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The influence of packaging attributes on recycling and food waste behaviour – an environmental comparison of two packaging alternatives

Abstract

This paper analyses how user behaviour influences the environmental comparison of two different packages for minced meat - a lightweight tube and a tray. The direct and indirect environmental effects are evaluated using simplified LCA. A number of packaging attributes with regard to food waste and recycling behaviour are analysed for the packages, and then used for the scenario calculations. The results show that the tube is the superior environmental alternative when only the direct effects are considered. When indirect effects and user behaviour are included in the comparison, the tray is the better alternative due to higher recycling rates and, most importantly, less food waste during the process of emptying. However, the environmental impacts due to the food waste in the tube may be compensated for, if the longer shelf-life of the tube results in lower wastage in the households. It is concluded that indirect environmental effects and user behaviour should be included in environmental assessments of packaging to obtain meaningful results.

Keywords

Packaging LCA, food waste, indirect environmental effects, user behaviour

Highlights

- Packaging attributes influence recycling rates and food waste.
- Including indirect environmental effects and user behaviour may drastically change packaging LCA comparisons.

1. Introduction

This paper analyses both the direct environmental impact and the indirect one which is dependent on the behaviour of consumers in households, for two different types of packaging for minced meat. The behaviour analysis includes the recycling or otherwise of the packaging, and also the amount of food waste occurring due to the packaging attributes. The aim is to demonstrate the importance of consumer behaviour and packaging attributes on packaging life-cycle assessment (LCA).

The user behaviour may have a profound influence on the outcome of an LCA of a product supply chain (Polizzi di Sorrentino et al. 2016). Several studies show that measures undertaken to reduce the indirect impacts are often, by far, more important than those undertaken to reduce the direct ones (e.g. Silvenius et al. 2013, Williams and Wikström 2011, Wikström et al. 2014, Humbert et al. 2009, Büsser and Jungbluth 2009). However, the environmental concerns about packaging which dominate legislative regulations are still mostly the *direct* environmental impacts - the production of packaging materials and

end-of-life treatment (e.g. The European Council Directive 94/62/EC). These direct environmental impacts which also dominate consumer perceptions about packaging (Plumb et al. 2013) can be addressed not only by minimizing the packaging material impact (e.g. removal of excessive packaging, smarter product packaging, light-weighting, concentration of liquid products, refill packaging (Mariesse et al. 2013), but also by developing the necessary recycling infrastructure.

However, measures to decrease the direct environmental impact without considering indirect effects may strain the gnat but swallow the camel, to use a Biblical allusion, or in the worst case, result in an increase in the indirect environmental impacts, by increasing food waste, for example. Therefore, more attention should be directed to the indirect environmental impacts of packaging, which are related to user behaviour. In packaging LCA, it is particularly important to consider how consumer behaviour is influenced by packaging attributes. About one-third of the food waste is generated in European households, and this does not include the food wasted upstream at retailer-sites or in food-processing units due to low consumer tolerance for imperfections, etc (Fusion 2014, LEI 2013). Moreover, packaging attributes influence how consumers participate in recycling (Langley et al. 2011). While user behaviour is indisputably important in packaging LCA, modelling its relationship with packaging attributes is challenging, as it is affected by several factors.

A strong driver for user behaviour is the set of prevailing attitudes and social norms. (Polizzi de Sorrentiono et al. 2016). The individual attitude towards environmental responsibility and the social norms about wasting food and participating in recycling, are probably more important than packaging attributes. The infrastructure to recycle packaging: storing facilities at home, distance to recycling facilities, etc., also influence behaviour (e.g. Martin et al. 2009, Perrin and Barton 2001). Households that experience economic stress may not invest in time to recycle (Martin et al. 2009) and in households where food is a minor part of expenses; food waste may be a relatively smaller issue. Hage et al. (2009) observed that the importance of effect of attitudes on user behaviour decreased when the recycling systems were improved; thus underlining the interdependence among different factors. The degree of complexity is also valid when one attempts to understand why consumers waste food (Aschemann-Witzel et al. 2015).

In this backdrop it can be understood and agreed that the correlation between packaging attributes and behaviour is difficult to determine, quantitatively. A first step is to identify packaging attributes that may influence behaviour and indirect environmental impacts (Williams et al. 2008, Lindh et al. 2016). A second step is to calculate the potential influence of packaging attributes on indirect environmental impacts vis-à-vis the direct ones - for instance, smaller packaging size versus less food waste (e.g. Silvenius et al. 2013, Wikström et al. 2014). The degree of importance of packaging attributes varies depending on the environmental impact of the contents, the packaging itself, the levels of food waste and the degree of recycling (Williams and Wikström 2011). Therefore, it is important to perform calculations for individual products, and avoid generalisations. Thirdly, the influence of packaging attributes on behaviour can be explored in consumer studies, providing data that can be used to model scenarios in packaging LCA.

In this paper, we have used information from published consumer studies to examine the influence of packaging attributes on food waste and recycling behaviour for two different

types of packaging for minced meat - tube and tray. They are both made of plastics. Light-weighting is one alternative for packaging developers to reduce the direct environmental impact, demonstrated by the tube studied in this paper. However, as will be shown, it is important to study the effect of changes in packaging attributes very closely to avoid unexpected negative environmental impacts.

2. Method

2.1 Packaging attributes influence behaviour

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 that provide pre-requisites for a service to occur and be experienced. The product attributes can script consumer behaviour (Jelsma, 2006). The consumer interaction with the product depends on the design of the product, consumer preferences and experience, and the context of the consumer (Löfgren 2005). This means that to design a package that helps the consumer to reduce food waste and duly recycle the packaging, it is necessary to get insights into how consumers think and act, and the context of the situation in which the decision to recycle or not, is made. Some circumstances that may hinder recycling behaviour are longer distances between households and sorting bins, packaging attributes and stress (Langley et al. 2011). All these factors which are perceived as obstacles to recycle, will lower the tolerance to invest in time to clean, separate and sort packaging.

Based on literature studies, the following attributes concerning food waste and recycling behaviour are examined in this paper:

Easy to empty. If there is food left inside the packaging, it will take more time to clean it and this may be perceived as disgusting. In studies that examine waste bins, often, there is food left in the packaging (Juul, 2012; Langley et al. 2011, Plumb et al. 2013). This attribute influences packaging waste handling and the amount of food wasted.

Easy to clean. Even if the package is properly emptied, some combinations of food and packaging will leave food residues on the surface of the package. Again, experience of time stress and disgust can result in the packaging being consigned to the waste bin (Langley et al. 2011).

Easy to separate into different fractions. Can also be experienced as too time-consuming and there can be uncertainties regarding how to separate (Henriksson et al. 2009).

Easy to fold. Space for sorting bins in households are normally limited, hence the space occupied for the recycled package is important (Martin et al. 2006).

Information on how to sort. Uncertainty regarding the type of material or how different materials should be separated is a common reason behind packaging materials ending up in the waste bin (Henriksson et al. 2009). Lack of knowledge about how clean the packaging must be in order to be recycled is also an obstacle. Generally, it seems that consumers do not invest time to scan the packaging for instructions (Langley et al. 2011). This may be due to confusion regarding the different symbols used, instructions that are

difficult to find or read, unclear instructions or rules of thumb. It can also be so that everyday sorting is habitual (Henriksson et al. 2009) and users are reluctant to spend a little time to look up the information carefully. How perceptible the information on the packaging is, plays a key role here; the use of smaller-size fonts at the bottom will not attract attention.

The attribute *preserve content* (in this case the time period between than packaging date and the expiration date) can have a strong influence on food waste, if food is discarded on or after the expiry date. (Lindh et al. 2016, Plumb et al. 2013).

Mass: Langley et al (2011) reported that the perceived value of the packaging influenced waste handling. The perceived value depended on the packaging material (glass had a higher value vis-à-vis plastics), mass (the more the material, greater the value) or packaging functions like resealability. However, it is difficult to determine if the low perceived value of plastics in the study mainly depends on material type or that plastic packagings have lower masses. In our study, we use this attribute, assuming that higher the mass of the packaging, greater is the likelihood that it is recycled.

Containing the desired quantity: The amounts of minced meat in the two packages compared in this paper, are equal. Therefore, this attribute is not included in the analysis. However, this is often very important when an analysis of food waste is carried out (Lindh et al, 2016).

The authors of this paper have discussed, judged and motivated the qualities of these attributes, for the two types of packaging analysed. The influence of these attributes on behaviour and environmental impacts are discussed in relation to the model results.

2.2 Formulae

A model that takes into account consumer food waste and recycling behaviour in food-packaging LCA has been presented earlier (Wikström and Williams 2010; Wikström et al. 2014). The main difference between this model and most others, is that the functional unit in this one, is “eaten food” instead of “delivered food” and the environmental burden of production and waste handling of wasted food is included. A short summary of the model is presented hereunder.

The equation for the amount of eaten food e , is:

$$e = B - BL \quad (\text{Eqn 1})$$

B is the amount of purchased (*Bought*) food and L is the fraction *Lost* [0-1], which make BL the amount of purchased food that is wasted. (See also Table 1 for a description of the nomenclatures.)

If 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), then

$$E = BF + P + W_P + WBL \quad (\text{Eqn 2})$$

F is the environmental impact per kg (or litre) of the food item and includes agriculture, food processing, retail, 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 expressed in terms of ‘per package of the food item’. W is the environmental impact of waste handling per unit of lost food at the consumer’s. The last term in Eqn 3 is the handling of the food waste, often neglected in food-packaging LCAs. Nomenclature in Table 1.

Eqn 2 can be rearranged to express the specific environmental impact per eaten unit food:

$$E/e = (BF+P+W_p)/e + W(B-e)/e \quad (\text{Eqn 3})$$

if Eqn 1 is used to substitute L in Eqn 3. If the food loss $L=0$ ($B=e$), the last term in Eqn (3) disappears. This corresponds to the functional unit “delivered food”, used in many LCA studies.

The environmental impact (E) may be calculated for energy use, global warming potential (GWP), acidification potential, ozone depletion potential, eutrophication potential, etc. The main motivation of this paper is to demonstrate the importance of the inclusion of consumer behaviour vis-à-vis packaging attributes in a simplified packaging LCA; and not to carry out a detailed environmental analysis. While acknowledging this, the analyse is limited to carbon dioxide equivalents (100-yr, IPCC 2007), acidification potential and ozone depletion potential.

Table 1. Nomenclature

Symbol	Denotes	Unit
e	Eaten food	kg
E	Energy use or environmental impact	CO ₂ - equivalents (global warming) SO ₂ - equivalents (acidification) CFC-11 equivalents (ozone depletion)
B	Amount of purchased food	kg
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 of food to the consumer, with the exception of packaging.	CO ₂ - 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.	CO ₂ - equivalents, etc
W_p	Waste handling of the package.	CO ₂ - equivalents, etc
W	Energy use or environmental impact of waste handling per unit of the food lost in the consumer phase.	CO ₂ - equivalents, etc per unit of food

2.3 Scenarios

The environmental impacts of each packaging are analysed by taking recourse to the scenarios constructed. Firstly, the influence of consumer recycling behaviour is analysed. The packaging waste is either material-recycled or disposed to the waste bin. The contents of the waste bin are incinerated for energy recovery. Recycling and incineration are considered as the only two alternatives for end-of-life handling. Thereby, the sum of the percentages of material recycled and incinerated would equal 100%. This analysis includes only the packaging life-cycle, P and W_p .

Secondly, the influence of food wasted in the process of opening the packaging is added to the analysis according to equation 3. Wastage due to the attribute *preserve content* is not included in the calculations because of lack of data for realistic scenarios (also referred to in the Discussion section of the paper).

2.4 Data

2.4.1 Packaging data

Two types of packages have been analysed, a conventional plastic tray and a tube that recently has been launched in Sweden as a package for minced meat. Both packages include about 500 g of minced meat. The functional unit is set to 1 kg 'eaten minced meat'.

Figure 1. The packages

The components of the packaging – tray and tube were dismantled and weighed using a Vetek PS 1000.R.1 digital weighing machine (resolution of 0.001g). The masses determined thus, are tabulated in Table 2. The packages were carefully washed and dried before measuring.

Table 2: The masses of the components of the 500 g minced meat packaging. Material compositions have been provided by the manufacturers (personal communication) and masses have been determined by the authors.

Tray packaging			Tube packaging		
Component	Material	Weight (g)	Component	Material	Weight (g)
Tray	PET	18.2	Plastic sheet	Polyamide	3.3
Film	LDPE + PET	1.39 + 0.4	Clips	Aluminium	1.1
Plastic label	LDPE	0.66	Label	LDPE	1.45
Paper label	Paper	0.5	Minced meat	Food	500
Minced meat	Food	508			

2.4.2 Food waste data

No meat was left over inside the tray after it was emptied in one smooth action. The tube packaging was ripped open in the centre to get the meat out of it; and the mass of the meat sticking to the inside of the plastic was estimated as 10 g, by weighing the package before and after washing it. When a spoon was used to carefully remove meat particles from inside the opened packaging, the loss of meat was reduced to 5 g. When the tube package was ripped in the end and the content was squeezed out, the waste was of a similar magnitude.

2.4.3 Lifecycle data for food and packaging

GHG emissions for bone-free meat vary from 17-40 CO₂e/kg from cradle-to-farm-gate (Sonesson et al. 2010). The higher figures are from studies conducted after 2007, when the IPCC (Intergovernmental Panel for Climate Change) increased the global-warming-potential characterisation factors for methane and nitrous oxide (IPCC 2007). The variability between studies also depends on the allocation between milk and meat in the dairy farms. In this study, 30 CO₂e per kg meat has been used, as the global warming potential. The emission coefficients for acidification and ozone depletion were obtained from the Ecoinvent database, and are respectively 349g SO₂-eq per kg meat and 5 mg CFC-11 eq./ kg meat respectively. (Swiss Centre for Life Cycle Inventories, 2015) LCA data for the production of packaging P , waste handling of packaging W_P and food W (Table 3) were collected from datasets from SIMAPRO, tabulated in Appendix I. Data for the impacts related to the water consumed for cleaning the packaging (in the case of recycling the polyamide tube) were obtained from the dynamic metabolism model

EU-average data have been used in this analysis. In the case of incineration as an end-of-life handling step, the materials are assumed to be incinerated in a co-fired plant, where both the electricity and thermal production replace the respective average European mixes. While the upstream production/manufacturing and assembly operations, and the downstream waste handling processes – incineration and recycling – are considered in the analysis, intermediate transport from manufacturer/producer to wholesaler; from wholesaler to retailer; and from retailer to user; and likewise from the user to the waste-handling centres have not been considered. The impacts attributed to storage and refrigeration at the wholesalers', retailers' and end-users' have also not been factored in.

Table 3. Used and calculated values for food and packaging.

	GHG emissions in CO ₂ e	Acidification in SO ₂ e	Ozone depletion in CFC-11 e
F(Minced beef)	30 kg /kg food	349 g /kg food	5 mg /kg food

P(Tray)	99.28 g	0.44 g	9.69 µg
P(Tube)	44.65 g	0.167g	10.7 µg
W _p (Tray, recycling)	48.4 g	0.21 g	8.27 µg
W _p (Tray, incineration)	149 g	0.437 g	9.15 µg
W _p (Tube, recycling)	18.2 g	4.29 mg	3.06 µg
W _p (Tube, incineration)	57 g	0.17 g	4.03 µg
W (food waste, wastewater treatment plant)	1.98 g / g food waste	0.9 mg / g food waste	Negligible
W (food waste, incineration)	49 mg /g food waste	8.5 mg / g food waste	0.45 µg / g food waste

2.4.5 Data for cleaning packaging in households

If the polyamide plastic in the tube needs to be washed and dried to be made 'recycling-ready', water and eventually heat to warm the water is used. The heat energy used within households to wash the polyamide packaging before making it recycling-ready is assumed to a maximum of 2 litres of washwater heated from room temperature of 15°C to 50°C. If heated by electricity, emissions between 0.0165 kg CO₂e (Nordic electricity mix (210 kg CO₂e per MWh) and 0.05 kg CO₂e (coal power) is caused. The treatment of wastewater should be of marginal impact in this case and is not included in the analysis. In Venkatesh et al. (2014), the system-wide specific net GHG emissions per litre of water treated, supplied, collected and treated before discharge, is reported to be 0.0013 kilograms-CO₂e for the urban water system in Oslo, using the Nordic electricity mix. The corresponding figure for acidification was estimated to 0.9 mg SO₂e/ g food waste Venkatesh et al. (2014). **In Venkatesh et al (2014), the ozone depletion potential was considered to be negligible and thereby not considered in the analysis of the water cycle in Oslo.**

3. Results

3.1 Packaging attributes

The judgements of packaging attributes are shown in Table 4. The likely impact of these attributes can be summarized as:

- There will be no food waste after the tray is emptied of the minced meat. However, in the case of the tube, this is not the case. Some meat sticks to the inner surface of the tube and the two ends with the metal clip can be difficult to empty.
- Most probably the tube will end up with the unsorted waste fraction. It has low mass and is made of plastic (polymer); the value is considered to be low by most consumers. Most consumers will probably feel that it is necessary to clean it if it needs to be recycled for its material value, and sense that cleaning it is a bit difficult. The tray, on the other hand, is more likely to be material-recycled. In general however, many consumers are not really inclined towards handling meat packaging to make it amenable to recycling.
- The difficulty to separate plastics and aluminium clips will also decrease the probability for the material-recycling of the tube. The instructions clearly state that plastics and aluminium should be separated but it is difficult to do so without suitable tools; and it is also time-consuming.

Table 4. Packaging attributes that affect behaviour. The attributes evaluated are motivated in section 2.1. The results and motivations are based on the three authors evaluation of each attribute.

<i>Attribute</i>	<i>Minced meat- Tray</i>	<i>Minced meat – tub</i>
<i>Easy to empty</i>	Yes, no meat left on packaging surface.	No, some meat sticks to the plastic.
<i>Easy to clean</i>	Yes, just rinsing.	Very difficult due to packaging design. The meat may be looked upon as a bit disgusting to handle.
<i>Easy to separate into different fractions</i>	Not needed.	No. The metal clips can only be separated from the plastic by using a pair of scissors.
<i>Easy to fold</i>	No, takes some space.	Yes
<i>Information on how to sort</i>	Yes	Yes, but difficult to do, see “Easy to separate”.
<i>Preserve content</i>	9 days from packaging date to expiry date.	16 days from packaging date to expiry date.
<i>Mass</i>	Moderate to high.	Very low.

3.2 Life-cycle assessment

Figure 2 shows the climate impacts for the life-cycles of the two types of packages, depending on the rate of recycling and food waste.

The tube is the superior alternative when recycling rates are in the same magnitude and no food waste is included in the comparison. The difference decreases with higher recycling rates. The tray is the better alternative only if all tube-packages are incinerated and all tray-packages are recycled. Also, the tray can be a better alternative if a large volume of warm water is used for cleaning the tube prior to disposal for recycling. (This has not been included in the figure though). It is probable that the tube will be cleaned if it has to be material-recycled. The break-even with regard to GHG emissions happens when 1 litre of warm water, heated by coal-sourced thermal power is used to clean one package. This corresponds to about 10-20 seconds under running tap-water. Of course, if the electricity mix is more diverse (not 100% coal), more than 1 litre of warm water can be used, for the breakeven. This process of cleaning is susceptible to large variations and thereby difficult to estimate with a good deal of certainty. However, it may contribute significantly to the overall environmental impact of the tube.

The result changes when food waste is included in the analysis. When losses of 10g minced meat are added to the tube (top line in Figure 2), it is at once seen that food waste dominates over all the other factors - packaging composition, recycling rates and cleaning. Even a dedicated environmentalist, scraping residues with a spoon, will be unsuccessful

in reducing the wastage below 5 g. This means that the tray will be a significantly better environmental alternative, regardless of the higher impact of the packaging itself.

Figure 3-4 shows the results of the same analysis, but for acidification potential and ozone depletion potential. The pattern is similar to global warming, but the greater impact of the food losses is much more conspicuous.

Figure 2. Specific GHG emissions per kg minced meat consumed. 0% recycling (left) means that all packages are incinerated, 100% (right) that all packages are material-recycled. The tube is the superior environmental alternative when losses of minced meat are excluded from the analyse but the difference decreases if the tray is recycled to a higher extent, and if warm water is used for cleaning the tube (not included in the figure). However, when a loss of 10 g minced meat are added to the life-cycle of the tube, it has significantly higher global warming impact than the tray, for which no losses are assumed.

Figure 3: The pattern for acidification potential is similar to that for global warming but the effect of the losses of minced meat are stronger compared to the impact of the packages, vis-à-vis global warming. The difference between recycling and incineration is less than for climate change due to the assumptions of avoided burden for the energy delivered from an efficient incineration plant. Other assumptions will strongly effect the comparison between incineration and recycling.

Figure 4: The pattern for ozone depletion potential is similar to that for global warming and acidification above, though, but the effect of the losses of minced meat are stronger compared to the impact of the packages, vis-à-vis global warming. The difference between recycling and incineration is less than for climate change due to the assumptions of avoided burden for the energy delivered from an efficient incineration plant. Other assumptions will strongly effect the comparison between incineration and recycling.

4. Discussion

The results show that an evaluation of the types of packages to determine which of those is the best environmental alternative, would give very different results, depending on what is included in the assessment. The influence of packaging attributes on user behaviour with regard to food losses, recycling and cleaning are more important for the environmental outcome than the direct impact of the packages.

As expected, the tube is the better environmental alternative when only direct effects are considered. However, the user perceptions of the packaging attributes *easy to clean* and *easy to separate into different fractions* will probably direct the tube to the waste bin. This scenario is even more likely owing to the fact that the tube-packaging has low mass, is made of plastic and is perceived as having a low value. The tray on the other hand, being easier to clean and looked upon as being of relatively-higher value, may be recycled to a higher degree. In that case, the differences between the packages will decrease, as well as if warm-water is used for cleaning the tube.

The tray is the superior environmental alternative when food wasted in the emptying procedure is included in the analyses. The attribute *easy to empty* turns out to be the most important factor, and outcompetes the differences in packaging material composition and recycling rates. Probably, the amount of minced meat from the tube which is wasted may be about 10 grams or even higher in many cases.

But there may be a twist in the tale here. The tube is better when it comes to preserving the food it contains. The food waste of 10g which happens during the opening of the tube-package, could be justified if the wastage of minced meat drops by 2 percentage points in the other stages of the life-cycle. In Sweden, figures of 0.5 % minced meat wasted at retailers' has been reported (Eriksson et al. 2014) – this is quite small to motivate the use of the tube. This means that, for Swedish conditions, the wastage in households must decrease due to the increased shelf-life of the tube, if it should be a better environmental alternative. The authors of this paper have no evidence if this is likely or not. In a UK study (Quested and Murphy 2014), the wastage of beef (all kinds) classified as avoidable was 8 % of the purchased amount. Of this, less than half was 'not used in time' and so discarded.

To motivate a shift from trays to tubes for Swedish conditions from an environmental perspective, the likelihood of a decrease in the wastage of minced meat by two percentage points or more, must be established.

Needless to say, there are limitations to this analysis. The number of environmental impact categories can be increased. The tube, being more compact, may reduce the transportation energy requirements in the distribution phase. However, the most important limitation of the study is the lack of quantitative data about how packaging attributes influence consumer attitudes and behaviour. The user behaviour – a purchase triggered by the attractiveness of packaging, the mode of utilisation of the contents and the way the packaging is handled by the consumer at the end of its life-cycle - all together, determine what the overall environmental footprint is. This is an interesting area of research for the future, work in which will contribute to holistic environmental assessments leading to sustainable development in the packaging sector. Among other

things, it must certainly be borne in mind that the conditions that influence consumer behaviour vary among different countries and cultures and also among individuals within the same country and having the same/similar cultural background. It should also be noted that the magnitude of direct and indirect environmental impacts can be very different for other products (Williams and Wikström 2011). In the case of packaged food products for which the environmental impact of the content is relatively low (as opposed to the ones considered in this analysis), the difference between the direct and indirect environmental impacts may not be significant and this may detract a little from the importance of studying the indirect impacts.

5. Conclusion

The intention of this paper is to advocate strongly that indirect environmental impacts and user behaviour must certainly be considered when a judgment about the environmental impacts of packaging is made. The importance of including indirect effects in the environmental assessment of packaging is now well recognized (e.g. Kooijman 1993, Hanssen 1998, Svanes et al. 2010, Grönman et al. 2013, Mpagalile 2013., Bertoluci et al. 2014, Verghese et al. 2015). The meaningfulness of making environmental assessments of packaging without considering these effects, can thereby, be questioned. To move LCA of packaging further, there is a strong quest for research and method development about how user behaviour is influenced by packaging attributes, and how the environmental assessment should be developed to take these variable factors into consideration.

The integration of behavioural sciences into LCA is only emerging and is certainly not straightforward, but can provide valuable insights to eco-design (Polizzi de Sorrentiono et al. 2016). We believe that the method presented in this paper and similar approaches can assist in the progress towards a more comprehensive understanding on how packaging should be designed to reduce the overall environmental impact.

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8. Appendix

I. Datasets used from databases in **SIMAPRO 8.0**¹

Dataset	Database
Plastics/polymers	
Thermoforming, with calendering (RER), production	Ecoinvent 3
PET fibres, via dimethyl terephthalate (DMT), production mix, EU-27	ELCD
Polyamide 6.6 fibres (PA 6.6), from adipic acid and hexamethylene diamine, production mix, EU-27	ELCD
Extrusion, plastic fibres (RER), production mix	Ecoinvent 3
PE-low density granulate, production mix	ELCD
Paper (board boxes and carton converting assumed as proxies)	
Corrugated board boxes, technology mix, production mix, 16.6% primary fibre, EU-25	ELCD
Beverage carton converting, converting mix, at plant, beverage carton EU-27	ELCD
Metal	

¹ PRE Consultants 2014 Simapro 8. Amersfoort, the Netherlands: Pre Consultants.

Aluminium, cast alloy (RoW), treatment of aluminium scrap, post-consumer, prepared for recycling at refiner	Ecoinvent 3
Metalworking, average for aluminium product manufacturing (RoW)	Ecoinvent 3
Waste handling	
Incineration	
Waste incineration of plastics (PE, PP, PS, PB), EU 27	ELCD
Waste incineration of paper fraction in municipal solid waste	ELCD
Waste incineration of biodegradable fraction of municipal solid waste, EU 27	ELCD
Aluminium in car shredder residue (waste treatment), RoW, treatment of municipal waste by incineration	Ecoinvent 3
Waste incineration of plastics (PET, PC, PMMA),	ELCD
Recycling	
Paper (waste treatment), GLO, recycling of paper	Ecoinvent 3
Aluminium (waste treatment), recycling of aluminium	ELCD
PE (waste treatment), GLO, recycling of PE	Ecoinvent 3
Mixed plastics (waste treatment), GLO, recycling of mixed plastics	Ecoinvent 3
PET (waste treatment), GLO, recycling of PET	Ecoinvent 3