0.06924	kg	0.37	0.0256188
RM	Butter	0.02472	kg	1.9437	0.048048264
RM	Palm oil	0.12772	kg	0.3698	0.047230856
TR	Transport ship (raw materials to manufacturer)	2027.4	kg*km	5.00E-08	0.00010137
TR	Transport lorry (raw materials to manufacturer)	17.544	kg*km	0.00003	0.00052632
RM	Flour white	0.1488	kg	0.936	0.1392768
RM	Palm oil	0.031	kg	0.3698	0.0114638
RM	Sugar	0.1426	kg	0.37	0.052762
RM	Soda	0.0186	kg	0.33	0.006138
RM	Salt	0.003968	kg	0.13	0.00051584
RM	Water	0.0279	L	0.0016	0.00004464
RM	Fructose - glucose	0.031	kg	3	0.093
RM	Eggs pasteurised	0.186	kg	5.99	1.11414
RM	Glycerine	0.0279	kg	2.4	0.06696
RM	Acetic acid	0.000744	kg	0.46	0.00034224

Table S2 continued

Cake slices	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
RM	Sorbic acid	0.001488	kg	79.19	0.11783472
TR	Transport lorry (raw materials to manufacturer)	93.62	kg*km	0.00003	0.0028086
TR	Transport ship (raw materials to manufacturer)	491.66	kg*km	5.00E-08	0.000024583
MA	Electricity	0.5522	MJ	0.022	0.0121484
MA	Gas	0.581	MJ	0.0054	0.0031374
Ma	Steam	0.536	MJ	0.034	0.018224
MA	Lubricants	0.0000062	kg	0.664	4.1168E-06
MA	Wastewater	0.31	L	0.0013	0.000403
MA	Water	0.31	L	0.0016	0.000496
PA	Polyethylene bottle	0.0667	kg	1.57	0.104719
PA	Polyethylene film	0.00909	kg	1.57	0.0142713
PA	Folding box	0.0306	kg	0.14	0.004284
PA	Cardboard secondary packaging	0.057	kg	0.14	0.00798
TR	Transport lorry (packaging to manufacturer)	24.5	kg*km	0.00003	0.000735
DC	Water	0.00796	L	0.0016	0.000012736
TR	Transport lorry	150	kg*km	0.00003	0.0045
DC	Electricity	0.00000235	MJ	0.022	5.17E-08
DC	Wastewater	0.00796	L	0.0013	0.000010348
DC	LDPE tertiary packaging	0.00047	kg	1.57	0.0007379
TR	Transport lorry (packaging to distribution centre)	0.0705	kg*km	0.00003	0.000002115
RE	Water	2.39	L	0.0016	0.003824
RE	Electricity	0.000942	MJ	0.022	0.000020724
RE	Wastewater	2.39	L	0.0013	0.003107
RE	Waste to recycling (secondary packaging)	0.049305	kg	0.06	0.0029583
S	Recycled corrugated board savings	-0.0443745	kg	0.14	-0.00621243
RE	Waste to landfill (secondary packaging)	0.007695	kg	0.99	0.00761805
RE	Waste to energy (tertiary packaging)	-0.0478629	MJ	0.022	-0.001052984
RE	Waste to landfill (tertiary packaging)	0.00047	kg	0.99	0.0004653
S	Energy from thermal treatment	-0.0106596	MJ	0.022	-0.000234511
TR	Transport lorry	50	kg*km	0.00003	0.0015
PA	Plastic bags 1 bag weight 0.0075 kg and costs 5p	0.0054	kg	6.6	0.03564
TR	Consumer's car	0.135	km	0.12	0.0162

Table S2 continued

Cake slices	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
CO	Waste to landfill (plastic bags)	0.003132	kg	0.1	0.0003132
CO	Waste to thermal treatment (plastic bags)	0.002268	kg	0.99	0.00224532
S	Energy from thermal treatment	-0.04164048	MJ	0.022	-0.000916091
CO	Electricity	0.0393	MJ	0.022	0.0008646
CO	Detergent	0.0016	kg	6.65	0.01064
CO	Water	0.14	L	0.0016	0.000224
CO	Wastewater	0.14	L	0.0013	0.000182
EOL	Waste to thermal treatment (primary packaging folding box)	0.002448	kg	0.99	0.00242352
EOL	Waste to Landfill (primary packaging folding box)	0.002754	kg	0.1	0.0002754
EOL	Waste to recycling plant (primary packaging folding box)	0.025398	kg	0.06	0.00152388
S	Recycled folding box savings	-0.0060588	kg	0.14	-0.000848232
S	Energy from thermal treatment	-0.01141992	MJ	0.022	-0.000251238
EOL	Waste to thermal treatment (primary packaging, plastic)	0.031836	kg	0.99	0.03151764
EOL	Waste to landfill (primary packaging, plastic)	0.043964	kg	0.1	0.0043964
S	Energy from thermal treatment	-0.58450896	MJ	0.022	-0.012859197
EOL	Bio-waste to composting plant	0.024	kg	0.06	0.00144
S	Savings compost	-0.00144	kg	0.125	-0.00018
EOL	Bio-waste to landfill	0.176	kg	0.1	0.0176
Pies	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
RM	Sugar	0.042	kg	0.37	0.01554
RM	Water	0.084	kg	0.0016	0.0001344
RM	Apple	0.1008	kg	0.61	0.061488
MA	Electricity (pre-processing apple filling)	0.042714	MJ	0.022	0.000939708
MA	Bio-waste to composting plant	0.0168	kg	0.06	0.001008
S	Compost	-0.0084	kg	0.125	-0.00105
TR	Transport lorry (raw materials to manufacturer)	20.16	kg*km	0.00003	0.0006048
RM	Flour white	0.35313	kg	0.936	0.33052968
RM	Palm oil	0.24253	kg	0.3698	0.089687594
RM	Sugar	0.05372	kg	0.37	0.0198764

Table S2 continued

Pies	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
RM	Eggs pasteurised	0.13746	kg	5.99	0.8233854
TR	Transport lorry (raw materials to manufacturer)	220.252	kg*km	0.00003	0.00660756
TR	Transport ship (raw materials to manufacturer)	3847.3	kg*km	5.00E-08	0.000192365
MA	Electricity	0.826	MJ	0.022	0.018172
MA	Gas	1.06	MJ	0.0054	0.005724
Ma	Steam	0.986	MJ	0.034	0.033524
MA	Lubricants	0.0000079	kg	0.664	5.2456E-06
MA	Wastewater	0.395	L	0.0013	0.0005135
MA	Water	0.395	L	0.0016	0.000632
PA	Aluminium	0.0136	kg	1.22	0.016592
PA	Polyethylene bottle	0.0246	kg	1.57	0.038622
PA	Folding box	0.0832	kg	0.14	0.011648
PA	Cardboard secondary packaging	0.064	kg	0.14	0.00896
TR	Transport lorry (packaging to manufacturer)	27.83	kg*km	0.00003	0.0008349
DC	Water	0.00668	L	0.0016	0.000010688
TR	Transport lorry (manufacturer to distribution centre)	150	kg*km	0.00003	0.0045
DC	Electricity	0.00000198	MJ	0.022	4.356E-08
DC	Wastewater	0.00668	L	0.0013	0.000008684
DC	LDPE tertiary packaging	0.00047	kg	1.57	0.0007379
TR	Transport lorry (packaging to distribution centre)	0.0705	kg*km	0.00003	0.000002115
RE	Water	2	L	0.0016	0.0032
RE	Electricity	0.000791	MJ	0.022	0.000017402
RE	Wastewater	2	L	0.0013	0.0026
RE	Waste to recycling (secondary packaging)	0.05536	kg	0.06	0.0033216
S	Recycled corrugated board savings	-0.049824	kg	0.14	-0.00697536
RE	Waste to landfill (secondary packaging)	0.00864	kg	0.99	0.0085536
RE	Waste to energy (tertiary packaging)	0.0537408	kg	0.022	0.001182298
RE	Waste to landfill (tertiary packaging)	0.00047	kg	0.99	0.0004653
S	Energy from thermal treatment	-0.0106596	MJ	0.022	-0.000234511
TR	Transport lorry	50	kg*km	0.00003	0.0015
PA	Plastic bags 1 bag weight 0.0075 kg and costs 5p	0.0045	kg	6.6	0.0297
TR	Consumer's car	0.135	km	0.12	0.0162
CO	Waste to landfill (plastic bags)	0.00261	kg	0.1	0.000261

Table S2 continued

Pies	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
CO	Waste to thermal treatment (plastic bags)	0.00189	kg	0.99	0.0018711
S	Energy from thermal treatment	-0.0347004	MJ	0.022	-0.000763409
CO	Electricity	0.0393	MJ	0.022	0.0008646
CO	Detergent	0.0012	kg	6.65	0.00798
CO	Water	0.14	L	0.0016	0.000224
CO	Wastewater	0.14	L	0.0013	0.000182
EOL	Waste to thermal treatment (Primary packaging folding box)	0.001088	kg	0.99	0.00107712
EOL	Waste to Landfill (primary packaging folding box)	0.001224	kg	0.1	0.0001224
EOL	Waste to recycling plant (primary packaging folding box)	0.011288	kg	0.06	0.00067728
S	Recycled folding box savings	-0.0026928	kg	0.14	-0.000376992
S	Energy from thermal treatment	-0.00507552	MJ	0.022	-0.000111661
EOL	Waste to thermal treatment (Primary packaging, plastic)	0.010332	kg	0.99	0.01022868
EOL	Waste to landfill (Primary packaging, plastic)	0.014268	kg	0.1	0.0014268
S	Energy from thermal treatment	-0.18969552	MJ	0.022	-0.004173301
EOL	Bio-waste to composting plant	0.024	kg	0.06	0.00144
S	Savings compost	-0.00144	kg	0.125	-0.00018
EOL	Bio-waste to landfill	0.176	kg	0.1	0.0176
EOL	Waste to recycling (Primary packaging Aluminium)	0.0079152	kg	0.06	0.000474912
EOL	Waste to landfill (Primary packaging Aluminium)	0.0056848	kg	0.1	0.00056848
S	Savings aluminium	-0.0079152	kg	1.22	-0.009656544
Cupcakes	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
RM	Sugar icing	0.36315	kg	0.37	0.1343655
RM	Citrus	0.018	kg	0.793	0.014274
RM	butter	0.06885	kg	1.9437	0.133823745
TR	Transport lorry (raw materials to manufacturer)	13.77	kg*km	0.00003	0.0004131
RM	Flour white	0.132	kg	0.936	0.123552
RM	Palm oil	0.0825	kg	0.3698	0.0305085
RM	Sugar	0.099	kg	0.37	0.03663
RM	Soda	0.01925	kg	0.33	0.0063525
RM	Water	0.044	L	0.0016	0.0000704

Table S2 continued

Cupcakes	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
RM	Fructose - Glucose	0.0275	kg	3	0.0825
RM	Sorbic acid	0.00132	kg	79.19	0.1045308
RM	Eggs pasteurised	0.1265	kg	5.99	0.757735
RM	Acetic acid	0.00066	kg	0.46	0.0003036
RM	Glycerine	0.0165	kg	2.4	0.0396
TR	Transport lorry (raw materials to manufacturer)	102.85	kg*km	0.00003	0.0030855
TR	Transport ship (raw materials to manufacturer)	1309	kg*km	5.00E-08	0.00006545
MA	Electricity	0.4941	MJ	0.022	0.0108702
MA	Gas	0.515	MJ	0.0054	0.002781
Ma	Steam	0.4748	MJ	0.034	0.0161432
MA	Lubricants	0.0000055	kg	0.664	0.000003652
MA	Wastewater	0.275	L	0.0013	0.0003575
MA	Water	0.275	L	0.0016	0.00044
PA	Paper	0.0331	kg	0.14	0.004634
PA	Polyethylene bottle	0.0922	kg	1.57	0.144754
PA	Folding box	0.0305	kg	0.14	0.00427
PA	Cardboard secondary packaging	0.147	kg	0.14	0.02058
TR	Transport lorry (packaging to manufacturer)	45.33	kg*km	0.00003	0.0013599
DC	Water	0.0137	L	0.0016	0.00002192
TR	Transport lorry (distribution centre to manufacturer)	150	kg*km	0.00003	0.0045
DC	Electricity	0.00000404	MJ	0.022	8.888E-08
DC	Wastewater	0.0137	L	0.0013	0.00001781
DC	LDPE tertiary packaging	0.00047	kg	1.57	0.0007379
TR	Transport lorry (packaging to distribution centre)	0.0705	kg*km	0.00003	0.000002115
RE	Water	4.1	L	0.0016	0.00656
RE	Electricity	0.00162	MJ	0.022	0.00003564
RE	Wastewater	4.1	L	0.0013	0.00533
RE	Waste to recycling (secondary packaging)	0.127155	kg	0.06	0.0076293
S	Recycled corrugated board savings	-0.1144395	kg	0.14	-0.01602153
RE	Waste to landfill (secondary packaging)	0.019845	kg	0.99	0.01964655
RE	Waste to energy (tertiary packaging)	-0.1234359	kg	0.022	-0.00271559

Table S2 continued

Cupcakes	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
RE	Waste to landfill (tertiary packaging)	0.00047	kg	0.99	0.0004653
S	Energy from thermal treatment	-0.0106596	MJ	0.022	-0.000234511
TR	Transport lorry	50	kg*km	0.00003	0.0015
PA	Plastic bags 1 bag weight 0.0075 kg and costs 5p	0.0091	kg	6.6	0.06006
TR	Consumer's car	0.135	km	0.12	0.0162
CO	Waste to landfill (plastic bags)	0.005278	kg	0.1	0.0005278
CO	Waste to thermal treatment (plastic bags)	0.003822	kg	0.99	0.00378378
S	Energy from thermal treatment	-0.08305206	MJ	0.022	-0.001827145
CO	Electricity	0.105	MJ	0.022	0.00231
CO	Detergent	0.0016	kg	6.65	0.01064
CO	Water	0.374	L	0.0016	0.0005984
CO	Wastewater	0.374	L	0.0013	0.0004862
EOL	Waste to thermal treatment (primary packaging folding box)	0.00244	kg	0.99	0.0024156
EOL	Waste to Landfill (primary packaging folding box)	0.002745	kg	0.1	0.0002745
EOL	Waste to recycling plant (primary packaging folding box)	0.025315	kg	0.06	0.0015189
S	Recycled folding box savings	-0.006039	kg	0.14	-0.00084546
S	Energy from thermal treatment	-0.0113826	MJ	0.022	-0.000250417
EOL	Waste to thermal treatment (primary packaging, plastic)	0.038724	kg	0.99	0.03833676
EOL	Waste to landfill (primary packaging, plastic)	0.053476	kg	0.1	0.0053476
S	Energy from thermal treatment	-0.87826032	MJ	0.022	-0.019321727
EOL	Bio-waste to composting plant	0.024	kg	0.06	0.00144
S	Savings compost	-0.00144	kg	0.125	-0.00018
EOL	Bio-waste to landfill	0.176	kg	0.1	0.0176
EOL	Waste to recycling (primary packaging , paper)	0.027473	kg	0.06	0.00164838
EOL	Waste to landfill (primary packaging , paper)	0.002979	kg	0.1	0.0002979
EOL	Waste to thermal treatment (primary packaging, paper)	0.002648	kg	0.99	0.00262152
S	Recycled paper	-0.0247257	kg	0.14	-0.003461598
S	Savings thermal treatment	-0.01647056	MJ	1.22	-0.020094083

Table S2 continued

Cheesecake	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
RM	Flour white	0.05264	kg	0.936	0.04927104
RM	Four wholemeal	0.01232	kg	1	0.01232
RM	Palm oil	0.0224	kg	0.3698	0.00828352
RM	Sugar	0.01568	kg	0.37	0.0058016
RM	Soda	0.00224	kg	0.33	0.0007392
RM	Salt	0.00112	kg	0.13	0.0001456
TR	Transport lorry (raw materials to manufacturer)	24.864	kg*km	0.00003	0.00074592
TR	Transport ship (raw materials to manufacturer)	355.04	kg*km	5.00E-08	0.000017752
RM	Strawberry	0.15	kg	2.26	0.339
TR	Transport lorry (raw materials to manufacturer)	30	kg*km	0.00003	0.0009
RM	Soft cheese	0.209592	kg	2.2813	0.47814223
MA	Electricity	0.196308	MJ	0.022	0.004318776
RM	Water	0.089298	L	0.0016	0.000142877
RM	Milk powder	0.208116	kg	2.185	0.45473346
RM	Citrus	0.104796	kg	0.793	0.083103228
RM	Milk cream	0.089298	kg	0.98	0.08751204
TR	Transport lorry (raw materials to manufacturer)	129.7404	kg*km	0.00003	0.003892212
MA	Electricity	2.2334	MJ	0.022	0.0491348
MA	Gas	0.466	MJ	0.0054	0.0025164
Ma	Steam	0.1381	MJ	0.034	0.0046954
MA	Lubricants	0.00000112	kg	0.664	7.4368E-07
MA	Wastewater	0.056	L	0.0013	0.0000728
MA	Water	0.056	L	0.0016	0.0000896
PA	Polypropylene	0.0253	kg	1.69	0.042757
PA	Polyethylene bottle	0.0016	kg	1.57	0.002512
PA	Folding box	0.0472	kg	0.14	0.006608
PA	Cardboard secondary packaging	0.058	kg	0.14	0.00812
TR	Transport lorry (packaging to manufacturer)	19.82	kg*km	0.00003	0.0005946
TR	Diesel	0.00000118	L	0.24	2.832E-07
TR	Refrigerant R134a	0.000016	kg	12.8	0.0002048
DC	Water	0.00468	L	0.0016	0.000007488
DC	Electricity	0.00000323	MJ	0.022	7.106E-08
DC	liquid ammonia	0.000000357	L	0.33	1.1781E-07

Table S2 continued

Cheesecake	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
TR	Transport lorry (manufacturer to distribution centre)	150	kg*km	0.00003	0.0045
DC	Wastewater	0.00468	L	0.0013	0.000006084
DC	LDPE tertiary packaging	0.00047	kg	1.57	0.0007379
TR	Transport lorry (packaging to distribution centre)	0.0705	kg*km	0.00003	0.000002115
TR	Diesel	0.00000148	L	0.24	3.552E-07
TR	Refrigerant R134a (transport to retailer)	0.000016	kg	12.8	0.0002048
RE	Water	0.702	L	0.0016	0.0011232
RE	Refrigerant R134a	0.00000268	kg	12.8	0.000034304
RE	Electricity	0.00159	MJ	0.022	0.00003498
RE	Wastewater	0.702	L	0.0013	0.0009126
RE	Waste to recycling (secondary packaging)	0.05017	kg	0.06	0.0030102
S	Recycled corrugated board savings	-0.045153	kg	0.14	-0.00632142
RE	Waste to landfill (secondary packaging)	0.00783	kg	0.99	0.0077517
RE	Waste to energy (tertiary packaging)	-0.0487026	kg	0.022	-0.001071457
RE	Waste to landfill (tertiary packaging)	0.00047	kg	0.99	0.0004653
S	Energy from thermal treatment	-0.0106596	MJ	0.022	-0.000234511
TR	Transport lorry	50	kg*km	0.00003	0.0015
PA	Plastic bags 1 bag weight 0.0075 kg and costs 5p	0.0032	kg	6.6	0.02112
TR	Consumer's car	0.135	km	0.12	0.0162
CO	Waste to landfill (plastic bags)	0.001856	kg	0.1	0.0001856
CO	Waste to thermal treatment (plastic bags)	0.001344	kg	0.99	0.00133056
S	Energy from thermal treatment	-0.03048192	MJ	0.022	-0.000670602
CO	Refrigerant R134a	0.00000456	kg	12.8	0.000058368
CO	Electricity	0.4315	MJ	0.022	0.009493
CO	Detergent	0.0024	kg	6.65	0.01596
CO	Water	0.281	L	0.0016	0.0004496
CO	Wastewater	0.281	L	0.0013	0.0003653
EOL	Waste to thermal treatment (primary packaging folding box)	0.003776	kg	0.99	0.00373824
EOL	Waste to Landfill (primary packaging folding box)	0.004248	kg	0.1	0.0004248
EOL	Waste to recycling plant (primary packaging folding box)	0.039176	kg	0.06	0.00235056
S	Recycled folding box savings	-0.0093456	kg	0.14	-0.001308384
S	Energy from thermal treatment	-0.01761504	MJ	0.022	-0.000387531

Table S2 continued

Cheesecake	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
EOL	Waste to thermal treatment (primary packaging, plastic)	0.011298	kg	0.99	0.01118502
EOL	Waste to landfill (primary packaging, plastic)	0.015602	kg	0.1	0.0015602
S	Energy from thermal treatment	-0.25623864	MJ	0.022	-0.00563725
EOL	Bio-waste to composting plant	0.024	kg	0.06	0.00144
S	Savings compost	-0.00144	kg	0.125	-0.00018
EOL	Bio-waste to landfill	0.176	kg	0.1	0.0176
Moulded chocolate	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
RM	Sugar	0.44	kg	0.37	0.1628
RM	Palm oil	0.05	kg	0.3698	0.01849
RM	Cocoa butter	0.17	kg	2.114	0.35938
RM	Cocoa liquor	0.1	kg	2.6507	0.26507
RM	Milk powder	0.24	kg	2.185	0.5244
TR	Transport lorry (raw materials to manufacturer)	73	kg*km	0.00003	0.00219
TR	Transport ship (raw materials to manufacturer)	793	kg*km	5.00E-08	0.00003965
MA	Electricity	1.3586	MJ	0.022	0.0298892
MA	Ammonia	0.00021	kg	0.33	0.0000693
MA	Wastewater	0.5	L	0.0013	0.00065
MA	Water	0.5	L	0.0016	0.0008
PA	Aluminium	0.0015	kg	1.22	0.00183
PA	Cardboard secondary packaging	0.0684	kg	0.14	0.009576
TR	Transport lorry (packaging to manufacturer)	68.625	kg*km	0.00003	0.00205875
DC	Water	0.00356	L	0.0016	0.000005696
TR	Transport lorry (manufacturer to distribution centre)	150	kg*km	0.00003	0.0045
DC	Electricity	0.00000105	MJ	0.022	2.31E-08
DC	Wastewater	0.00356	L	0.0013	0.000004628
DC	LDPE tertiary packaging	0.00047	kg	1.57	0.0007379
TR	Transport lorry (packaging to distribution centre)	0.0705	kg*km	0.00003	0.000002115
PA	Plastic bags 1 bag weight 0.0075 kg and costs 5p	0.0024	kg	6.6	0.01584
RE	Water	1.07	L	0.0016	0.001712
RE	Electricity	0.000421	MJ	0.022	0.000009262
RE	Wastewater	1.07	L	0.0013	0.001391
TR	Transport lorry (distribution centre to retailer)	50	kg*km	0.00003	0.0015

Table S2 continued

Moulded chocolate	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
RE	Waste to recycling (secondary packaging)	0.059166	kg	0.06	0.00354996
RE	Waste to energy (secondary packaging)	0.009234	kg	0.1	0.0009234
S	Recycled corrugated board savings	-0.0532494	kg	0.14	-0.007454916
S	Energy from thermal treatment (secondary packaging)	-0.05743548	MJ	0.022	-0.001263581
RE	Waste to energy (tertiary packaging)	0.00047	kg	0.99	0.0004653
S	Energy from thermal treatment (tertiary packaging)	-0.106596	MJ	0.022	-0.002345112
TR	Consumer's car	0.135	km	0.12	0.0162
CO	Waste to landfill (plastic bags)	0.001392	kg	0.1	0.0001392
EOL	Waste to thermal treatment (plastic bags)	0.001008	kg	0.99	0.00099792
S	Energy from thermal treatment (plastic bags)	-0.02286144	MJ	0.022	-0.000502952
EOL	Waste to recycling plant (primary packaging)	0.000873	kg	0.06	0.00005238
EOL	Waste to Landfill (primary packaging)	0.000627	kg	0.1	0.0000627
S	Saving from recycling (primary packaging)	-0.000873	kg	1.22	-0.00106506
Chocolate countlines	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
RM	Sugar	0.2904	kg	0.37	0.107448
RM	Palm oil	0.033	kg	0.3698	0.0122034
RM	Cocoa butter	0.1122	kg	2.114	0.2371908
RM	Cocoa liquor	0.066	kg	2.6507	0.1749462
RM	Milk powder	0.1584	kg	2.185	0.346104
TR	Transport lorry (raw materials to manufacturer)	48.18	kg*km	0.00003	0.0014454
TR	Transport ship (raw materials to manufacturer)	523.38	kg*km	5.00E-08	0.000026169
RM	Flour white	0.1156	kg	0.936	0.1082016
RM	Sugar	0.0833	kg	0.37	0.030821
RM	Eggs pasteurised	0.00238	kg	5.99	0.0142562
RM	Salt	0.00068	kg	0.13	0.0000884
RM	Water	0.13328	L	0.0016	0.000213248
RM	Butter	0.00238	kg	1.9437	0.004626006
RM	Whey powder	0.00238	kg	1.0644	0.002533272
RM	Transport lorry (raw materials to manufacturer)	24.684	kg*km	0.00003	0.00074052
MA	Electricity (manufacturing milk chocolate)	0.176616	MJ	0.022	0.003885552
MA	Electricity (manufacturing wafers)	0.26384	MJ	0.022	0.00580448
MA	Gas [manufacturing wafers]	1.4144	MJ	0.0054	0.00763776

Table S2 continued

Chocolate countlines	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
MA	Electricity (final production line)	1.635	MJ	0.022	0.03597
MA	Ammonia	0.00021		0.33	0.0000693
MA	Wastewater	0.5	L	0.0013	0.00065
MA	Water	0.5	L	0.0016	0.0008
PA	Aluminium	0.0253	kg	1.22	0.030866
PA	Cardboard secondary packaging	0.0566	kg	0.14	0.007924
TR	Transport lorry (packaging to manufacturer)	12.29	kg*km	0.00003	0.0003687
DC	Water	0.00374	L	0.0016	0.000005984
TR	Transport lorry (manufacturer to distribution centre)	150	kg*km	0.00003	0.0045
DC	Electricity	0.00000111	MJ	0.022	2.442E-08
DC	Wastewater	0.00374	L	0.0013	0.000004862
DC	LDPE tertiary packaging	0.00047	kg	1.57	0.0007379
TR	Transport lorry (packaging to distribution centre)	0.0705	kg*km	0.00003	0.000002115
PA	Plastic bags 1 bag weight 0.0075 kg and costs 5p	0.0025	kg	6.6	0.0165
RE	Water	1.12	L	0.0016	0.001792
RE	Wastewater	0.000443	L	0.0013	5.759E-07
TR	Transport lorry (distribution centre to retailer)	50	kg*km	0.00003	0.0015
RE	Waste to recycling (secondary packaging)	0.048959	kg	0.06	0.00293754
RE	Waste to energy [secondary packaging]	0.007641	kg	0.1	0.0007641
S	Recycled corrugated board savings	-0.0440631	kg	0.14	-0.006168834
S	Energy from thermal treatment [secondary packaging]	-0.04752702	MJ	0.022	-0.001045594
RE	Waste to energy (tertiary packaging)	0.00047	kg	0.99	0.0004653
S	Energy from thermal treatment [tertiary packaging]	-0.0106596	MJ	0.022	-0.000234511
TR	Consumers' car [km]	0.135	km	0.12	0.0162
CO	Waste to landfill [plastic bags]	0.00145	kg	0.1	0.000145
CO	Waste to thermal treatment (plastic bags)	0.00105	kg	0.99	0.0010395
S	Energy from thermal treatment [plastic bags]	-0.019278	MJ	0.022	-0.000424116
EOL	Waste to recycling plant (Primary packaging)	0.0147246	kg	0.06	0.000883476
EOL	Waste to Landfill (primary packaging)	0.0105754	kg	0.1	0.00105754
S	Saving from recycling (primary packaging)	-0.0147246	kg	1.22	-0.017964012

Table S2 continued

Chocolates in bag	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
RM	Sugar	0.3212	kg	0.37	0.118844
RM	Palm oil	0.0365	kg	0.3698	0.0134977
RM	Cocoa butter	0.1241	kg	2.114	0.2623474
RM	Cocoa liquor	0.073	kg	2.6507	0.1935011
RM	Milk powder	0.1752	kg	2.185	0.382812
TR	Transport lorry (raw materials to manufacturer)	53.29	kg*km	0.00003	0.0015987
TR	Transport ship (raw materials to manufacturer)	578.89	kg*km	5.00E-08	2.89445E-05
RM	Sugar	0.0481	kg	0.37	0.017797
RM	Milk powder	0.0429	kg	2.185	0.0937365
RM	Cocoa butter	0.039	kg	2.114	0.082446
TR	Transport lorry (raw materials to manufacturer)	8.58	kg*km	0.00003	0.0002574
RM	Flour white	0.02171	kg	0.936	0.02032056
RM	Milk powder	0.04329	kg	2.185	0.09458865
RM	Starch	0.02171	kg	1.12	0.0243152
RM	Sugar	0.04329	kg	0.37	0.0160173
TR	Transport lorry (raw materials to manufacturer)	17.342	kg*km	0.00003	0.00052026
MA	Electricity [manufacturing milk chocolate until tempering]	0.195348	MJ	0.022	0.004297656
MA	Electricity [manufacturing white chocolate]	0.021398	MJ	0.022	0.000470756
MA	Electricity [Manufacturing malted milk powder]	0.00351	MJ	0.022	0.00007722
MA	Electricity [manufacturing maltesers centre]	0.054106	MJ	0.022	0.001190332
MA	Electricity [manufacturing chocolate in bags]	1.372	MJ	0.022	0.030184
MA	Ammonia	0.00021	kg	0.33	0.0000693
MA	Wastewater	0.5	L	0.0013	0.00065
MA	Water	0.5	L	0.0016	0.0008
PA	Aluminium	0.0398	kg	1.22	0.048556
PA	Cardboard secondary packaging	0.137	kg	0.14	0.01918
TR	Transport lorry (packaging to manufacturer)	26.57	kg*km	0.00003	0.0007971
DC	Water	0.0116	L	0.0016	0.00001856
TR	Transport lorry (manufacturer to distribution centre)	150	kg*km	0.00003	0.0045
DC	Electricity	0.00000343	MJ	0.022	7.546E-08
DC	Wastewater	0.0116	L	0.0013	0.00001508
DC	LDPE tertiary packaging	0.00047	kg	1.57	0.0007379

Table S2 continued

Chocolates in bag	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
TR	Transport lorry (packaging to distribution centre)	0.0705	kg*km	0.00003	0.000002115
PA	Plastic bags 1 bag weight 0.0075 kg and costs 5p	0.0035	kg	6.6	0.0231
RE	Water	3.48	L	0.0016	0.005568
RE	Electricity	0.00137	MJ	0.022	0.00003014
RE	Wastewater	3.48	L	0.0013	0.004524
TR	Transport lorry (distribution centre to retailer)	50	kg*km	0.00003	0.0015
RE	Waste to recycling (secondary packaging)	0.118505	kg	0.06	0.0071103
RE	Waste to energy [secondary packaging]	0.018495	kg	0.1	0.0018495
S	Recycled corrugated board savings	-0.1066545	kg	0.14	-0.01493163
S	Energy from thermal treatment (secondary packaging)	-0.1150389	MJ	0.022	-0.002530856
RE	Waste to energy (tertiary packaging)	0.00047	kg	0.99	0.0004653
S	Energy from thermal treatment (tertiary packaging)	-0.0106596	MJ	0.022	-0.000234511
TR	Consumer's car	0.135	km	0.12	0.0162
CO	Waste to landfill (plastic bags)	0.00203	kg	0.1	0.000203
CO	Waste to thermal treatment (plastic bags)	0.00147	kg	0.99	0.0014553
S	Energy from thermal treatment (plastic bags)	-0.0269892	MJ	0.022	-0.000593762
EOL	Waste to recycling plant (primary packaging)	0.0231636	kg	0.06	0.001389816
EOL	Waste to Landfill (primary packaging)	0.0166364	kg	0.1	0.00166364
S	Saving for recycling (primary packaging)	-0.0231636	kg	1.22	-0.028259592
Vanilla regular Ice cream	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
RM	Sugar	0.15	kg	0.37	0.0555
RM	Vanillin	0.000034	kg	11.97	0.00040698
RM	Raw milk	1.56	kg	0.2444	0.381264
TR	Transport lorry (raw materials to manufacturer)	157	kg*km	0.00003	0.00471
MA	Electricity (manufacturing milk pre-processing)	0.26995	MJ	0.022	0.0059389
MA	Steam (milk pre-processing)	0.2551	MJ	0.034	0.0086734
MA	Ammonia	6.45E-08		0.33	2.1285E-08
MA	Water	1.538	L	0.0016	0.0024608
MA	Wastewater	1.3613	L	0.0013	0.00176969
MA	Sodium hydroxide	0.00102	kg	0.416	0.00042432
MA	Nitric acid	0.00049	kg	0.141	0.00006909

Table S2 continued

Vanilla regular ice cream	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
MA	Electricity (manufacturing ice cream)	3.3713	MJ	0.022	0.0741686
MA	Steam (ice cream manufacturing)	0.2365		0.034	0.008041
MA	Ammonia	0.00543	kg	0.33	0.0017919
MA	light fuel	0.034	L	1.2	0.0408
PA	Polypropylene	0.075	kg	1.69	0.12675
PA	Low density polyethylene film	0.00047	kg	1.57	0.0007379
PA	Cardboard secondary packaging	0.033	kg	0.14	0.00462
TR	Transport lorry (packaging to manufacturer)	10.8	kg*km	0.00003	0.000324
RE	Electricity	2	MJ	0.022	0.044
TR	Transport lorry (manufacturer to retailer)	100	kg*km	0.00003	0.003
RE	Waste to recycling (secondary packaging)	0.028545	kg	0.06	0.0017127
RE	Waste to energy (secondary packaging)	0.004455	kg	0.1	0.0004455
S	Recycled corrugated board savings	-0.0256905	kg	0.14	-0.00359667
S	Energy from thermal treatment (secondary packaging)	-0.00277101	MJ	0.0684	-0.000189537
RE	Waste to energy (tertiary packaging)	0.00047	kg	0.99	0.0004653
S	Energy from thermal treatment (tertiary packaging)	-0.0106596	MJ	0.022	-0.000234511
TR	Diesel	0.00082	L	1.2	0.000984
RE	Refrigerant R134a	0.0005176	kg	12.8	0.00662528
PA	Plastic bags 1 bag weight 0.0075 kg and costs 5p	0.025	kg	6.6	0.165
TR	Consumer's car	0.135	km	0.12	0.0162
CO	Refrigerant R134a	0.000000084	kg	12.8	1.0752E-06
CO	Detergent	0.0016	kg	6.65	0.01064
CO	Electricity	0.2242	MJ	0.1519	0.03405598
CO	Water	0.0722	L	0.0016	0.00011552
CO	Wastewater	0.272	L	0.0013	0.0003536
CO	Waste to landfill (plastic bags)	0.0145	kg	0.1	0.00145
CO	Waste to thermal treatment (plastic bags)	0.0105	kg	0.99	0.010395
S	Energy from thermal treatment (plastic bags)	-0.19278	kg	0.022	-0.00424116
EOL	Waste to landfill (primary packaging)	0.0435	kg	0.1	0.00435
EOL	Waste to thermal treatment (primary packaging)	0.0315	kg	0.99	0.031185
S	Energy from thermal treatment (primary packaging)	-0.57834	MJ	0.022	-0.01272348

Table S2 continued

Chocolate regular Ice cream	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
RM	Sugar	0.16	kg	0.37	0.0592
RM	Cocoa powder	0.03	k	2.8471	0.085413
RM	Raw milk	1.5	kg	0.2444	0.3666
TR	Transport lorry (raw materials to manufacturing)	151	kg*km	0.00003	0.00453
MA	Electricity (manufacturing milk pre-processing)	0.22966	MJ	0.022	0.00505252
MA	Steam (milk pre-processing)	0.3281	MJ	0.034	0.0111554
MA	Ammonia	6.07E-08		0.33	2.0031E-08
MA	Water	1.634	L	0.0016	0.0026144
MA	Wastewater	1.28123	L	0.0013	0.001665599
MA	Sodium hydroxide	0.000961	kg	0.416	0.000399776
MA	Nitric acid	0.000461	kg	0.141	0.000065001
MA	Electricity (manufacturing ice cream)	3.1913	MJ	0.022	0.0702086
MA	Steam (ice cream manufacturing)	0.2365	MJ	0.034	0.008041
MA	Ammonia	0.005604		0.33	0.00184932
MA	light fuel	0.034	L	1.2	0.0408
PA	Polypropylene	0.075	kg	1.69	0.12675
PA	Low density polyethylene film	0.00047	kg	1.57	0.0007379
PA	Cardboard secondary packaging	0.033	kg	0.14	0.00462
TR	Transport lorry (packaging to manufacturer)	10.8	kg*km	0.00003	0.000324
RE	Electricity	2	MJ	0.022	0.044
TR	Transport lorry (manufacturer to retailer)	100	kg*km	0.00003	0.003
RE	Waste to recycling (secondary packaging)	0.028545	kg	0.06	0.0017127
RE	Waste to energy (secondary packaging)	0.004455	kg	0.1	0.0004455
S	Recycled corrugated board savings	-0.0256905	kg	0.14	-0.00359667
S	Energy from thermal treatment (secondary packaging)	-0.0277101	MJ	0.0684	-0.001895371
RE	Waste to energy (tertiary packaging)	0.00047	kg	0.99	0.0004653
S	Energy from thermal treatment (tertiary packaging)	-0.0106596	kg	0.022	-0.000234511
TR	Diesel	0.00082	L	1.2	0.000984
RE	Refrigerant R134a	0.0005176	kg	12.8	0.00662528
PA	Plastic bags 1 bag weight 0.0075 kg and costs 5p	0.025	kg	6.6	0.165
TR	Consumer's car	0.135	km	0.12	0.0162
CO	Refrigerant R134a	0.000000084	km	12.8	1.0752E-06
CO	Detergent	0.0016	kg	6.65	0.01064
CO	Electricity	0.2242	MJ	0.1519	0.03405598
CO	Water	0.0722	L	0.0016	0.00011552

Table S2 continued

Chocolate regular ice cream	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
CO	Wastewater	0.272	L	0.0013	0.0003536
CO	Waste to landfill (plastic bags)	0.0145	kg	0.1	0.00145
CO	Waste to thermal treatment (plastic bags)	0.0105	kg	0.99	0.010395
S	Energy from thermal treatment (plastic bags)	-0.19278	MJ	0.022	-0.00424116
EOL	Waste to landfill (primary packaging)	0.0435	kg	0.1	0.00435
EOL	Waste to thermal treatment (primary packaging)	0.0315	kg	0.99	0.031185
S	Energy from thermal treatment (primary packaging)	-0.57834	kg	0.022	-0.01272348
Vanilla premium ice cream	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
RM	Sugar	0.17	kg	0.37	0.0629
RM	Vanilla extract	0.000034	kg	155	0.00527
RM	Egg yolk	0.014	kg	10.95	0.1533
RM	Raw milk	1.63	kg	0.2444	0.398372
TR	Transport lorry (raw materials to manufacturer)	168.4034	kg*km	0.00003	0.005052102
MA	Electricity (manufacturing milk pre-processing)	0.25382	MJ	0.022	0.00558404
MA	Steam (milk pre-processing)	0.1631	MJ	0.034	0.0055454
MA	Ammonia	6.87E-08		0.33	2.2671E-08
MA	Water	1.844	L	0.0016	0.0029504
MA	Wastewater	1.45139	L	0.0013	0.001886807
MA	Sodium hydroxide	0.00109	kg	0.416	0.00045344
MA	Nitric acid	0.000521	kg	0.141	0.000073461
MA	Electricity (manufacturing ice cream)	3.3713	MJ	0.022	0.0741686
MA	Steam (ice cream manufacturing)	0.2365	MJ	0.034	0.008041
MA	Ammonia	0.005577		0.33	0.00184041
MA	light fuel	0.034	L	1.2	0.0408
PA	Polypropylene	0.075	kg	1.69	0.12675
PA	Low density polyethylene film	0.00047	kg	1.57	0.0007379
PA	Cardboard secondary packaging	0.033	kg	0.14	0.00462
TR	Transport lorry (packaging to manufacturer)	78.3	kg*km	0.00003	0.002349
RE	Electricity	2	MJ	0.022	0.044

Table S2 continued

Vanilla premium ice cream	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
TR	Transport lorry (manufacturer to retailer)	100	kg*km	0.00003	0.003
RE	Waste to recycling (secondary packaging)	0.028545	kg	0.06	0.0017127
RE	Waste to energy (secondary packaging)	0.004455	kg	0.1	0.0004455
S	Recycled corrugated board savings	-0.0256905	kg	0.14	-0.00359667
S	Energy from thermal treatment (secondary packaging)	-0.0277101	MJ	0.0684	-0.001895371
RE	Waste to energy (tertiary packaging)	0.00047	kg	0.99	0.0004653
S	Energy from thermal treatment (tertiary packaging)	-0.0106596	kg	0.022	-0.000234511
TR	Diesel	0.00082	L	1.2	0.000984
RE	Refrigerant R134a	0.0005176	kg	12.8	0.00662528
PA	Plastic bags 1 bag weight 0.0075 kg and costs 5p	0.025	kg	6.6	0.165
TR	Consumer's car	0.135	km	0.12	0.0162
CO	Refrigerant R134a	8.40E-08	kg	12.8	1.0752E-06
CO	Detergent	0.0016	kg	6.65	0.01064
CO	Electricity	0.2242	MJ	0.1519	0.03405598
CO	Water	0.0722	L	0.0016	0.00011552
CO	Wastewater	0.272	L	0.0013	0.0003536
CO	Waste to landfill (plastic bags)	0.0145	kg	0.1	0.00145
CO	Waste to thermal treatment (plastic bags)	0.0105	kg	0.99	0.010395
S	Energy from thermal treatment (plastic bags)	-0.19278	MJ	0.022	-0.00424116
EOL	Waste to landfill (primary packaging)	0.0435	kg	0.1	0.00435
EOL	Waste to thermal treatment (primary packaging)	0.0315	kg	0.99	0.031185
S	Energy from thermal treatment (primary packaging)	-0.57834	MJ	0.022	-0.01272348
Chocolate premium ice cream	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
RM	Sugar	0.19	kg	0.37	0.0703
RM	Cocoa powder	0.035	kg	2.8471	0.0996485
RM	Egg yolk	0.014	kg	10.95	0.1533
RM	Raw milk	1.59	kg	0.2444	0.388596
TR	Transport lorry (raw materials to manufacturer)	166.9	kg*km	0.00003	0.005007
MA	Electricity [manufacturing milk pre-processing]	0.24569	MJ	0.022	0.00540518

Table S2 continued

Chocolate premium ice cream	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
MA	Steam [milk pre-processing]	0.1616	MJ	0.034	0.0054944
MA	Ammonia	6.67E-08		0.33	2.2011E-08
MA	Water	1.792	L	0.0016	0.0028672
MA	Wastewater	1.40135	L	0.0013	0.001821755
MA	Sodium hydroxide	0.00105	kg	0.416	0.0004368
MA	Nitric acid	0.000506	kg	0.141	0.000071346
MA	Electricity [manufacturing ice cream]	3.3713	MJ	0.022	0.0741686
MA	Steam [ice cream manufacturing]	0.2365	MJ	0.034	0.008041
MA	Ammonia	0.005577		0.33	0.00184041
MA	light fuel	0.034	L	1.2	0.0408
PA	Polypropylene	0.075	kg	1.69	0.12675
PA	Low density polyethylene film	0.00047	kg	1.57	0.0007379
PA	Cardboard secondary packaging	0.033	kg	0.14	0.00462
TR	Transport lorry (packaging to manufacturer)	78.3	kg*km	0.00003	0.002349
RE	Electricity	2	MJ	0.022	0.044
TR	Transport lorry (manufacturer to retailer)	100	kg*km	0.00003	0.003
RE	Waste to recycling (secondary packaging)	0.028545	kg	0.06	0.0017127
RE	Waste to energy (secondary packaging)	0.004455	kg	0.1	0.0004455
S	Recycled corrugated board savings	-0.0256905	kg	0.14	-0.00359667
S	Energy from thermal treatment (secondary packaging)	-0.0277101	MJ	0.0684	-0.001895371
RE	Waste to energy (tertiary packaging)	0.00047	kg	0.99	0.0004653
S	Energy from thermal treatment (tertiary packaging)	-0.0106596	MJ	0.022	-0.000234511
TR	Diesel	0.00082	L	1.2	0.000984
RE	Refrigerant R134a	0.0005176	kg	12.8	0.00662528
PA	Plastic bags 1 bag weight 0.0075 kg and costs 5p	0.025	kg	6.6	0.165
TR	Consumer's car	0.135	km	0.12	0.0162
CO	Refrigerant R134a	8.40E-08	kg	12.8	1.0752E-06
CO	Detergent	0.0016	kg	6.65	0.01064
CO	Electricity	0.2242	MJ	0.1519	0.03405598
CO	Water	0.0722	L	0.0016	0.00011552
CO	Wastewater	0.272	L	0.0013	0.0003536
CO	Waste to landfill (plastic bags)	0.0145	kg	0.1	0.00145

Table S2 continued

Chocolate premium Ice cream	Activities	Value per functional unit (1 kg of product)	Unit	Unit price (£)	Total cost (£)
CO	Waste to thermal treatment (plastic bags)	0.0105	kg	0.99	0.010395
S	Energy from thermal treatment (plastic bags)	-0.19278	MJ	0.022	-0.00424116
EOL	Waste to landfill (primary packaging)	0.0435	kg	0.1	0.00435
EOL	Waste to thermal treatment (primary packaging)	0.0315	kg	0.99	0.031185
S	Energy from thermal treatment (primary packaging)	-0.57834	MJ	0.022	-0.01272348

Table S3 Contribution of different life cycle stages to the total life cycle costs (contribution <1% excluded)

Products	Raw materials	Manufacturing	Packaging	Distribution centre	Retail	Consumption	End-of-life waste management	Transport	Credits
Biscuits									
Crackers	78.8%	5.7%	11.2%					3.1%	
Low fat/sugar	84.1%	6.4%	5.6%					3.4%	
Semi-Sweet	83.1%	6.6%	5.7%					3.5%	
Chocolate coated	85.1%	7.3%	3.8%					3.3%	
Chocolate cream	85.9%	5.8%	3.9%					3.6%	
Vanilla cream	84.8%	6.3%	4.3%					3.6%	
Cakes									
Whole cakes	93.5%	1.2%	2.2%						
Slices	86.0%	2.0%	8.0%				3.0%		
Pies	84.3%	4.0%	7.0%		1.2%		2.2%	2.0%	-1.5%
Cupcakes	80.1%	1.7%	12.8%		2.2%		3.9%	1.5%	-3.2%
Cheesecake	86.5%	3.5%	4.6%			1.6%	2.2%	1.6%	
Chocolates									
Milk chocolate	94.1%	2.2%	1.9%					1.8%	
Chocolate	89.9%	4.7%	4.8%					2.0%	-2.3%
Chocolates in bag	90.6%	2.6%	6.2%		1.3%			1.7%	-2.9%
Ice cream									
Vanilla regular	43.0%	14.0%	29.0%		5.0%	6.0%	3.0%	2.0%	-2.0%
Chocolate regular	47.0%	13.0%	27.0%		5.0%	5.0%	3.0%	2.0%	-2.0%
Vanilla premium	51.0%	12.0%	25.0%		4.0%	5.0%	3.0%	2.0%	-2.0%
Chocolate premium	55.0%	11.0%	23.0%		4.0%	4.0%	3.0%	2.0%	-2.0%

Table S4 Costs, sales prices and value added (£/kg)

Product category	Product	Cost to manufacturer (£/kg)	Cost to retailer (£/kg)	Costs to consumer (£/kg)	Total life cycle costs (£/kg)	Sales price (£/kg)	Value added (£/kg)
Biscuits	Crackers	0.844	0.857	0.904	0.908	1.3	0.443
	Low fat biscuits	0.760	0.774	0.812	0.808	1.5	0.726
	Semi-sweet	0.735	0.749	0.787	0.787	1.1	0.351
	Chocolate coated	0.838	0.851	0.881	0.879	2	1.149
	Chocolate cream	0.739	0.752	0.784	0.783	6.5	5.748
	Vanilla cream	0.674	0.685	0.717	0.717	6.4	5.715
Cakes	Whole cakes	2.534	2.556	2.601	2.640	6.8	4.244
	Slices	1.998	2.019	2.070	2.128	8	5.981
	Pies	1.423	1.448	1.494	1.517	2	0.552
	Cupcakes	1.674	1.720	1.797	1.828	13	11.280
	Cheese cake	1.645	1.666	1.703	1.756	4.3	2.634
Chocolate	Moulded chocolate	1.377	1.391	1.423	1.414	7.5	6.109
	Chocolate countlines	1.135	1.146	1.179	1.156	6	4.854
	Chocolate in bags	1.429	1.455	1.495	1.458	8.3	6.845
Ice cream	Vanilla regular	0.721	0.778	0.959	1.029	2	1.222
	Chocolate regular	0.785	0.842	1.023	1.099	2	1.158
	Vanilla premium	0.910	0.967	1.149	1.210	5	4.033
	Chocolate premium	0.999	1.056	1.238	1.301	5	3.944

Table S5 Data for uncertainty analysis

Crackers	Value (-)	Percentile	Value (-)	Low fat/sugar biscuits	Value (-)	Percentile	Value (-)
Minimum	0.74	5%	0.81	Minimum	0.65	5%	0.71
Maximum	1.06	10%	0.83	Maximum	0.96	10%	0.73
Mean	0.91	15%	0.84	Mean	0.81	15%	0.74
Std Dev	0.06	20%	0.85	Std Dev	0.06	20%	0.75
Variance	0.00	25%	0.86	Variance	0.00	25%	0.76
Skewness	-0.01	30%	0.87	Skewness	-0.01	30%	0.77
Kurtosis	2.36	35%	0.88	Kurtosis	2.34	35%	0.78
Median	0.91	40%	0.89	Median	0.81	40%	0.79
Mode	0.91	45%	0.90	Mode	0.82	45%	0.80
Left X	0.81	50%	0.91	Left X	0.71	50%	0.81
Left P	0.03	55%	0.92	Left P	0.03	55%	0.82
Right X	1.00	60%	0.92	Right X	0.90	60%	0.82
Right P	0.98	65%	0.93	Right P	0.98	65%	0.83
Diff X	0.19	70%	0.94	Diff X	0.19	70%	0.84
Diff P	0.95	75%	0.95	Diff P	0.95	75%	0.85
#Errors	0.00	80%	0.96	#Errors	0.00	80%	0.86
Filter Min	Off	85%	0.97	Filter Min	Off	85%	0.87
Filter Max	Off	90%	0.99	Filter Max	Off	90%	0.89
#Filtered	0.00	95%	1.00	#Filtered	0.00	95%	0.90

Semi sweet biscuits	Value (-)	Percentile	Value (-)	Chocolate coated Biscuits	Value (-)	Percentile	Value (-)
Minimum	0.64	5%	0.69	Minimum	0.76	5%	0.82
Maximum	0.92	10%	0.71	Maximum	1.00	10%	0.83
Mean	0.78	15%	0.72	Mean	0.88	15%	0.84
Std Dev	0.05	20%	0.73	Std Dev	0.04	20%	0.85
Variance	0.00	25%	0.74	Variance	0.00	25%	0.85
Skewness	-0.01	30%	0.75	Skewness	0.00	30%	0.86
Kurtosis	2.34	35%	0.76	Kurtosis	2.62	35%	0.86
Median	0.78	40%	0.77	Median	0.88	40%	0.87
Mode	0.79	45%	0.78	Mode	0.87	45%	0.87
Left X	0.69	50%	0.78	Left X	0.82	50%	0.88
Left P	0.03	55%	0.79	Left P	0.03	55%	0.88

Table S5 continued

Semi sweet biscuits	Value (-)	Percentile	Value (-)	Chocolate coated Biscuits	Value (-)	Percentile	Value (-)
Right X	0.87	60%	0.80	Right X	0.94	60%	0.89
Right P	0.98	65%	0.80	Right P	0.98	65%	0.89
Diff X	0.17	70%	0.81	Diff X	0.11	70%	0.90
Diff P	0.95	75%	0.82	Diff P	0.95	75%	0.90
#Errors	0.00	80%	0.83	#Errors	0.00	80%	0.91
Filter Min	Off	85%	0.84	Filter Min	Off	85%	0.92
Filter Max	Off	90%	0.85	Filter Max	Off	90%	0.93
#Filtered	0.00	95%	0.87	#Filtered	0.00	95%	0.94

Chocolate cream biscuits	Value (-)	Percentile	Value (-)	Vanilla cream biscuits	Value (-)	Percentile	Value (-)
Minimum	0.68	5%	0.72	Minimum	0.61	5%	0.66
Maximum	0.90	10%	0.74	Maximum	0.82	10%	0.67
Mean	0.78	15%	0.74	Mean	0.72	15%	0.68
Std Dev	0.04	20%	0.75	Std Dev	0.04	20%	0.68
Variance	0.00	25%	0.76	Variance	0.00	25%	0.69
Skewness	-0.01	30%	0.76	Skewness	-0.01	30%	0.70
Kurtosis	2.50	35%	0.77	Kurtosis	2.45	35%	0.70
Median	0.78	40%	0.77	Median	0.72	40%	0.71
Mode	0.78	45%	0.78	Mode	0.72	45%	0.71
Left X	0.72	50%	0.78	Left X	0.66	50%	0.72
Left P	0.03	55%	0.79	Left P	0.03	55%	0.72
Right X	0.84	60%	0.79	Right X	0.78	60%	0.73
Right P	0.98	65%	0.80	Right P	0.98	65%	0.73
Diff X	0.12	70%	0.80	Diff X	0.12	70%	0.74
Diff P	0.95	75%	0.81	Diff P	0.95	75%	0.74
#Errors	0.00	80%	0.82	#Errors	0.00	80%	0.75
Filter Min	Off	85%	0.82	Filter Min	Off	85%	0.76
Filter Max	Off	90%	0.83	Filter Max	Off	90%	0.77
#Filtered	0.00	95%	0.84	#Filtered	0.00	95%	0.78

Table S5: continued

Whole cakes	Value (-)	Percentile	Value (-)	Cake slices	Value (-)	Percentile	Value (-)
Minimum	2.21	5%	2.40	Minimum	1.81	5%	1.95
Maximum	3.09	10%	2.45	Maximum	2.44	10%	1.98
Mean	2.64	15%	2.48	Mean	2.13	15%	2.01
Std Dev	0.14	20%	2.51	Std Dev	0.11	20%	2.03
Variance	0.02	25%	2.53	Variance	0.01	25%	2.05
Skewness	0.00	30%	2.56	Skewness	-0.01	30%	2.06
Kurtosis	2.44	35%	2.58	Kurtosis	2.40	35%	2.08
Median	2.64	40%	2.60	Median	2.13	40%	2.10
Mode	2.63	45%	2.62	Mode	2.13	45%	2.11
Left X	2.40	50%	2.64	Left X	1.95	50%	2.13
Left P	0.03	55%	2.66	Left P	0.03	55%	2.14
Right X	2.88	60%	2.68	Right X	2.30	60%	2.16
Right P	0.98	65%	2.70	Right P	0.98	65%	2.17
Diff X	0.47	70%	2.72	Diff X	0.36	70%	2.19
Diff P	0.95	75%	2.75	Diff P	0.95	75%	2.21
#Errors	0.00	80%	2.77	#Errors	0	80%	2.23
Filter Min	Off	85%	2.80	Filter Min	Off	85%	2.25
Filter Max	Off	90%	2.83	Filter Max	Off	90%	2.27
#Filtered	0.00	95%	2.88	#Filtered	0.00	95%	2.30

Pies	Value (-)	Percentile	Value (-)	Cupcakes	Value (-)	Percentile	Value (-)
Minimum	1.26	5%	1.38	Minimum	1.57	5%	1.70
Maximum	1.78	10%	1.41	Maximum	2.07	10%	1.73
Mean	1.52	15%	1.43	Mean	1.83	15%	1.74
Std Dev	0.08	20%	1.44	Std Dev	0.08	20%	1.76
Variance	0.01	25%	1.46	Variance	0.01	25%	1.77
Skewness	0.00	30%	1.47	Skewness	-0.01	30%	1.78
Kurtosis	2.53	35%	1.48	Kurtosis	2.50	35%	1.80
Median	1.52	40%	1.49	Median	1.83	40%	1.81
Mode	1.51	45%	1.51	Mode	1.85	45%	1.82
Left X	1.38	50%	1.52	Left X	1.70	50%	1.83
Left P	0.03	55%	1.53	Left P	0.03	55%	1.84
Right X	1.66	60%	1.54	Right X	1.95	60%	1.85

Table S5: continued

Pies	Value (-)	Percentile	Value (-)	Cupcakes	Value (-)	Percentile	Value (-)
Right P	0.98	65%	1.55	Right P	0.98	65%	1.86
Diff X	0.28	70%	1.56	Diff X	0.25	70%	1.87
Diff P	0.95	75%	1.58	Diff P	0.95	75%	1.88
#Errors	0.00	80%	1.59	#Errors	0.00	80%	1.90
Filter Min	Off	85%	1.61	Filter Min	Off	85%	1.91
Filter Max	Off	90%	1.63	Filter Max	Off	90%	1.93
#Filtered	0.00	95%	1.66	#Filtered	0.00	95%	1.95

Cheesecake	Value (-)	Percentile	Value (-)	Moulded chocolates	Value (-)	Percentile	Value (-)
Minimum	1.52	5%	1.64	Minimum	1.17	5%	1.30
Maximum	2.03	10%	1.66	Maximum	1.66	10%	1.33
Mean	1.76	15%	1.68	Mean	1.41	15%	1.34
Std Dev	0.07	20%	1.70	Std Dev	0.07	20%	1.36
Variance	0.01	25%	1.71	Variance	0.00	25%	1.37
Skewness	-0.01	30%	1.72	Skewness	-0.03	30%	1.38
Kurtosis	2.79	35%	1.73	Kurtosis	2.77	35%	1.39
Median	1.76	40%	1.74	Median	1.41	40%	1.40
Mode	1.77	45%	1.75	Mode	1.41	45%	1.41
Left X	1.64	50%	1.76	Left X	1.30	50%	1.41
Left P	0.03	55%	1.77	Left P	0.03	55%	1.42
Right X	1.87	60%	1.78	Right X	1.52	60%	1.43
Right P	0.98	65%	1.78	Right P	0.98	65%	1.44
Diff X	0.24	70%	1.79	Diff X	0.22	70%	1.45
Diff P	0.95	75%	1.81	Diff P	0.95	75%	1.46
#Errors	0.00	80%	1.82	#Errors	0.00	80%	1.47
Filter Min	Off	85%	1.83	Filter Min	Off	85%	1.48
Filter Max	Off	90%	1.85	Filter Max	Off	90%	1.50
#Filtered	0.00	95%	1.87	#Filtered	0.00	95%	1.52

Table S5: continued

Chocolate countlines	Value (-)	Percentile	Value (-)	Chocolates in bag	Value (-)	Percentile	Value (-)
Minimum	0.98	5%	1.08	Minimum	1.26	5%	1.37
Maximum	1.31	10%	1.10	Maximum	1.63	10%	1.39
Mean	1.16	15%	1.11	Mean	1.46	15%	1.40
Std Dev	0.05	20%	1.12	Std Dev	0.05	20%	1.41
Variance	0.00	25%	1.12	Variance	0.00	25%	1.42
Skewness	0.01	30%	1.13	Skewness	-0.03	30%	1.43
Kurtosis	2.75	35%	1.14	Kurtosis	2.79	35%	1.44
Median	1.16	40%	1.14	Median	1.46	40%	1.44
Mode	1.17	45%	1.15	Mode	1.46	45%	1.45
Left X	1.08	50%	1.16	Left X	1.37	50%	1.46
Left P	0.03	55%	1.16	Left P	0.03	55%	1.46
Right X	1.23	60%	1.17	Right X	1.54	60%	1.47
Right P	0.98	65%	1.17	Right P	0.98	65%	1.48
Diff X	0.15	70%	1.18	Diff X	0.17	70%	1.49
Diff P	0.95	75%	1.19	Diff P	0.95	75%	1.49
#Errors	0.00	80%	1.20	#Errors	0.00	80%	1.50
Filter Min	Off	85%	1.20	Filter Min	Off	85%	1.51
Filter Max	Off	90%	1.22	Filter Max	Off	90%	1.52
#Filtered	0.00	95%	1.23	#Filtered	0.00	95%	1.54

Vanilla regular ice cream	Value (-)	Percentile	Value (-)	Chocolate regular ice cream	Value (-)	Percentile	Value (-)
Minimum	0.88	5%	0.96	Minimum	0.95	5%	1.03
Maximum	1.18	10%	0.98	Maximum	1.24	10%	1.04
Mean	1.03	15%	0.99	Mean	1.10	15%	1.05
Std Dev	0.04	20%	0.99	Std Dev	0.04	20%	1.06
Variance	0.00	25%	1.00	Variance	0.00	25%	1.06
Skewness	-0.02	30%	1.01	Skewness	0.02	30%	1.07
Kurtosis	2.62	35%	1.01	Kurtosis	2.65	35%	1.08
Median	1.03	40%	1.02	Median	1.09	40%	1.08
Mode	1.04	45%	1.03	Mode	1.10	45%	1.09
Left X	0.96	50%	1.03	Left X	1.03	50%	1.09
Left P	0.03	55%	1.04	Left P	0.03	55%	1.10

Table S5: continued

Vanilla regular ice cream	Value (-)	Percentile	Value (-)	Chocolate regular ice cream	Value (-)	Percentile	Value (-)
Right X	1.10	60%	1.04	Right X	1.16	60%	1.11
Right P	0.98	65%	1.05	Right P	0.98	65%	1.11
Diff X	0.14	70%	1.06	Diff X	0.14	70%	1.12
Diff P	0.95	75%	1.06	Diff P	0.95	75%	1.12
#Errors	0.00	80%	1.07	#Errors	0.00	80%	1.13
Filter Min	Off	85%	1.08	Filter Min	Off	85%	1.14
Filter Max	Off	90%	1.09	Filter Max	Off	90%	1.15
#Filtered	0.00	95%	1.10	#Filtered	0.00	95%	1.20

Vanilla premium ice cream	Value (-)	Percentile	Value (-)	Chocolate premium ice cream	Value (-)	Percentile	Value (-)
Minimum	1.05	5%	1.14	Minimum	1.15	5%	1.23
Maximum	1.39	10%	1.16	Maximum	1.49	10%	1.25
Mean	1.21	15%	1.17	Mean	1.30	15%	1.26
Std Dev	0.05	20%	1.18	Std Dev	0.05	20%	1.27
Variance	0.00	25%	1.19	Variance	0.00	25%	1.28
Skewness	-0.01	30%	1.19	Skewness	0.00	30%	1.28
Kurtosis	2.70	35%	1.20	Kurtosis	2.74	35%	1.29
Median	1.22	40%	1.21	Median	1.31	40%	1.30
Mode	1.21	45%	1.21	Mode	1.30	45%	1.30
Left X	1.14	50%	1.22	Left X	1.23	50%	1.31
Left P	0.03	55%	1.23	Left P	0.03	55%	1.32
Right X	1.30	60%	1.23	Right X	1.39	60%	1.32
Right P	0.98	65%	1.24	Right P	0.98	65%	1.33
Diff X	0.15	70%	1.25	Diff X	0.16	70%	1.33
Diff P	0.90	75%	1.25	Diff P	0.95	75%	1.34
#Errors	0.00	80%	1.26	#Errors	0.00	80%	1.35
Filter Min	Off	85%	1.27	Filter Min	Off	85%	1.36
Filter Max	Off	90%	1.28	Filter Max	Off	90%	1.37
#Filtered	0.00	95%	1.30	#Filtered	0.00	95%	1.39

Table S6 Annual life cycle costs and value added at the sectoral level

Products	Sales value (£m)	Retail price (£)	Yearly sales volumes (t)	Product shares to sub-sectors	Life cycle costs (£/kg)	Savings (£/kg)	Costs to retailer (£/kg)	Value added (£/kg)
Crackers	362	1.3	278,462	16.2%	0.908	0.006	0.857	0.443
Low fat biscuits	612	1.5	408,000	23.8%	0.808	0.010	0.774	0.726
Semi-sweet biscuits	281.5	1.1	255,909	14.9%	0.787	0.006	0.749	0.351
Chocolate-coated biscuits	208.5	2	104,250	6.1%	0.879	0.007	0.851	1.149
Chocolate cream biscuits	208.5	6.5	32,077	1.9%	0.783	0.005	0.752	5.748
Vanilla cream biscuits	281.5	6.4	43,984	2.6%	0.717	0.004	0.685	5.715
Other biscuits confectionary	654	1.1	594,545	34.6%	0.908	0.004	0.857	0.243
Whole cakes	287	6.8	42,206	11.7%	2.640	0.009	2.556	4.244
Slices/bars	362.3	8	45,288	12.6%	2.128	0.020	2.019	5.981
Pies	362.3	2	181,150	50.4%	1.517	0.022	1.448	0.552
Cupcakes	362.3	13	27,869	7.7%	1.828	0.058	1.720	11.280
Cheesecake	272	4.3	63,256	17.6%	1.756	0.013	1.666	2.634
Moulded chocolate	845	7.5	112,667	17.7%	1.414	0.010	1.391	6.109
Chocolate countlines	1817	6	302,833	47.6%	1.156	0.026	1.146	4.854
Chocolate in bags	1304	8.3	157,108	24.7%	1.458	0.042	1.455	6.845
Other chocolate confectionary	378	6	63,000	9.9%	1.458	0.01	1.455	4.545
Vanilla regular ice cream	55	2	27,500	6.8%	1.029	0.020	0.778	1.222
Chocolate regular ice cream	55	2	27,500	6.8%	1.099	0.022	0.842	1.158
Vanilla premium ice cream	221.5	5	44,300	11.0%	1.210	0.022	0.967	4.033
Chocolate premium ice cream	221.5	5	44,300	11.0%	1.301	0.022	1.056	3.944
Other ice cream products	580	2.225	260,674	64.5%	1.301	0.02	1.056	1.169

Table S6 Continued.

Products	Annual life cycle costs (£m)	Annual life cycle savings (£m)	Annual value added (£m)
Crackers	253	1.75	123
Low fat biscuits	330	4.05	296
Semi-sweet biscuits	201	1.56	90
Chocolate-coated biscuits	92	0.76	120
Chocolate cream biscuits	25	0.16	184
Vanilla cream biscuits	31	0.18	251
Other biscuits confectionary	540	2.38	144
Whole cakes	111	0.40	179
Cakes slices	96	0.92	271
Pies	275	4.04	100
Cupcakes	51	1.62	314
Cheesecake	111	0.84	167
Moulded chocolate	159	1.15	688
Chocolate countlines	350	7.88	1470
Chocolate in bags	229	6.54	1075
Other chocolate confectionary	92	0.63	286
Vanilla regular ice cream	28	0.54	34
Chocolate regular ice cream	30	0.59	32
Vanilla premium ice cream	54	0.95	179
Chocolate premium ice cream	58	0.95	175
Other ice cream products	339	5.21	305