Journal of Cleaner Production 73 (2014) 100–108

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

The influence of packaging attributes on consumer behaviour in food-packaging life cycle assessment studies - a neglected topic

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ARTICLE INFO

Article history:
Received 8 April 2013
Received in revised form
2 September 2013
Accepted 22 October 2013
Available online 7 November 2013

Keywords:
Functional unit
Consumer behaviour
Packaging
Food waste
LCA
Packaging attributes

ABSTRACT

The role of packaging systems to reduce food waste is rarely modelled in life cycle assessment (LCA) studies. This means that a packaging system format with a lower environmental impact that causes high food waste, may appear to be a better alternative than a packaging system with a higher environmental impact that reduces food waste. This can be contradictory to the purpose of using LCA to reduce overall environmental impacts, because food generally has a higher environmental impact than the packaging system. This paper highlights packaging attributes that may influence food waste, and demonstrates via six packaging scenarios how the environmental impact for the functional unit of “eaten food” can be calculated when food waste is included. The results show that the function of “avoiding food waste” is a critical packaging issue. The connection between packaging design and food waste should be acknowledged and valued by relevant stakeholders such as: food producers, manufacturers, brand owners, retailers and consumers, and also in packaging regulations. To fully explore the potential for packaging systems to reduce their overall environmental impact, food waste should be included.

1. Introduction

The purpose of this paper is to analyse the consequences of dismissing food waste from life cycle assessments (LCA) of packaging systems. The paper highlights packaging attributes that influence food waste, and presents a developed method and scenarios to illustrate how food waste may be integrated into future packaging LCAs.

Like any material, packaging materials contribute to environmental issues associated with the consumption of resources and energy, and resultant waste stream at end-of-life. The resources used to produce packaging, and resultant problems with waste management have been the subject of environmental concern and research. So far, most attention has been focused on minimising the environmental impacts associated with sourcing and producing packaging materials, as well as resource recovery at end-of-life. Strategies have included: the light weighting of materials in the change from rigid plastics to flexible films and pouches, the selection of more renewable materials, and enhancing the efficiency and energy consumption associated with sourcing, producing and converting packaging materials. Regulatory frameworks including the Directive on Packaging and Packaging Waste in Europe (European Council, 1994; European Commission, 2006) and the voluntary Australian Packaging Covenant (APCC, 2010) have assisted the packaging supply chain to rethink the design of packaging materials and formats to reduce their environmental impacts.

The primary function of packaging is to protect the content, however this is often neglected in the environmental analysis of packaging systems. The function of packaging to reduce food waste has rarely been discussed in Packaging Directives (European Council, 1994). In the APC's Sustainable Packaging Guidelines, there is one question that seeks a response to consider product residue remaining in pack.

The packaging system often consists of primary packaging (in direct contact with the product and the one that the consumer purchases) and secondary packaging (e.g., a corrugated carton to group and contain a number of primary packaging units conveniently). The containment of primary and secondary packaging on a pallet with additional packaging is tertiary level packaging (Hellström and Saghir, 2007). Produce like fruits sometimes have no primary packaging, but bags provided at the retailer serve the same function. The secondary and tertiary packaging would have been used through the supply chain to move the fruit from the farm through to the retail shelf.

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http://dx.doi.org/10.1016/j.jclepro.2013.10.042

The packaging system should protect the content (food) from being wasted from the field to fork. Packaging should facilitate convenient handling all the way from the farm through to transport, wholesale, retail, and final consumption in preparation for serving. Packaging design and food waste is dynamic, influenced by the complex array of changing consumption patterns, industry and supply chain structures and trends, improvements in the efficiencies of supply chains and an increased focus upon policies to reduce food waste (Verghese et al., 2013). From field to fork, there are a number of possibilities for food loss and waste to occur. And it does occur. For food, it has been approximated that up to 50% of the edible food produced, does not reach the fork (Kader, 2005). Food waste studies at present are hindered by poor data resolution (Parfitt et al., 2010; Mena et al., 2011). However Gunders (2012) estimates in Fig. 1 food losses and waste at each step in the supply chain. Numerous studies have also reported that 20–30% of the food purchased in the industrialized world is wasted by consumers (Ventour, 2008; Quested and Johnson, 2009; WRAP, 2009).

When this food is lost all of the embodied resources associated with food production are also lost. These losses are significant given that food contributes to approximately a third of a person's carbon footprint (Dey et al., 2007). Service institutions (Engström and Carlsson-Kanyama, 2004) and restaurants (SRA, 2010) have also reported similar food loss figures. These figures do not include inedible food components such as bones, seeds, and peels etc. This consumer phase also creates demand for waste management with food representing approximately 38–41% of municipal waste in Australia (Dee, 2012), with associated environmental impacts from collection and treatment. During its degradation in landfill, food waste may produce methane contributing to global warming.

The focus of this paper is on food packaging and its relationship to consumer food waste. This focus is due to the high percentage of food waste at the consumer stage of the supply chain. It is acknowledged that many of the reasons for food losses in production and retail may not relate to packaging. Cosmetic imperfections (Dorward, 2012; White et al., 2011), spillage and degradation during processing (Parfitt et al., 2010), inaccurate forecasting of demands and promotions that lead to oversupply in the market (Mena et al., 2011) all contribute to food waste. These, however are outside the scope of the paper.

At the household stage of the supply chain, a causal relationship is proposed to exist between packaging and food waste. Williams et al. (2012) estimated that 20% of food waste in households could be attributed to packaging (not including food waste of fruit and vegetables due to too little packaging). This causal relationship between packaging and food waste is scarcely investigated in LCA.

By excluding food waste when estimating the environmental impact of packaging systems means that packaging with a lower environmental impact that causes high food waste, may appear to be a better alternative than packaging with somewhat higher environmental impact that reduces food waste. This is contradictory to the purpose of using LCA to reduce environmental impacts, because food generally has a much higher environmental impact than the packaging (Hanssen, 1998). For example, the climate impact of bread packaging could be doubled, if it led to a reduction in bread waste by 5% (Williams and Wikström, 2011). A packaging LCA that has not included bread waste may favour larger packaging for geometrical reasons, as well as the lower ratio of packaging material/kg of food product.

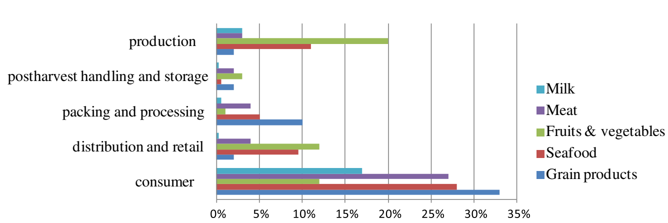

Fig. 1. Food losses at each step in the supply chain (Gunders, 2012).

The importance of consumer behaviour in a food LCA is sometimes stated (e.g., Verghese et al., 2012a) but seldom included. There can be several reasons for this, primarily the lack of empirical studies on how the design of different food products and packaging effect heterogeneous consumer behaviour. However, if one acknowledges that packaging attributes may contribute to or ameliorate food waste then more comprehensive packaging LCA's that include food product and food waste are desirable. This requires an "upscaling" of the functional unit (Verghese et al., 2012a; Wikström and Williams, 2010) to become the delivery of *eaten* food.

Upscaling the functional unit to include food waste presents methodological challenges for LCA, in that it is hard to imagine how the user phase can be standardized to make LCA studies comparable. This also raises questions of why LCA is used. Is it to improve environmental performance or to compare products? The main purpose of this paper is not to solve these problems, but to demonstrate how packaging attributes may affect consumer behaviour and food waste, and thus influence the outcome from a LCA study on packaging. The intention of this paper is to demonstrate the importance of considering and calculating food waste impacts, so that this can influence different packaging designs and environmental optimisations.

Section 2.1 presents the methodology used in streamlined LCA to analyse the environmental outcome of packaging systems when the functional unit is eaten food. Section 2.2 presents a discussion on how service-thinking could be used to identify packaging attributes that influence food waste. Section 2.3 presents the 6 packaging scenarios utilised in the study. The LCA results for the packaging scenarios and how food waste alters environmental impacts are presented in Section 3. The paper closes with a discussion of the effects of including food waste in LCA and possible methods that could assist in including food waste within LCA studies.

2. Method

2.1. Theory

In food-packaging LCA, the functional unit is normally expressed as "a unit of food delivered to home". As stated earlier, food waste is usually not included in the functional unit, and we propose an upscaling of the functional unit to be the unit "eaten food". The equation for the amount of eaten food *e*, is:

$$e = B - BL \tag{1}$$

B is the amount of purchased (*B*ought) food and *L* is the fraction *L*ost [0–1], which make BL the amount of purchased food that is wasted. (See also Table 1 for nomenclature.) Rearranging, the equation becomes:

$$B = e/(1 - L) \tag{2}$$

This equation illustrates that a non-linear relationship between L and total environmental impact. If $L = 0.5$ (50% of purchased food is continually wasted), then it would be necessary to produce twice as much food and packaging (100% increase) to compensate for the food loss relative to if no waste existed. This contrasts the often-

Table 1
Nomenclature.

Symbol	Denotes	Unit
e	Eaten food	kg, litre, nutrient content, etc.
E	Energy use or environmental impact	MJ, carbon dioxide equivalents, etc.
B	Amount of purchased food	kg, litre, nutrient content, etc.
L	Fraction of food lost in the consumer phase, ($L = 0$ means no losses, $L = 1$ means that all purchased food is lost)	No dimension
F	Energy use or environmental impact to produce and distribute one unit food to the consumer, with the exception of packaging. F includes storing of food at home.	MJ, carbon dioxide equivalents, etc., per unit of the food item (not related to the amount purchased)
P	Energy use or environmental impact to produce the package for the purchased food item.	MJ, carbon dioxide equivalents, etc.
W_P	Waste handling of the package.	MJ, carbon dioxide equivalents, etc.
W	Energy use or environmental impact of waste handling per unit of the food lost in the consumer phase.	MJ, carbon dioxide equivalents, etc., per unit of food

assumed linear relationship between food waste and the total environmental impact.

To calculate the environmental impact per unit eaten food, Wikström and Williams (2010) developed a model dependent on consumer food waste levels, here slightly modified to better adapt to the way data generally are given in databases. (Food waste upstream consumer phase can also be included.) E is the environmental impact of a specific food item in a package, equal to the sum of the environmental impact of purchased food (BF), packaging (P), and waste handling of packaging (W_P) and food (WBL):

$$E = \mathrm{BF} + P + \mathrm{WP} + \mathrm{WBL} \tag{3}$$

F is the environmental impact per kg (or volume) of the food item and includes agriculture, food processing, retailer, and transport phases. At best, it includes all environmental impacts from field to fork or waste, including storing and preparation at home. The environmental impact of the packaging production (P) and packaging waste (W_P) are per package of the food item. W is the environmental impact of waste handling per unit of lost food at the consumer. The last term in Eq. 3 is the waste handling of food lost, often neglected in food-packaging LCA. See also Table 1.

Eq. 3 can be rearranged to express the specific environmental impact per eaten unit food:

$$E/e = (BF + P + \mathrm{WP})/e + W(B - e)/e \tag{4}$$

if Eq. 1 is used to substitute L in Eq. 3.

The environmental impact (E) may be calculated for example: energy use, global warming potential (GWP), eutrophication potential, etc. In this paper, while it is acknowledged that this can restrict the environmental comparison, carbon dioxide equivalents (100-yr eqv, IPCC, 2007) are only used to simplify the presentation of the results.

Data on the majority of food types (F) can be found in food LCA's from peer reviewed journals and Environmental Product Disclosure (EPD) websites available in the public domain. For example, the authors identified CO_2e data for 200+ foods from 62 studies. Audsley et al.'s (2009) study alone provides environmental impact data on 100+ foods in the United Kingdom, and the International EPD system (2012) lists 44 EPD's from a range of brands. In our study, GWP of food were calculated using data from peer reviewed LCA's (Carlsson-Kanyama, 1998; Lindenthal et al., 2010).

Data for packaging production (P) and waste (W_P) can also be found in the public domain. Streamlined LCA tools such as the Packaging Impact Quick Evaluation Tool (PIQET) may assist in quickly evaluating and re-evaluating changed packaging system specifications (Verghese et al., 2010). Similarly, full LCA software packages such as SimaPro may be used. The calculations in this study were completed in excel. P and W_P was calculated using factors from the Ecoinvent database (2012).

The environmental impact of food waste treatment, W, depends on the characteristics of the food item and the treatment method. Composting and biogas production facilitate nutrient recycling. If food waste is landfilled it can result in long-term methane emissions. There are no available data for specific food items in specific waste treatments so generic data has been utilised in the case studies below.

The part of the equation that lacks sound data, and is most variable is the percentage of food wasted per food-packaging system. Therefore this paper utilised six packaging formats and three waste level percentages to generate multiple scenarios that illustrate the altered environmental impact on the packaging system when food waste is included.

2.2. How packaging attributes assist in reducing food waste

The broader design literature does acknowledge the 'scripting' role of designed goods (Jelsma, 2006). Product attributes enable or restrict consumers to act in a particular way. Jelsma (2006) points that we may design 'moralized products' that encourage consumers to act in the most desirable way. For example, packaging that reseals properly after opening may script a reduction in waste. Understanding the context in which consumers purchase, store and consume food is critical to ensuring that the entire product-packaging supply chain is designed to minimise food loss from field to fork (Verghese et al., 2013; Svanes et al., 2010).

By taking a service perspective, the focus can move from the product itself, to the process it is used for (Vargo and Lusch, 2004; Edvardsson et al., 2005). The product can be described by attributes. Each attribute provides prerequisites for the service to occur and be experienced and assists to script individual behaviour and experiences, and potentially the environmental outcome e.g., the amount of food waste generated. The consumer interaction with the product depends on the design of the product, the consumer preferences and experiences, and the context of the consumer (Löfgren, 2006).

For example, consider the attribute *contain the desired quantity*. If the offered quantity of fresh bread does not agree with the desired portion, the service of eating fresh bread may not be used for the entire piece of bread. Some may be frozen, some may be eaten "old", and some may be wasted depending on consumer preferences and behaviour. Therefore, the size of the bread can affect the consumer behaviour and the amount of food that is discharged, and thus the environmental outcome. In Australia, Bakers Delight introduced small block loaves of bread to provide a simple alternative to the full loaf of bread – potentially reducing associated food waste for single person or small households (Verghese et al., 2011). By understanding the consumer preferences and behaviour that the services provide for, a specific packaging attribute can be designed to better meet the consumer needs and facilitate consumers to waste less food. Williams et al. (2008) identified a range of packaging attributes that may ameliorate food waste, introduced below.

Packaging should provide for *mechanical protection*. The packaging should not leak and it should protect fragile products from mechanical impact. The packaging must resist pressure, strikes, and rips and should facilitate ease of handling and stacking at the retailer, home transport and storage and handling at home. Packaging also offers *physical–chemical protection* of the product, such as protecting the product against oxygen, water or other agents from the surrounding atmosphere. This can be achieved by introducing different kinds of barriers in the packaging material or by a modified atmosphere. These solutions can extend the time that the product is fresh.

The attribute *resealability* can affect physical–chemical protection by avoiding degradation of food in an opened package, for example a packaging placed where it can incorporate odour from other food products and result in a reduction of experienced consumer quality. A better resealability can also help to avoid spillage during consumer handling in home or "on-the go".

Spillage during handling could also be avoided by the accessibility attributes *easy to: open*, *grip*, *dose* and *empty*. There is a wide range of consumers that handle packaging, be that children, the elderly, people with reduced strength in their hands, visually impaired, etc., giving different needs of attributes and their functions. The ease at which packaging is accessible – to open, grip and dose and to visually read ingredients and directions, is an increasingly important attribute that packaging technologists and designers are only starting to realise its implications (Barry, 2012). About one-third of a group of elderly reported that spillage occurred frequently in connection with opening (Duizer et al., 2009). The design of the packaging's opening, the shape and the surface of the packaging can affect how much food is wasted. Packaging that is too large or too heavy can also increase the risk for spillage. A smooth surface can be made safer to grip by using laminate on the surface, making creases in board packaging or by making the surface ribbed. The attribute easy to dose may be improved for example, by introducing a spout mechanism. The ability to dose/empty can be influenced by surface treatment inside the package, possibility to reach all food in the package, and ability to mechanically squeeze the last food out of the packaging.

Contains the correct quantity is an important attribute of packaging, as mentioned above. If the food quantity in a package is higher than the turnover of the food item in the household, the risk that the food item is wasted increases, either because of physical degradation of food, or because the product is out-of-date (see below). In a Swedish food waste diary study, the households documented "too large packaging" as one important factor for food losses (Williams et al., 2012). If the quantity of product in a package is slightly more than desired, there is a possibility that it increases the surplus that is wasted directly, or worse, too much food is prepared and wasted after the meal. The waste of prepared food can be significant in households (Ventour, 2008; Katajajuuri et al., 2012; Williams et al., 2012). As the amount of single households and elderly increases in many countries, it is especially important to offer suitable packaging sizes to avoid food waste. The amount of wasted food per person was noted to be higher in households with few persons (Williams et al., 2012; Baker et al., 2009).

Food safety/freshness information is also important. One of the most important reasons for food waste is consumer confusion about date coding (Ventour, 2008). "Best before", "Sell by", "Use by" and other dating nomenclature that indicate the premium quality period are treated as dates when the food should be thrown away. These misconceptions cause substantial food waste, either at the retailer (food items with "short" dates are rejected) and at home. Food waste could probably be reduced with better information on the packaging that explains the dating system, if and when the food item could be unhealthy, and how the consumer could judge the quality of the food item. The introduction of smart labels or 'intelligent indicators' that indicate when the food item is safe/of high quality is also a possibility (Mahalik and Nambiar, 2010). Other information channels other than packaging can also be used, but the packaging has the advantage to provide specific information on the particular item just when it's needed. Consumers are interested in packaging that gives clear messages about how to store, 'freezeability' and 'use by' and 'best before'. Better communication about the packaging functions that influences food waste can help consumers waste less. However, consumers are not using the information that is already on the packaging about how to increase shelf life and are generally not aware of packaging functions (such as reclosable, materials and atmosphere combinations) that increase shelf life (Plumb et al., 2013). How this information should be provided is an important issue to explore.

The packaging should *facilitate sorting of household waste*, so that the packaging components can be easy to clean, separate into different fractions and/or fold when necessary (Langley et al., 2011). This is essential in the design stage of the packaging to make sure that if it is designed for mechanical recycling that the materials and components are compatible in the recycling system and that the design is such that is supports the consumer in this. The packaging can also provide *information* of how this should be done with the use of diagrams, logos or text.

This list is by no means complete; however, it demonstrates that there are many packaging attributes that influence consumer behaviour and food waste. In the "move towards sustainable food packaging, the relational complexity between the role of packaging and reduced food waste needs to be included beyond just extending shelf life to consider user behaviour" (Verghese et al., 2012a, p 402).

2.3. Data for case studies

Two food items, rice and yoghurt, and a number of different packaging types are used to illustrate the possible outcome of the attributes "*contains the correct quantity*" and "*easy to dose*". The food items are chosen because of the variation in GWP per kg, and their documented high wastages. Jean-Babtise et al.'s (2011) analysis of kitchen food waste diaries identified cooked rice as a common food prone to waste. In the UK, 57,800 tonnes of cooked rice is wasted (Ventour, 2008). Consumption of uncooked rice is 5.6 kg/capita (Schenker, 2012), with a population of 61 million in 2007 this equates to 12% of rice being wasted in the UK. The Australian state of New South Wales (NSW) *Love Food Hate Waste* survey indicated that a third of recipients found it hard to estimate how much rice to cook per person (DECCW, 2009, p.2).

Ventour (2008) showed that 67,300 tonnes of avoidable yoghurt and yoghurt drinks was wasted in all types of packaging types. With the consumption of yoghurt products from Nov 2012 of 574,720 tonnes (DairyCo, 2012) this results in 12% wastage. However in the study by Ventour, yoghurt products poured out into the sink was not included. Yoghurt is mainly wasted due to past 'best before date', which indicates that consumers are buying too much

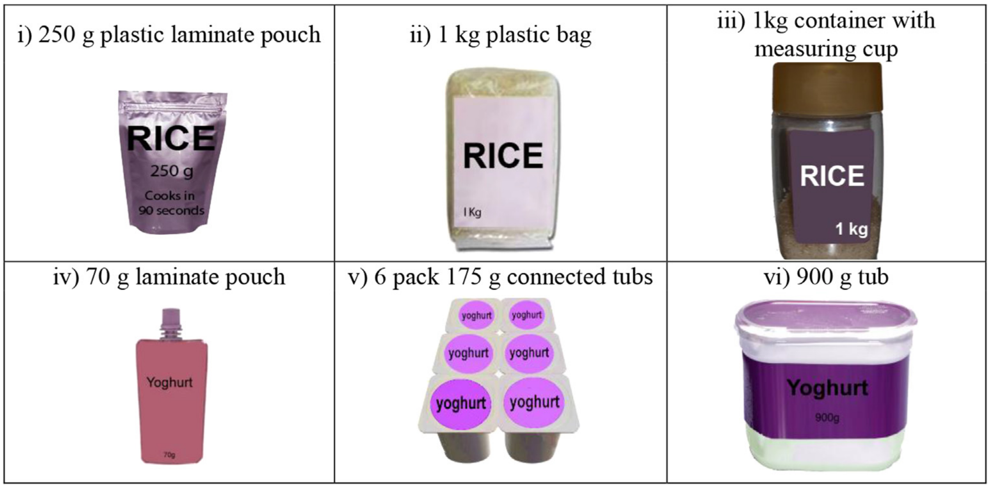

Fig. 2. The different packaging types used in the calculations. i) a 250 g pre-cooked rice packaging in a plastic laminate flexible pouch, ii) a bulk purchase 1 kg plastic bag, iii) 1 kg container with measuring cup, iv) a 70 g yoghurt in laminate pouch, v) 6 pack 175 g connected tubs of yogurts and vi) a 900 g yoghurt in a polypropylene tub.

(Ventour, 2008). This could have to do with too large packaging and consumers not finishing the product in time. Once opened, the large yogurt tub needs be consumed in a timeframe that is not always met, whereas the individual packets are generally consumed in one serve.

Six packaging formats were included in the case study to illustrate impacts of different sizes and design, see Fig. 2. First, the GWP of the six packaging formats were analysed for the packaging itself, as in a traditional packaging LCA. Calculations were made for 100% material recycling and 100% incineration. Second, the GWP per unit

Table 2
Data from other sources. CO_2e per 100 yr (IPCC, 2007). Food data from field to fork.

	kg CO_2e/kg	Source
Pack mtr LDPE, extruded	2.6	Ecoinvent 2.2 database (2012) CO_2e/100 yr (IPCC, 2007)
Pack mtr PP, injection moulded	3.3	Ecoinvent 2.2 database (2012) CO_2e/100 yr (IPCC, 2007)
Pack mtr PET, blow moulded	3.54	Ecoinvent 2.2 database (2012) CO_2e/100 yr (IPCC, 2007)
Pack mtr GPPS, thermoformed	4.19	Ecoinvent 2.2 database (2012) CO_2e/100 yr (IPCC, 2007)
Pack mtr PE + Alu	4.82	Ecoinvent 2.2 database (2012) CO_2e/100 yr (IPCC, 2007)[a]
Pack mtr Aluminum	12.5	Ecoinvent 2.2 database (2012) CO_2e/100 yr (IPCC, 2007)
Recycling LDPE	−1.8	Ecoinvent database (2012) CO_2e/100 yr (IPCC, 2007)[b]
Recycling PP	−1.7	Ecoinvent database (2012) CO_2e/100 yr (IPCC, 2007)[b]
Recycling PET	−2.4	Ecoinvent database (2012) CO_2e/100 yr (IPCC, 2007)[b]
Recycling Aluminium	−11.7	Ecoinvent database (2012) CO_2e/100 yr (IPCC, 2007)
Recycling PE + Alu	−4.1	Ecoinvent database (2012) CO_2e/100 yr (IPCC, 2007)[c]
Recycling GPPS	−3.23	Ecoinvent database (2012) CO_2e/100 yr (IPCC, 2007)[b]
Incineration, 100% dry LDPE	2.99	Ecoinvent database (2012) CO_2e/100 yr (IPCC, 2007)[d]
Incineration, 100% dry PP,	3.01	Ecoinvent database (2012) CO_2e/100 yr (IPCC, 2007)[d]
Incineration, 100% dry PET	2.03	Ecoinvent database (2012) CO_2e/100 yr (IPCC, 2007)[d]
Incineration, 100% dry PS	3.16	Ecoinvent database (2012) CO_2e/100 yr (IPCC, 2007)[d]
Incineration, 100% dry Al	0.019	Ecoinvent database (2012) CO_2e/100 yr (IPCC, 2007)[d]
Incineration PE + Alu, energy rec.	1.19	Ecoinvent 2.2 database (2012) CO_2e/100 yr (IPCC, 2007)[a,d]
Rice (*F*)	6.4	Carlsson-Kanyama (1998)
Youghurt (*F*)	1.2	Lindenthal et al. (2010)
Food compost (*W*)	0.2	US EPA (2006) (recalculated)

[a] Rule of mixtures based on a mixture of 23% aluminium, 77% PE by weight. Split taken from film thicknesses for commercially available multi-layered packaging.
[b] Avoidance credits given.
[c] Recycling may not be technically feasible. Rule of mixture as in.[a]
[d] No energy credits given.

Table 3
Measured and assumed data. Rice case. 250 g precooked rice equal to about 180 g uncooked rice, intended for two persons.

Packaging type	Pouch	Packet	Container
Packaging material weight	8 g LDPE	10 g LDPE	34 g PP 87 g PET
Amount rice in package (*B*)	180 g	1000 g	1000 g

Table 4
Measured and assumed data. Yoghurt case. The flaps of the connected tubs are well below 1 g and are neglected in the calculations.

Packaging type	Pouches	Connected tubs	Tub
Packaging material weight	2 g PE + Al 4 g PP	6 × 7 g PS	35 g PP 2 g Alu
Amount yoghurt in package (*B*)	70 g	1050 g	900 g

eaten food were analysed for three food waste levels (5, 12 and 20%), and two packaging waste scenarios (100% material recycling or 100% incineration without energy credits). Food waste was assumed to be composted in an industrial setting. This can represent end-of-life waste management in Europe for example.

The data used for food production, packaging materials and waste handling are given in Table 2. Data for the six packaging formats are given in Tables 3 and 4.

3. Results

A comparison of the global warming potential (GWP) of different packaging formats for rice and yoghurt are presented in Fig. 3. The results were calculated per unit of purchased food, and do not include the GWP of the food item itself This kind of result is representative of traditional packaging system LCA's. As can be expected, packaging with low material weight per unit of food seems to be the best alternative, i.e., the rice packet and yoghurt tubs. The large yoghurt tub has about the same weight per unit food as the small tubs, but is made with polypropylene that has a higher impact (when recycling is included) than the polystyrene used in the small tubs.

The importance of the food waste levels in the results is obvious when the packaging system and food waste is included in the analysis. Figs. 4 and 5 shows the GWP per unit of eaten food. The absolute levels of GWP are much higher when food is included. Generally, food waste levels are of much higher importance than the packaging itself with respect to the environmental outcome. When rice packages are recycled, there are hardly any differences between the packaging formats for a certain rice waste level. The performance of the packaging to assist to reduce rice waste turns out to be the most important factor. If the use of rice pouches or the rice containers included measuring cup assist to reduce rice waste levels in comparison to the rice packet, it may be better to invest in these alternatives despite their higher climate impact from the packaging system. However, if packaging materials are incinerated without energy credits, the reduction of rice waste must be high to motivate the use of the rice container.

The waste level of yoghurt is less important for the outcome than in the rice case scenario. This is due to the higher GWP in the production of rice than in yoghurt. When all packaging materials are recycled, the waste level of yoghurt determines the best alternative, like in the rice cases. However, when packaging materials are incinerated without energy credits, it becomes hard to motivate the use of yoghurt pouches from a climate perspective. This is especially valid if pouches are incinerated and some fraction of the tubs material are recycled, a likely alternative in many countries that recycles packaging.

4. Discussion

To summarize the last sections, we can conclude that:

- the inclusion of food waste substantially changes the outcomes of the GWP for different packaging formats
- a reduction of food waste may often motivate a packaging format with higher climate impact

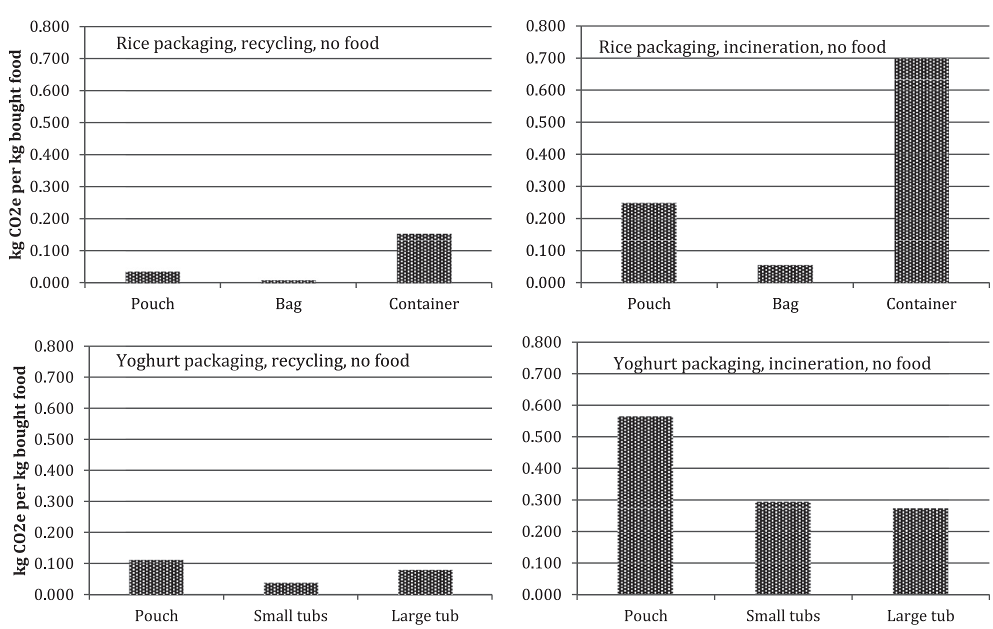

Fig. 3. The GWP of each packaging per kg purchased food (($P + W_P$)/B). Packaging material recycling better alternative:(left) or incinerated (right) is included, no food waste is assumed. The GWP of the food itself is not included; the figure shows the relative GWP of the packaging itself. Packaging materials with lowest weight and low-impact materials have the lowest environmental impact.

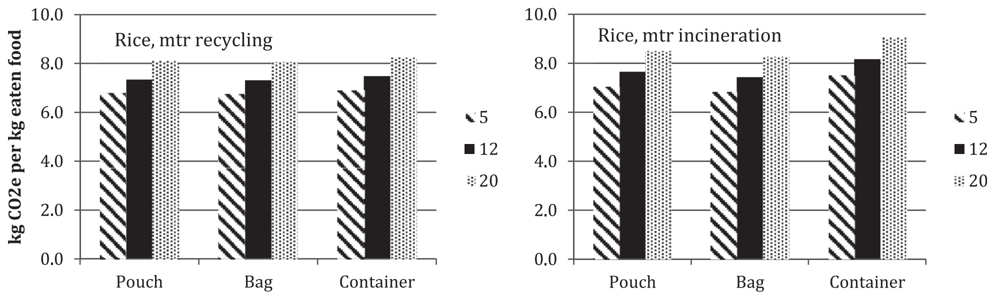

Fig. 4. The GWP per unit of eaten food (rice) according to Eq. 4, for three food waste levels, 5, 12 and 20% of purchased food. GWP of food production and waste handling of food and packaging are included. Packaging materials are assumed to be recycled (left) or incinerated (right) and food waste is composted. Generally, the food waste level is of higher importance for the environmental outcome than the packaging itself. The difference is marginal between different packages in the recycling scenario, but about 0.4 kg CO_2e between food waste levels for each packaging type. This means, for example, that if the measuring function of the rice container reduce the waste level to 5%, and the use the rice bag results in 12% waste, the container is the best choice despite the higher impact of the packaging itself (see Fig. 3).

- the higher degree of packaging material recycling, the more important to consider food waste
- the impact of food waste levels are strong for food products with high production GWP (rice, meat etc.)

For food items with very high GWP impact, like red meat (25.5 kg CO_2-eq/kg bone free meat (Eady et al., 2011)) almost any packaging measure that can reduce meat waste would be worthwhile from a climate perspective, regardless of the waste treatment systems. For food items with lower GWP, the relative importance of packaging and packaging waste treatments is higher, and it is more important to include realistic packaging waste treatment data. The calculations can also be done for different scenarios with landfill, biogas production, incineration etc.

For food products with high waste levels, the non-linear relationship between food waste levels and environmental impact (Eq. 2) indicate that the reduction of food waste levels may be very important also for low GWP food products. The waste levels used in the scenarios above are conservative in many cases. Waste levels of rice up to 40% are reported (Today Newspaper, 2013) indicating that the waste scenarios utilised for rice waste may be conservative. Also, 12% yoghurt waste is likely to be conservative since no yoghurt poured into the sink was included in the references above. High waste levels are also reported for bread, vegetables and fruits (Gustavsson et al., 2011). This indicates that the inclusion of food waste would most likely transform the results of many existing LCA studies where waste is excluded.

Anecdotal evidence from the authors own studies indicate that bulk packaging may have higher waste figures than small ones. In a small personal study, yoghurt waste was measured at an average of 7% after consumption by the authors' children. The single serve rice pouch also had low wastage levels. Generally, each food-packaging system must be judged in its own context, ideally with empirical evidence exploring the link between packaging types to waste levels.

It is beyond any doubt that one of the most important environmental issues for packaging development is to reduce food waste, from field to fork. The next question is how this can be accomplished. This paper illustrates a first step. Packaging attributes such as "*contains the correct quantity*" and "*easy to dose*" can be analysed for different packaging formats using a simple scenario technique. Data for food production, packaging materials and end-of-life treatments are fairly easy to find in the public domain.

The difficult part is to understand and estimate the relationship between packaging attributes and food waste for different food items and packaging formats. This is an important field for future research. By understanding the consumer preferences and behaviour, the services that are provided from a specific packaging attribute can be designed to better meet the consumer needs and facilitate consumers to waste less food. The packaging attributes that influence food waste elaborated in Section 2.2 provide a guide for packaging designers to assist them in designing packaging to facilitate reduced food waste by the consumer. Simple improvements should not be neglected, for example better communication on different serving sizes. The portion size differs obviously

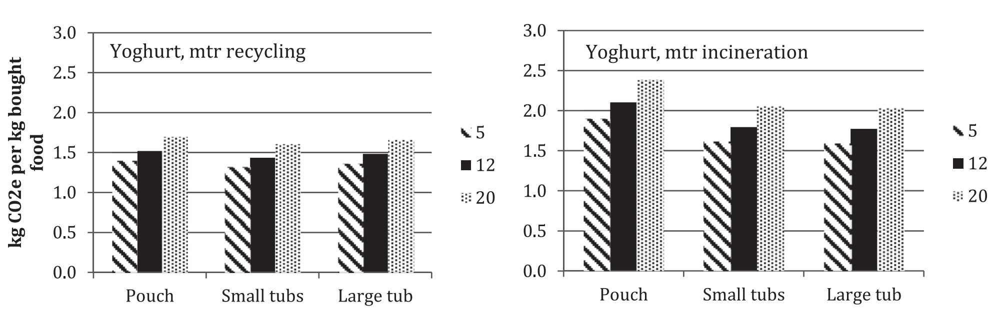

Fig. 5. The GWP per unit of eaten food (yoghurt) according to Eq. 4, for three food waste levels, 5, 12 and 20% of purchased food. GWP of food production and waste handling of food and packaging are included. Packaging materials are assumed to be recycled (left) or incinerated (right) and food waste is composted. The same pattern as in Fig. 4, but the environmental impact of the packagings is more important relative the food waste in this case. This is because the production of rice causes higher emissions of greenhouse gases than the production of yoghurt. The use of yoghurt pouches can hardly be motivated unless the yoghurt waste levels are strongly reduced compared to the packaging alternatives, especially if the pouches are incinerated and the tubs recycled. In the incineration scenario, pouches only turns out to be the best alternative if they generate 5% yoghurt waste and the other two packaging generate 20%. There are small differences between the small yoghurt tubs and the large tub, the one that generate least yoghurt waste is the best alternative.

between a teenager boy and an elderly person. It is noteworthy that the instructions of the amount of rice to cook in three different brands sold in Australia were 60 g, 70 g and 100 g, respectively.

A recent stakeholder engagement forum in Australia with food brand owners identified that they rarely complete user trials on how packaging is actually used in the home (Verghese et al., 2012b). To test the success of alternate packaging scenarios requires 'additional fieldwork and empirical research outside the traditional boundaries of LCA' (Verghese et al., 2012a, p. 403). The newly published study by Plumb et al. (2013) included some new methods of worth e.g., accompanying consumers in home and at shopping.

At present, simple scenario analysis and reasonable assumptions on waste levels for different packaging types in intended user situations are a starting point, for example considering an elderly person, or single-person households may be useful in the packaging development process. This analysis itself may raise important questions and observations.

Also, we want to emphasise that packaging design to reduce food waste should not always have to result in an increase in the environmental impact of packaging in isolation. Traditional packaging design solutions such as light-weighting and material selection could apply as well, for example to reduce material intensity of the yoghurt tub in this case. Consideration of regional waste treatments is also important.

This study has focused on the inclusion of consumer food waste in LCA studies. The same methodology could be expanded to include food waste in distribution and retail. In order to develop packaging systems that reduces the environmental impact, the primary packaging needs to be developed in conjunction with its secondary and tertiary packaging. Changes in primary packaging will effect what is needed for protection of food in secondary packaging and vice versa. For example, introduction of shelf ready packaging (SRP) may have positive effects on food waste due to more efficient product rotation and support a more efficient stock accountability (Jackson, 2012). However, the secondary packaging of perforated shippers, which allows for easy opening, reduces the box strength and may be damaged during handling processes in storage and transport, thus increasing food waste.

5. Conclusion

The results of this paper show the importance of including food waste in LCAs of packaging systems. Scenarios that explore the potential of packaging systems to reduce the overall environmental impact via reducing food waste are desirable. Generating a standardized method to estimate food waste is challenging, however the results indicate that the inclusion of food waste in LCA packaging studies dramatically alters the results. The connection between packaging design and food waste must be acknowledged and valued by all involved stakeholders, including food producers, manufacturers, brand owners, retailers and consumers, and also in packaging regulations.

This paper illustrates a first step, in simple scenario analysis that may explore how the outcome of different packaging attributes may influence the reduction or prevention of food waste. The change of the functional unit to "eaten food" rather than "delivered food" or "bought food" is a key for progress. For the future, there is an urgent need for empirical studies to explore how packaging attributes affect food waste in different circumstances.

Acknowledgements

The authors are grateful to Dr. Enda Crossin and Simon Lockrey for assisting with data. Financial support for this research study was partly provided by Gunnar Sundblad Research Foundation, the European Regional Development Fund and Region Värmland.

References

APCC, 2010. Australian Packaging Covenant – a Commitment by Governments and Industry to the Sustainable Design, Use and Recovery of Packaging. Australian Packaging Covenant Council. Amended 10 October 2011.

Audsley, E., Brander, M., Chatterton, J., Murphy-Bokern, D., Webster, C., Williams, A., 2009. How Low Can We Go? an Assessment of Greenhouse Gas Emissions from the UK Food System and the Scope to Reduce Them by 2050. FCRN-WWF-UK.

Baker, D., Fear, J., Denniss, R., 2009. What a Waste: an Analysis of Household Expenditure on Food. Policy Brief No. 6. The Australia Institute, Canberra.

Barry, F., 2012. Making your packaging more user-friendly – from first idea to finished packaging. In: Presentation to Innopack: Lean Packaging Development Harnessing Packaging Innovations and Improvements to Drive Sustainability, Customer Sales and Cost-Optimisation, Thursday 15th November 2012. Melbourne Convention Exhibition Centre, Melbourne, Australia.

Carlsson-Kanyama, A., 1998. Climate change and dietary choices—how can emissions of green-house gases from food consumption be reduced? Food Policy 23 (3/4), 277–293.

DairyCo, 2012. Market Information. Retrieved 6/03/2013, from: http://www.dairyco.org.uk/market-information/dairy-sales-consumption/yogurt-market/yogurt-market/.

DECCW, 2009. Food Waste Avoidance Benchmark Study 2009. Retrieved 27 March 2013 from: http://www.lovefoodhatewaste.nsw.gov.au/portals/0/docs/11339FWABenchmarkstudy.pdf.

Dee, J., 2012. Food Waste: an Overview. Retrieved 6/03/2013, from: http://foodwise.com.au/food-waste/food-waste-an-overview/.

Dey, C., Berger, C., Foran, B., Foran, M., Joske, R., Lenzen, M., Wood, R., 2007. Household Environmental Pressure from Consumption: an Australian Environmental Atlas. Water, Wind, Art and Debate: How Environmental Concerns Impact on Disciplinary Research G. Birch. Sydney University Press, Sydney.

Dorward, L.J., 2012. Where are the best opportunities for reducing greenhouse gas emissions in the food system (including the food chain)? A comment. Food Policy 37 (4), 463–466.

Duizer, L.M., Robertson, T., Han, J., 2009. Requirements for packaging from an ageing consumer's perspective. Packag. Technol. Sci. 22 (4), 187–197.

Eady, S.J., Sanguansri, P., Bektash, R., Ridoutt, B., Simons, L., Swiergon, P., 2011. Carbon foot-print for Australian agricultural products and downstream food products in the supermarket. In: ALCAS Conference. ALCAS, Melbourne.

Edvardsson, B., Gustafsson, A., Roos, I., 2005. Service portraits in service research – a critical review. Int. J. Serv. Ind. Manage. 16 (1), 107–121.

Engström, R., Carlsson-Kanyama, A., 2004. Food losses in food service institutions: examples from Sweden. Food Policy 29 (3), 203–294.

European Commission. COM, 2006. Report from the Commission to the Council and the European Parliament on the Implementation of Directive 94/62/EC on Packaging and Packaging Waste and Its Impact on the Environment, as Well as the Functioning of the Internal Market.

Ecoinvent, 2012. Ecoinvent Database v2.2. Swiss Centre for Life Cycle Inventories, Hamburg.

European Council, 1994. Directive 94/62/EC on packaging and packaging waste. Off. J. Eur. Union L365, 0010–0023, 31/12/1994.

Gunders, D., 2012. Wasted: How America Is Losing up to 40 Percent of Its Food from Farm to Fork to Landfill. Natural Resources Defense Council, New York.

Gustavsson, J., Cederberg, C., Sonesson, U., 2011. Global Food Losses and Food Waste: Extent, Causes and Prevention. Report by the Swedish Institute for Food and Biotechnology for the Food and Agriculture Organization of the United Nations: Rome.

Hanssen, O.J., 1998. Environmental impacts of product systems in a life cycle perspective: a survey of five product types based on life cycle assessments studies. J. Clean. Prod. 6, 299–311.

Hellström, D., Saghir, M., 2007. Packaging and logistics interactions in retail supply chains. Packag. Technol. Sci. 20 (3), 197–216.

IPCC (Intergovernmental Panel on Climate Change), 2007. Climate Change 2007: the Physical Science Basis. Cambridge University Press, Cambridge, UK.

Jackson, C., 2012. Retail-ready Packaging Set to be the Norm. foodprocessing.com.au. Retrieved (2013-11-15) from http://www.foodprocessing.com.au/articles/53885-Retail-ready-packaging-set-to-be-the-norm.

Jean-Babtise, N., Michener, L., Wilson, R., 2011. Using a Food Waste Diary to Impact Food Waste Reduction in Sydney's Eastern Suburbs Waste – the Social Context. The Edmonton Waste Management Centre of Excellence EWMCE.

Jelsma, J., 2006. In: Verbeek, P.-P., Slob, A. (Eds.), Designing 'moralized' Products. User Behavior and Technology Development. Springer, Netherlands, pp. 221–231.

Kader, A.A., 2005. Increasing food availability by reducing postharvest losses of fresh produce. In: 5th Int. Postharvest Symposium. Retrieved 26 March 2013 from: http://ucce.ucdavis.edu/files/datastore/234-528.pdf.

Katajajuuri, J.-M., Silvennoinen, K., Hartikainen, H., Jalkanen, L., Koivupuro, H.-K., Reinikainen, A., 2012. In: Food Waste in the Food Chain and Related Climate Impacts, in LCA FOOD, St Malo.

Langley, B.J., Turner, N., Yoxall, A., 2011. Attributes of packaging and influences on waste. Packag. Technol. Sci. 24 (February), 161–175.
Lindenthal, T., Markut, T., Hörtenhuber, S., Rudolph, G., 2010. Greenhouse gas emissions of organic and conventional foodstuffs in Austria. In: Proceedings of the 7th International Conference on LCA in the Agri-food Sector, Bari, Italy, 22–24 September.
Löfgren, M., 2006. The Leader of the Pack. Faculty of Economic Sciences, Communication and IT. Karlstad, Karlstad University, ISBN 91-7063-089-5.
Mena, C., Adenso-Diaz, B., Yurt, O., 2011. The causes of food waste in the supplier–retailer interface: evidences from the UK and Spain. Resour. Conserv. Recycl. 55 (6), 648–658. http://dx.doi.org/10.1016/j.resconrec.2010.09.006.
Mahalik, N.P., Nambiar, A.N., 2010. Trends in food packaging and manufacturing systems and technology. Trends Food Sci. Technol. 21 (3), 117–128.
Parfitt, J., Barthel, M., Macnaughton, S., 2010. Food waste within food supply chains: quantification and potential for change to 2050. Phil. Trans. R. Soc. London. Ser. B, Biol. Sciences 365 (1554), 3065–3081.
Plumb, A., Downing, P., Parry, A., 2013. Consumer Attitudes to Food Waste and Food Packaging. ICARO Consulting and Wrap Report.
Quested, T., Johnson, H., 2009. Household Food and Drink Waste in the UK. WRAP, Banbury UK, ISBN 1-84405-430-6.
SRA (Sustainable Restaurant Association), 2010. To Good to Waste (2013-01-25) http://www.thesra.org.
Svanes, E., Vold, M., Moller, H., Kvalvåg Pettersen, M., Larsen, H., Hanssen, O.J., 2010. Sustainable packaging design: a holistic methodology for packaging design. Packag. Technol. Sci.. http://dx.doi.org/10.1002/pts.887.
Schenker, S., 2012. An overview of the role of rice in the UK diet. Nutr. Bull. 37 (4), 309–323.
Today Newspaper, 2013. Opinion: Wasteful POSTED: 01/24/13 10:27 AM. Retrieved 27 March 2013 from: http://www.todaysxm.com/2013/01/24/opinion-wasteful/.
Vargo, S.L., Lusch, R.F., 2004. Evolving to a new dominant logic for marketing. J. Market. 68 (1), 1–17.
Ventour, L., 2008. The Food We Waste. WRAP, Banbury UK, ISBN 1-84405-383-0.
Verghese, K., Horne, R., Carre, A., 2010. PIQET: the design and development of an online 'streamlined' LCA tool for sustainable packaging design decision support. Int. J. Life Cycle Assess. 15 (6), 608–620.
Verghese, K., Lewis, H., Clune, S., Lockrey, S., Crittenden, P., 2011. AFGC Future of Packaging Background Paper. RMIT University, Helen Lewis Research, and Sustainable Business, Melbourne.
Verghese, K., Lockrey, S., Clune, S., Sivaraman, D., 2012a. In: Yam, K.L. (Ed.), Life Cycle Assessment of Food and Beverage Packaging. Innovative and Sustainable Food and Beverage Packaging. Woodhead, Cambridge.
Verghese, K., Clune, S., Lockrey, S., Lewis, H., Crittenden, P., 2012b. Future of Packaging White Paper; Executive Summary (April). Australian Food and Grocery Council (AFGC), Canberra, Australia.
Verghese, K., Lewis, H., Lockrey, S., Williams, H., 2013. The Role of Packaging in Minimising Food Waste across the Supply Chain of the Future. Draft report for CHEP Australia. RMIT University, Melbourne, March.
Wikström, F., Williams, H., 2010. Potential environmental gains from reducing food losses through development of new packaging – a life-cycle model. Packag. Technol. Sci. 23 (7), 403–411. http://dx.doi.org/10.1002/pts.906.
Williams, H., Wikström, F., Löfgren, M., 2008. A life-cycle perspective on environmental effects of customer focused packaging development. J. Clean. Prod. 16, 853–859.
Williams, H., Wikström, F., 2011. Environmental impact of packaging and food losses in a life cycle perspective: a comparative analysis of five food items. J. Clean. Prod. 19, 43–48.
Williams, H., Wikström, F., Otterbring, T., Löfgren, M., Gustafsson, A., 2012. Reasons for household food waste with special attention to packaging. J. Clean. Prod. 24, 141–148.
White, A., Gallegos, D., Hundloe, T., 2011. The impact of fresh produce specifications on the Australian food and nutrition: a case study of the north Queensland banana industry. Public Health Nutr. 14 (8), 1489–1495.
WRAP, 2009. Household Food and Drink Waste in the UK. Final Report. H. J. Tom Quested. Waste & Resources Action Programme, Oxon.