Environmental sustainability issues in the food–energy–water nexus: Breakfast cereals and snacks

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\textbf{A B S T R A C T}

Understanding environmental impacts of complete food supply chains is important for the food industry to help devise strategies for reducing the impacts of current and future products. Breakfast cereals are one of the most important foods consumed in many countries, but their environmental impacts are currently unknown. Therefore, this study explores the environmental sustainability issues in the food–energy–water nexus by considering breakfast cereals manufactured by one of the world’s largest producers, Kellogg Europe. A life cycle assessment has been carried out for these purposes with the aim of helping the Company to integrate environmental sustainability considerations into the design of their products and packaging. The results indicate that the average global warming potential (GWP) of Kellogg’s breakfast cereals is 2.64 kg CO\textsubscript{2} eq. per kg of product. The main GWP hotspots are the ingredients (48%) and energy used in the manufacturing process (23%); packaging and transport contribute 15% each. Rice is the single largest contributor to the GWP of the ingredients (38%). The manufacturing stage is the main contributor of primary energy demand (34%), while the ingredients are responsible for more than 90% of the water footprint. The ingredients are also the main contributors to most other environmental impacts, including land use (97%), depletion of elements (61%), eutrophication (71%), human toxicity (54%) and photochemical smog (50%). The impacts from packaging are high for freshwater and marine toxicity. The contribution of transport is significant for depletion of elements and fossil resources (23%), acidification (32%), ozone depletion (28%) and photochemical smog (24%). Improvement opportunities explored in the paper include better agricultural practices, recipe modifications, improved energy efficiency of manufacturing processes and use of alternative packaging. Impacts from consumption are also discussed.

Keywords: Breakfast cereals; Global warming potential; Water footprint; Energy consumption; Life cycle assessment; Food–energy–water nexus

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1. \textbf{Introduction}

The provision, preparation and consumption of food is not only essential for sustenance of life but for most societies it represents an important part of their identity and culture. However, food systems depend heavily on land, water and energy resources and contribute significantly to greenhouse gas (GHG) emissions, eutrophication and other environment-
tal impacts (Tukker et al., 2006). For instance, direct and indirect GHG emissions from food production contribute 19%–29% of the global anthropogenic emissions, of which agriculture contributes more than 80% (Vermeulen et al., 2012). Agriculture also accounts for 70% of all freshwater withdrawals from rivers and aquifers globally (FAO, 2011a) and occupies more than 50% of the world’s vegetated land (Foley et al., 2005). Energy inputs to food production are also significant and have been increasing with technological development and increased mechanisation: it is estimated that the food sector accounts for around 30% of the global energy consumption (FAO, 2011b).

Therefore, food, water and energy systems are inextricably interconnected. The relationships and trade-offs within this triangle are known collectively as the food–energy–water nexus. The term “nexus” implies that action in one of the three systems has impacts on the other two as well as on the ecosystem (REEEP and FAO, 2014). A number of frameworks and approaches have been developed to define and understand the complex relationships between the nexus elements (e.g. Hoff, 2011 and WEF, 2011). The conceptual framework proposed by the Bonn 2011 Nexus conference is centred on security of water supply, energy and food and accounts for global trends including urbanisation, population growth and climate change (Hoff, 2011). The WEF (2011) approach links economic disparity and global governance failures to food, water and energy crisis. It also identifies specific relationships among the elements of nexus, such as intensity of energy use in food production as well as water use for provision of both food and energy. In addition to these approaches, application of life cycle thinking and life cycle assessment (LCA) is particularly important as it enables consideration of whole supply chains which are increasingly globalised, with the production and consumption of a product often occurring in different parts of the world and affecting the nexus in differing ways, depending on the region.

This paper applies life cycle thinking and LCA to explore the issues in the food–energy–water nexus through an analysis of carbon, water and energy footprints of breakfast cereals, along with other relevant environmental impacts. Breakfast cereals are an integral part of diet in many countries and are regarded by some as a healthier alternative to some traditional breakfasts, including meat-based products (CEEREAL, 2008). In Europe, 2 kg of breakfast cereals are consumed annually per capita, but this varies across different countries, from 0.9 kg in Italy to 8 kg in Ireland (CEEREAL, 2011). In total, the European breakfast cereal industry produces 1.1 million tonnes of breakfast cereals per year (CEEREAL, 2011). However, despite the importance of breakfast cereal products for the diet in many countries and the size of the market, there are still no published studies on their environmental impacts along the whole supply chains and how they may impact the food–energy–water nexus. In an attempt to bridge this knowledge gap, this paper considers for the first time the life cycle impacts of breakfast cereals aiming to identify the environmental hotspots in the nexus related to these products. The study considers ready-to-eat cereals (RTEC) and snacks produced by Kellogg Europe, one of the leading producers of cereals in Europe with a market share of over 35% (CEEREAL, 2011; Kellogg, 2013).

The methodology applied in the study is detailed in the next section. This is followed in Section 3 by the discussion of the results and improvement opportunities, with the conclusions drawn in Section 4.

2. Methodology

Life cycle assessment (LCA) has been used as a tool to estimate the environmental impacts of breakfast cereals, following the ISO 14040/14044 methodology (ISO, 2006a,b). The following sections define the goal and scope of the study together with the data and assumptions.

2.1. Goal and the scope of the study

The main objectives of the study are to estimate the environmental impacts and identify improvement opportunities along the Kellogg Europe’s supply chain. The results of this attributional study will be used to help the Company integrate environmental considerations into the design of their products and packaging.

The functional unit of the study is defined as the ‘production of 1 kg of breakfast cereal products’. The products considered are ready-to-eat breakfast cereals and snacks manufactured by Kellogg Europe.

Two system boundaries are considered:

- System boundary 1: from ‘cradle to grave’, encompassing agriculture, manufacturing, packaging, transport and waste management, but excluding consumption of the products; and
- System boundary 2: as above, but including consumption of cereals with milk.

The first system boundary is aimed at the producer and the second at the consumer of cereals. As outlined in Fig. 1, the following life cycle stages are considered:

- raw materials (ingredients): agricultural production of cereal grains and other ingredients;
- manufacturing: processing of ingredients such as sugar, flour, milled rice, wheat germ, chocolate, etc. to produce different breakfast cereals;
- packaging: production of packaging materials and packaging;
- waste management: management of process and consumer waste packaging;
- transport: transport of ingredients, packaging materials, products and wastes along the life cycle;
- consumption: consumption of cereals with semi-skimmed milk, washing up of dishes and associated wastewater treatment.

2.2. Inventory data and assumptions

Kellogg Europe has five manufacturing facilities across Europe, three in the UK and one each in Germany and Spain. The inventory data for the production of cereals and snacks at these plants have been obtained from Kellogg Europe for the year 2011. Note that the data are not supplied for the individual products but for each of the production plants which produce different products. Therefore, these data have been used to estimate the weighted-average impacts across all the products taking into account their annual production, rather than the impacts of individual products. This is congruent with the goal of the study which aims to identify the environmental hotspots along Kellogg’s supply chain. The background life cycle inventory (LCI) data have been sourced from the Ecoinvent (2010) and CCaLC (2013) databases as well as from the literature. The data and the assumptions are detailed below.
Raw materials (ingredients): Cereals, such as corn, rice and wheat, are the main ingredients in breakfast cereal products. As shown in Table 1, other ingredients include sugar and sweeteners, cocoa and chocolate, oils and fats, dried fruits, nuts, milk powder, malt, flavours, vitamins and salt. Table 2 also shows that the Kellogg Europe’s supply chain is global as these ingredients are sourced from around the world. As discussed below, the country-specific LCI data for the ingredients have been used from the databases and published studies whenever possible.

Corn, which is sourced from Argentina, has been modelled using LCI data from Pieragostini et al. (2014). Rice is procured from Italy, Spain, Thailand and Egypt and the LCI data have been obtained from Blengini and Busto (2009), Kasmaphruet et al. (2009) and Ecoinvent (2010). Country-specific LCI data from the Ecoinvent database have been used for wheat from Spain and US, while wheat from the UK has been modelled using data from Williams et al. (2010). Other cereal-based ingredients, such as flour, bran and wheat germ have been modelled using data on milling from the literature (Espinoza-Orias et al., 2013). Since the milling co-products cannot be produced in alternative systems, allocating the burdens between them by system expansion, a preferred approach according to ISO 14044 (ISO, 2006b) is not possible so that allocation based on the economic value of the co-products has been applied instead. Ecoinvent data have been used for beet and cane sugar which are imported from France, Germany and African, Caribbean and Pacific countries. Chocolate, freeze dried nuts and malt have been modelled based on the information from Kellogg and the literature (Carlsson-Kanyama and Faist, 2000; DEFRA, 2009; Klaeverpris et al., 2009; Nemecek et al., 2011). For some of the ingredients for which full LCA data were not available, the data gaps have been filled by using either GHG data if available in the literature or the best available proxy data (see Table 1). These substances constitute in total about 9% of the ingredients by weight and are cocoa and milk powder, oats, dry fruits, honey, sweeteners, flavours and vitamins. The production of cocoa is also linked to land use change (LUC) because of deforestation (DEFRA, 2009); this is also considered in this study as part of a sensitivity analysis.

Manufacturing: Production of breakfast cereals involves various processes, including grinding, boiling, mixing, cooking, extruding, puffing, drying and cooling, to produce different types of cereal forms, such as flaked, puffed, shredded and granola. The data for energy and water used in the production process for all five manufacturing plants are shown in Table 2. The difference in energy and water consumption in the plants reflects different manufacturing processes and the type of product produced by each plant. LCI data for electricity have been modelled using the Ecoinvent data for different sources of electricity and the 2010 national electricity mix for the countries where the manufacturing plants are based, i.e. Germany (Renewable Energy Agency, 2011), Spain (Öko-Institut, 2012) and the UK (DECC, 2011).

Packaging: The cereal products are packaged into carton boxes and HDPE bags (primary packaging), which are then packed into larger corrugated-board boxes that are wrapped with stretch film (secondary packaging) and loaded onto wooden pallets for distribution (tertiary packaging). The carton boxes and corrugated board used by Kellogg Europe are typically made of 80% and 98% recycled fibre, respectively. The data for the packaging of the products are shown in Table 3. The production of the packaging materials, including printing, has been modelled with the LCI data from Ecoinvent. Packaging for the ingredients is not considered as they are supplied in bulk bags which are reused.

Waste management: All relevant solid and liquid waste streams have been considered, generated by both processing plants and by the consumer (Table 4). Process waste includes losses of ingredients and cereals (8% of the product) which is used as animal feed. Process packaging waste is recycled and sludge from the on-site wastewater treatment plant is used as a fertiliser. For the disposal of post-consumer packaging waste, the average EU waste disposal data have been assumed (EC, 2012a,b). In accordance with ISO 14044 (ISO, 2006b), the system has been credited for the avoided burdens from recycling of different waste streams, the use of process waste (ingredients and cereals) as animal feed (grain maize feed) and sludge as a fertiliser. Treatment of human excretion related to cereal consumption is not considered in the analysis in line with common LCA practice.

Transport: The transport distances for each ingredient and packaging have been estimated from their country of origin to the Kellogg’s production plants (Table 5). The transport
Table 1 – Inventory data for the ingredients.

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Contribution to the total weight of ingredients</th>
<th>Country of origin</th>
<th>LCI data sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cocoa and chocolate</td>
<td>4.4%</td>
<td>West Africa (cocoa), Belgium, France, Germany and UK (chocolate), Turkey (nut cream)</td>
<td>Modelled using data from DEFRA (2009), Nemecek et al. (2011) and Ecoinvent (2010)</td>
</tr>
<tr>
<td>Corn</td>
<td>23.1%</td>
<td>Argentina</td>
<td>Modelled using data from Pieragostini et al. (2014) and Ecoinvent (2010)</td>
</tr>
<tr>
<td>Corn flour</td>
<td>1.8%</td>
<td>Argentina</td>
<td>Modelled using data from Pieragostini et al. (2014), Espinoza-Orias et al. (2011) and Ecoinvent (2010)</td>
</tr>
<tr>
<td>Dairy (milk powder and condensed milk)</td>
<td>0.6%</td>
<td>Europe</td>
<td>PROBAS (2008); CCaLC (2013)</td>
</tr>
<tr>
<td>Freeze-dried fruits</td>
<td>0.2%</td>
<td>Morocco, Poland, China, Serbia</td>
<td>Modelled using data from Williams et al. (2008), Ecoinvent (2010) and Carlson-Kanyama and Faist (2000)</td>
</tr>
<tr>
<td>Fruits and nuts</td>
<td>1.3%</td>
<td>USA, Chile and Turkey</td>
<td>Nemecek et al. (2011)</td>
</tr>
<tr>
<td>Honey</td>
<td>0.3%</td>
<td>Argentina</td>
<td>Modelled using data from Kløverpris et al. (2009) and Ecoinvent (2010)</td>
</tr>
<tr>
<td>Malt</td>
<td>0.6%</td>
<td>Germany, Spain and UK</td>
<td>Nielsen et al. (2003)</td>
</tr>
<tr>
<td>Oats</td>
<td>2.3%</td>
<td>Germany and Sweden</td>
<td>Ecoinvent (2010); WWF (2009); inorganic chemicals used as a proxy for vitamins</td>
</tr>
<tr>
<td>Oils and fats</td>
<td>0.3%</td>
<td>Brazil, Germany, Malaysia and UK</td>
<td>Ecoinvent (2010)</td>
</tr>
<tr>
<td>Other ingredients (rice flour, salt, flavours, vitamins, etc.)</td>
<td>3.2%</td>
<td>Various</td>
<td>Nemecek et al. (2011)</td>
</tr>
<tr>
<td>Peanuts</td>
<td>0.4%</td>
<td>Spain and USA</td>
<td>Modelled using data from Blengini and Busto (2009) and Ecoinvent (2010)</td>
</tr>
<tr>
<td>Rice (broken and whole)</td>
<td>20.8%</td>
<td>Egypt, Italy, Spain and Thailand</td>
<td>Ecoinvent (2010)</td>
</tr>
<tr>
<td>Sugar</td>
<td>17.8%</td>
<td>France, Germany and African, Caribbean and Pacific countries</td>
<td>Data for corn syrup from Renouf et al. (2008) used for all sweeteners</td>
</tr>
<tr>
<td>Sweeteners (corn syrup, glucose syrup, fructose syrup, sorbitol syrup, etc.)</td>
<td>2.4%</td>
<td>USA</td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>11.4%</td>
<td>Spain, UK and USA</td>
<td>Modelled using data from Ecoinvent (2010) and Williams et al. (2010)</td>
</tr>
<tr>
<td>Wheat-durum</td>
<td>1.0%</td>
<td>Spain</td>
<td>Ecoinvent (2010)</td>
</tr>
<tr>
<td>Wheat gluten</td>
<td>1.6%</td>
<td>Germany</td>
<td>CCaLC (2013)</td>
</tr>
<tr>
<td>Wheat bran</td>
<td>3.3%</td>
<td>Germany, Spain and UK</td>
<td>Modelled using data from Ecoinvent (2010), Williams et al. (2010) and Espinoza-Orias et al. (2011)</td>
</tr>
<tr>
<td>Wheat flour</td>
<td>3.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat germ</td>
<td>0.4%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**a**Ingredients used across different products.

**b**For this ingredient, only GHG emissions were available.

distances for intercompany transfers and distribution of products to retailers have been provided by Kellogg. The distances for disposal of all types of solid waste have been assumed at 100 km. The LCI data for transport have been sourced from the Ecoinvent database.

Consumption: Ready-to-eat cereals are usually eaten with milk. For most types, it is recommended on product packaging that 125 ml of semi-skimmed milk be added per 30 g serving. This recommendation has been followed in this study, assuming the use of cold milk (Table 6). As LCI data for milk are not available in LCA databases, they have been estimated by modelling data from the literature (Foster et al., 2007; Williams et al., 2007; Sheane et al., 2011). The data on refrigerated storage at retailer and at home have been obtained from Tassou et al. (2008) and Foster et al. (2007), respectively. Milk packaging is also considered (Table 6). Manual washing up of the cereal bowl is assumed and the data on the amount of water, detergent and energy have been taken from MTP (2008);
the LCI data for these have been sourced from Ecoinvent. The disposal of post-consumer packaging waste is considered as part of the waste management described above.

2.3. Impact assessment

GaBi V6.4 (PE International, 2014a) has been used to model the system and estimate the life cycle environmental impacts. The CML 2001 impact assessment method (Guinée et al., 2001), updated in April 2013, has been followed for the estimation of the following impacts: global warming (GWP), eutrophication (EP), freshwater aquatic ecotoxicity (FAETP), human toxicity (HTP), marine aquatic ecotoxicity (MAETP), ozone layer depletion (ODP), photochemical oxidants creation (POCP) and land use. Furthermore, primary energy demand (PED) and water footprint have also been estimated. PED has been estimated using Gabi software. It comprises both renewable and non-renewable energy resources which are directly withdrawn from the hydrosphere, atmosphere or geo-sphere or energy source without any anthropogenic changes; energy content of the ingredients is excluded (PE International, 2014b).

The volumetric water consumption has been quantified taking into account blue and green water, following the Water Footprint Network approach (Hoekstra et al., 2009). Green water is defined as rainwater stored in the soil as soil moisture. The water footprint has been estimated using CCaLC (2013), following the methodology developed by Pfister et al. (2009). This method assesses the environmental impacts of blue water consumption by considering the region specific Water Stress Index (WSI) which indicates water scarcity of a specific region/watershed. The water footprint is calculated as: Water footprint (l eq.) = Blue water use (l) × WSI.

3. Results and discussion

The results are discussed in the following sections, first excluding and then considering consumption of breakfast cereals.

3.1. Environmnetal impacts excluding consumption of cereals

3.1.1. Global warming potential (GWP)

The average GWP of Kellogg’s cereals and snack bars is estimated at 2.64 kg CO₂ eq/kg. As shown in Fig. 2, the ingredients are the major hotspot in the system, accounting for 48% of the total GWP. Energy consumption at the production facilities is the second major contributor, adding a further 23% to the total. Packaging and transport account for 15% each. The GWP of process waste management is negative because of the credits for the avoided burdens from animal feed, fertilisers and recycling of different waste streams. The contribution of post-consumer packaging waste is small (1%) as most is either recycled or incinerated with energy recovery (Table 4).

As shown in Fig. 2, the main contributor to the GWP of the ingredients is rice with 38%. Wheat and its derivatives cause 18% of this impact, followed by cocoa and chocolate with 11%, corn and the flour with 8% and sugar and sweeteners also with 8%. Emissions of methane, largely from rice cultivation, contribute 21% of the GWP from the ingredients.

Nitrous oxide, emitted in agriculture as a result of fertiliser application, contributes 20% to the GWP of the ingredients, with the remaining impact being from CO₂ generated during the production and processing of ingredients to manufacture cereal products. These results exclude the GHG emissions from LUC associated with cocoa powder, which is discussed next.

<table>
<thead>
<tr>
<th>Packaging material</th>
<th>Amount (kg/kg product)</th>
<th>Country of origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Folding-box board</td>
<td>0.16</td>
<td>Germany and Austria</td>
</tr>
<tr>
<td>Corrugated board</td>
<td>0.04</td>
<td>Germany, Spain and UK</td>
</tr>
<tr>
<td>Corrugated pallet layer pads</td>
<td>2.6 × 10⁻⁴</td>
<td>UK</td>
</tr>
<tr>
<td>Liner (HDPE)</td>
<td>1.4 × 10⁻²</td>
<td>Germany, Spain and UK</td>
</tr>
<tr>
<td>Stretch wrap (HDPE)</td>
<td>1.3 × 10⁻³</td>
<td>Germany, Spain and UK</td>
</tr>
<tr>
<td>Pallets</td>
<td>8.2 × 10⁻⁴</td>
<td>Germany, Spain and UK</td>
</tr>
</tbody>
</table>

Table 3 – Inventory data for packaging.

Table 4 – Inventory data for the process and post-consumer packaging waste.

<table>
<thead>
<tr>
<th>Waste</th>
<th>Quantity (kg/kg product)</th>
<th>Disposal type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wastewater</td>
<td>2.70</td>
<td>Onsite treatment plant</td>
</tr>
<tr>
<td>Process (food) waste</td>
<td>0.08</td>
<td>Animal feed</td>
</tr>
<tr>
<td>Other process wastes (cardboard, plastics, metals and sludge)</td>
<td>0.03</td>
<td>Recycled</td>
</tr>
<tr>
<td>Post-consumer packaging waste: folding box board, corrugated board and pads</td>
<td>0.20</td>
<td>Assumed EU waste disposal for packaging cardboard: 83% recycled, 9% landfilled, 6% incinerated with energy recovery and 2% incinerated without energy recovery (EC, 2012a).</td>
</tr>
<tr>
<td>Post-consumer packaging wastes: HDPE b liner and stretch wrap</td>
<td>0.02</td>
<td>Assumed EU non-recyclable municipal solid waste disposal for plastic: 58% landfilled, 34% incinerated with energy recovery and 8% incinerated without energy recovery (EC, 2012b).</td>
</tr>
</tbody>
</table>

Table 4 – Inventory data for the process and post-consumer packaging waste.

<sup>a</sup>Estimated based on the annual amount of packaging used for different products and the annual production of products.

<sup>b</sup>High density polyethylene.
Table 5 – Inventory data for transport.

<table>
<thead>
<tr>
<th>Transport mode</th>
<th>Distance—weighted average (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport of ingredients</td>
<td></td>
</tr>
<tr>
<td>Truck (32 tonne)</td>
<td>750</td>
</tr>
<tr>
<td>Container ship</td>
<td>3800</td>
</tr>
<tr>
<td>Transport of packaging</td>
<td></td>
</tr>
<tr>
<td>Truck (16 tonne)</td>
<td>1340</td>
</tr>
<tr>
<td>Inter-company transfer</td>
<td></td>
</tr>
<tr>
<td>Truck (28 tonne)</td>
<td>675</td>
</tr>
<tr>
<td>Rail freight</td>
<td>50</td>
</tr>
<tr>
<td>Container ship</td>
<td>180</td>
</tr>
<tr>
<td>Product distribution</td>
<td></td>
</tr>
<tr>
<td>Truck (28 tonne)</td>
<td>570</td>
</tr>
<tr>
<td>Container ship</td>
<td>210</td>
</tr>
<tr>
<td>Waste transport</td>
<td></td>
</tr>
<tr>
<td>Truck (16 tonne)</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 6 – Inventory data for the consumption of cereals.

<table>
<thead>
<tr>
<th>Consumption with cold milk</th>
<th>Quantity</th>
<th>Units</th>
<th>LCI data sources and assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk (semi-skimmed)</td>
<td>4.2</td>
<td>l/kg</td>
<td>Modelled using data from Foster et al. (2007), Williams et al. (2007) and Sheane et al. (2011)</td>
</tr>
<tr>
<td>Packaging (HDPE)</td>
<td>0.85</td>
<td>kg/kg</td>
<td>CCaLC (2013) and Ecoinvent (2010)</td>
</tr>
<tr>
<td>Electricity (retail storage)</td>
<td>0.2</td>
<td>kWh/kg</td>
<td>Tassou et al. (2008)</td>
</tr>
<tr>
<td>Refrigerants (R404A, R744 and R22)</td>
<td>27.5</td>
<td>mg/kg</td>
<td>15% annual loss of refrigerant assumed; data from Tassou et al. (2008)</td>
</tr>
<tr>
<td>Distribution (road transport)</td>
<td>185</td>
<td>km</td>
<td>Refrigerated transport and empty return assumed; data from Sheane et al. (2011)</td>
</tr>
<tr>
<td>Electricity (home chilling)</td>
<td>0.16</td>
<td>kWh/kg</td>
<td>Foster et al. (2007)</td>
</tr>
<tr>
<td>Post-consumer packaging waste (HDPE)</td>
<td>0.85</td>
<td>kg/kg</td>
<td>Assumed EU waste disposal for plastic packaging: 38% landfilled, 36% incinerated with energy recovery and 26% recycled (PlasticsEurope, 2013)</td>
</tr>
<tr>
<td>Manual washing up with warm water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>30</td>
<td>l/kg</td>
<td>Data from MTP (2008); LCI data from Ecoinvent (2010)</td>
</tr>
<tr>
<td>Energy</td>
<td>3.9</td>
<td>MJ/kg</td>
<td>Data from MTP (2008); LCI data from Ecoinvent (2010)</td>
</tr>
<tr>
<td>Detergent</td>
<td>12</td>
<td>ml/kg</td>
<td>Data from MTP (2008); LCI data from Ecoinvent (2010)</td>
</tr>
<tr>
<td>Wastewater</td>
<td>30</td>
<td>l/kg</td>
<td>Data from MTP (2008); LCI data for wastewater treatment from Ecoinvent (2010)</td>
</tr>
</tbody>
</table>

Fig. 2 – The global warming potential (GWP) of breakfast cereals (excluding consumption).

Deforestation for agricultural expansion is the leading cause of LUC (FAO, 2010), estimated to account for 9%–11% of the annual global GHG emissions (IPCC, 2014). PAS 2050 and some other standards recommend that land use change from agricultural activities should be considered if it occurred within the last 20 years. Since most ingredients are obtained from established agricultural fields which have been under cultivation for over 20 years (e.g., corn, rice, sugar etc.), they are not considered in the LUC assessment. However, the increased production of cocoa and palm oil is linked to
Fig. 3 – The global warming potential (GWP) of cereal products with and without land-use change (LUC) for cocoa powder.

LUC owing to deforestation (DEFRA, 2009; Stichnothe and Schuchardt, 2011). Since the palm oil used by Kellogg Europe is sourced from certified sustainable palm oil producers, it is not associated with the LUC, so that only the LUC for cocoa is considered here.

A study by DEFRA (2009) on cocoa powder from Ghana, carried out according to the IPCC methodology (2006), estimates that the GHG emissions including LUC are equivalent to 91 kg CO\textsubscript{2}eq./kg of cocoa powder. However, DEFRA acknowledges that this value is highly uncertain because of the use of secondary data for the estimates of the extent of LUC and the resulting GHG emissions. Nevertheless, in the absence of any other data, this value is used for the analysis here.

Fig. 3 compares the estimated GWP with and without LUC for cocoa powder. It can be observed that the total impact per kg of product increases by 64%, to 4.34 kg CO\textsubscript{2}eq./kg, when the LUC GHG emissions are considered. In that case, the contribution of ingredients to the GWP increases from 48% to 68%. Therefore, the influence of LUC on the GWP is significant, despite the small amount of cocoa used in cereal products.

3.1.2. Primary energy demand (PED)

As can be inferred from Fig. 4, the total primary energy demand is 32.3 MJ/kg product, 95% of which is from non-renewable resources, mainly natural gas and crude oil used across the life cycle of cereal products. The manufacturing stage is the main contributor to the PED, accounting for 34% of the total. The rest of the primary energy is consumed in the life cycles of ingredients (24%), packaging (23%) and transport (21%). The credits for energy recovery reduce the PED by 2% (Fig. 4).

3.1.3. Water footprint

Fig. 5 shows the average blue and green water consumption as well as the total water footprint of breakfast cereals. The blue and green water of cereals are estimated at 672 and 1100 l per kg of product, respectively; the water footprint is equal to 283 l eq. per kg. More than 90% of water is consumed for the cultivation of ingredients. Cocoa and chocolate are the major contributors (44%) to the green water consumption, while more than 75% of blue water and the water footprint are due to the irrigation of rice paddies.

3.1.4. Other environmental impacts

Table 7 summarises the results for the other environmental impacts considered in this study and Fig. 6 shows the life cycle stage contributions for each impact category. As mentioned earlier, for some of the ingredients only GHG emissions data were available (see Table 1) so that some of the environmental impacts might be underestimated.

As can be seen in Fig. 6, the ingredients are the main contributor to most environmental impacts, including the ADP elements (61%), AP (48%), EP (71%), HTP (54%), FAETP (43%), POCP (50%) and land use (97%). Most of these impacts are associated with the production of rice, corn, wheat and sugar.

The manufacturing of cereals is the main hotspot for the ADP fossil and ODP with the contribution of 33% and 30%, respectively. The contribution of the manufacturing stage to the other impacts such as the AP, FETP, HTP, MAETP and POCP is also significant, ranging from 10% to 31%. The impacts from the manufacturing stage are mostly related to the use of fossil fuels (coal, oil and natural gas in the electricity mix and natural gas in boilers and combined heat and power plants).

The contribution of packaging varies from 6% to 27% across the different impacts, while the contribution of the post-consumer packaging waste is negligible. The relative contribution of process waste is also very small owing to the credits for recycling. Transport is the important hotspot for the ADP (elements and fossil), AP, ODP and POCP, causing more than 20% of these impacts.

Fig. 4 – Primary energy demand (PED) of breakfast cereals (excluding consumption).
3.2. Environmental impacts including consumption of cereals

3.2.1. Global warming potential (GWP)
As shown in Fig. 7, the GWP of breakfast cereals when the consumption with cold milk is included is estimated at 8.84 kg CO$_2$ eq./kg. Therefore, the consumption stage increases the GWP by 2.3 times [(8.84–2.64)/2.64] compared to the impact when consumption is excluded from consideration. This is largely due to the milk which is responsible for 95% of the GWP of the consumption stage. The cradle-to-grave GWP of milk is estimated in this study at 1.41 kg CO$_2$ eq./l. If instead of using cold milk, the milk is heated up in a microwave for 1 min per serving (125 ml), the GWP would increase to 9.27 kg CO$_2$ eq./kg. Furthermore, if the dishwasher is used for washing up of bowls, the GWP would increase from 8.84 to 8.94 kg CO$_2$ eq./kg.
recognising the importance of working closely with primary producers, Kellogg has recently started providing training to farmers and helping them to share best practice (Kellogg, 2012). The Company is also engaging farmers through different multi-stakeholder partnerships, such as Sustainable Rice Platform, Sustainable Agriculture Initiatives Platform Europe, Cocoa foundation and Roundtable on Sustainable Palm Oil (Kellogg, 2012). However, as these initiatives are relatively new and still ongoing, it is not known yet how successful they will be, particularly as some previous studies found that voluntary partnerships are not so effective in engaging farmers in sustainable farming practices (Ruyschaert and Salles, 2014).

In addition to reducing the impacts from agriculture, there is also a scope for reducing the impacts from the ingredients by modifying the product recipes; for example, using less of some of the ingredients or replacing them by those that have lower environmental impacts. Note that the results presented in the previous section are for an average Kellogg Europe product—the impacts would vary significantly between different types of products, e.g. corn or wheat based RTEC and snacks would have lower impacts than rice based RTEC and snacks.

Furthermore, the contribution to the impacts of manufacturing, packaging and transport is also significant so that they too should be targeted for improvements. For example, energy consumption and the related impacts could be reduced by implementing energy-efficiency measures, installing combined heat and power plants (CHP) and on-site renewable energy technologies. Similarly, the impacts from packaging could be decreased by improving its design and using alternative packaging, such as standalone plastic bags or pouches instead of carton boxes (WRAP, 2009).

The feasibility of the above-mentioned measures is not assessed here as it would require a further detailed study. Instead, several hypothetical scenarios, some of which are based on Kellogg’s sustainability targets, are considered to assess the potential for reducing the environmental impacts through the implementation of different improvement opportunities, as follows:

- Opportunity 1—Engaging and influencing farmers: Based on the Kellogg’s work with farmers in different regions, the Company estimates that environmental impacts of the ingredients used in the production of cereal products could be reduced by 10%–20% through better agricultural practices, such as optimising application of fertilisers, reduction in the use of pesticides and irrigation water as well as improving the crop yield. Here, a conservative value of 10% reduction of all impacts is considered.

- Opportunity 2—Changing product recipes: Given the significant contribution of rice to the impacts, it is assumed that the quantity of rice is reduced by 25% and replaced with wheat, corn and barley in equal proportions.

- Opportunity 3—Reducing energy use: It is assumed that the energy use at the manufacturing plants can be reduced by 15% through implementation of various energy-efficiency related measures.

- Opportunity 4—Packaging changes: It is assumed that 20% of carton boxes are replaced with standalone HDPE bags.

As can be seen in Fig. 8, by engaging and influencing farmers to improve agricultural practices (Opportunity 1), Kellogg could reduce the GWP of its products by 5%. A further 4% reduction could be achieved by modifying the recipes (Opportunity 2). The implementation of energy-efficiency measures (Opportunity 3) and packaging improvements

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3.2.2. Other environmental impacts

Table 7 compares other environmental impacts of cereals with and without consumption. As can be seen, the use of milk increases all environmental impacts. The most notable increase is found for acidification, ozone layer depletion and land use, which are around four times higher compared to the impacts when consumption is not considered. The increase in acidification is due to the energy use in the milk supply chain and ozone layer depletion is mostly due to the refrigerant leakage from dairy plants and retail stores; land use increases because of the production of feed and fodder for cows. All other impacts increase between 1.6 and 3 times except for the water footprint which is 6% higher.

As mentioned in Section 2.2, treatment of human excretion related to cereal consumption is not considered in the analysis. According to Muñoz et al. (2010), inclusion of treatment and disposal of human excretion could increase eutrophication impacts of diet by 17%. However, the increase in other impacts, such as GWP, AP and PED, would be much smaller (2%–3%).

The following section discusses how the impacts from the production and consumption of breakfast cereals could be reduced.

3.3. Opportunities for improvements

As the results of this study reveal, the agricultural production of the ingredients is the main hotspot for most of the environmental impacts, with rice being the main contributor. There are a number of technically feasible options available for mitigating the impacts in agriculture, including a reduced use of chemical fertilisers, crop rotation and better land management. Particularly, the agricultural impacts from rice cultivation can be reduced through better management practices at farm, including mid-season drainage, alternate wet-dry cultivation and replacing urea with ammonium sulphate fertiliser (van Groenigen et al., 2013). For example, mid-season drainage can reduce methane emission from rice paddies by as much as 50%–60%, whereas replacing urea as a fertiliser with ammonium sulphate can reduce methane emissions by 40% (van Groenigen et al., 2013).

The implementation of these measures would involve engaging actively with the farmers and growers to increase their awareness of how environmental impacts could be reduced. However, for food companies to influence the agricultural supply chain could be a highly challenging and complex task because of the wide geographical spread as well as smallholder farmers involved in supply chains. Nevertheless,
The combined effect of all four improvements would result in a 14% reduction in the GWP. The implementation of these measures would also reduce most of the other environmental impacts. For example, the water footprint could decrease by more than 30% by better agricultural practices and by modifying the product recipes. However, the latter would lead to a 3% higher eutrophication because this impact from rice is lower than from its replacements such as wheat and barley. Through the energy-efficiency measures, the primary energy demand and depletion of fossil resources could be reduced by 5% each and ozone layer depletion by 4%. A reduction of up to 5% in the freshwater and marine ecotoxicity would be achieved through packaging improvements.

Although the reductions in the environmental impacts are relatively small when considering each improvement opportunity in isolation, combining them would result in an average reduction in the impacts of 14% across the categories considered. Further reductions could be possible by reducing the use of some of the ingredients with the higher impacts, such as milk powder, freeze-dried fruits, cocoa and chocolate. Moreover, optimising distribution of the products to minimise transportation and use more sustainable transport means could also reduce the environmental impacts. Therefore, it is recommended that these improvements be explored further, including their techno-economic feasibility and consumer acceptance of changes in the recipes and packaging.

Improvement opportunities also exist with respect to the consumption of cereal products. Using less milk or replacing it with a soy or oat milk or fruit juice would also reduce the environmental impacts. For example, reducing the amount of milk by 20% would reduce the total GWP by 13%. Using soy milk instead would reduce the GWP by 36%, from 8.84 to 5.63 kg CO$_2$ eq./kg. However, it is important to mention that with respect to nutrient content, dairy milk is superior to plant-based alternatives (Mäkinen et al., in press). Furthermore, eating dry cereals or snack bars would reduce the GWP by 3.35 times, from 8.84 to 2.64 kg CO$_2$ eq./kg. This is the same value as the one estimated for the breakfast cereals without considering the consumption with milk (see Fig. 7).

Therefore, raising consumer awareness of the implications of their choices could also help to reduce the impacts from cereals consumption. However, this is a complex issue as it is related to consumer taste and behaviour. Nevertheless, Kellogg and other food companies could work on providing guidance to consumers on what they could do to reduce environmental impacts from food consumption.

4. Conclusions and recommendations

This study has considered environmental sustainability in the food–energy–water nexus by assessing the life cycle environmental impacts of breakfast cereal products produced by Kellogg Europe. The assessment provides a baseline against which the Company can set targets and track performance of their product portfolio. It also identifies the hotspots along the supply chain to help identify improvement opportunities.

The findings indicate that the average global warming potential across the different Kellogg’s breakfast cereal products, excluding their consumption, is equal to 2.64 kg CO$_2$ eq. per kg of product. The major hotspots are the ingredients and energy used in the manufacturing process, contributing 48% and 23%, respectively; packaging and transport add a further 15% each. Consumption of cereals with milk increases the global warming potential by 2.3 times, to a total of 8.84 kg CO$_2$ eq./kg.

The manufacturing stage is the main contributor to primary energy demand, while the ingredients are responsible for more than 90% of the water footprint. The ingredients are also the main contributors to most of the other environmental impacts, including depletion of elements (61%), eutrophication (71%), human toxicity (54%), photochemical smog (50%) and land use (97%). The contribution of energy consumption is significant for depletion of the ozone layer and fossil resources as well as marine aquatic ecotoxicity. The impacts associated with the packaging are high for depletion of fossil resources, freshwater and marine ecotoxicity. The contribution of transport is significant for depletion of fossil resources, agricultural production and transport.
the ozone layer, elements and fossil resources, acidification and photochemical smog.

If land use change is considered for cocoa powder, the global warming potential of cereal products would increase by 65%. However, considering a high uncertainty of the extent of land use change and related greenhouse gas emissions from cocoa production in West Africa, there is a need for a detailed LCA study to estimate its real impacts.

The hotspot analysis indicates that the ingredients, cereals manufacturing and packaging should be targeted for environmental improvements. The impacts from the ingredients, which are mostly associated with agriculture, could be reduced by engaging with farmers and helping them to improve agricultural practices. These include optimizing application of fertilisers, reduction in the use of pesticides and irrigation water. Moreover, a responsible increase in crop yield and the corresponding resource efficiency could possibly mitigate some impacts related to land use change, improve farmers’ livelihoods and feed the world better. Furthermore, given the significant contribution of milk to the impacts, Kellogg should also explore opportunities for developing partnerships with dairy farmers to help reduce the impacts from milk production.

In addition to producers, consumers have a significant role to play in reducing the impacts of cereals (and other food) consumption since the majority of the impact is associated with consumption rather than production. However, this is a complex issue as it is related to consumer taste and behaviour. Therefore, it is recommended that Kellogg and other food companies work on identifying best ways of raising awareness and engaging with the consumer to help reduce the overall environmental footprint of food and address some of the sustainability issues in the food–energy–water nexus.

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References

Ecoinvent 2010. Ecoinvent V2.2 database. Swiss Centre for Life Cycle Inventories, Dübendorf, Switzerland.


