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Life cycle impact assessment of beverage packaging systems: focus on the collection of post-consumer bottles

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ABSTRACT

Choice of packaging material has a significant contribution to the overall impact of beverage value chain. Collection of post-consumer packaging materials is often controlled by national or regional regulation, which have to be based on sound considerations. Therefore, stakeholders alongside the packaging value chain need for supporting information to select environmentally sound packaging and define own policy. To meet comprehensiveness, five different packaging materials were examined during their whole life cycle. Due to the potentially direct impact of collection system on the human population, and lacking information on such an analysis in recent literature, we were focussing in detail on six bottle collection systems such as kerbside bin, kerbside bag, deposit-refund, combinations with thermal compression of plastic bottles as well as an attempt made toward examining refill-bottles.

Recycling allowed saving large amount greenhouse gas emission particularly in the case of aluminium can and glass-bottle. An appropriate managed packaging system supporting the bottle-to-bottle recycling can make aluminium cans beneficial in contrast to small polyethylene terephthalate bottles. From the post-consumer bottle collection point of view, the kerbside bag showed the best results followed by deposit-refund system and kerbside containers. Even though refilling of bottles leads to decreasing greenhouse gas emission, it became less significant after a certain number of reuse.

It was shown that the fostering of participation of consumers in collection via aimed policy is highly important. Kerbside bag collection is the most favourable solution, although subtle differences between the distinct selective collection-systems suggested the importance of case-specific examinations. For example, using deposit-refund system resulted in excellent environmental profile, as well, like kerbside bag system. Usage of thermal compressing of plastic bottles in value chain of collection showed large environmental impacts, despite achieving significant smaller volume for transportation, which should lead to lower impacts. Furthermore, usage of refill system has to be deeply analysed to estimate the number of refills and transport distances, which allows maximizing its environmental benefits.

1. Introduction

Growing world population requires more and more foods. It consequently leads to increasing amount of packaging wastes such as bottles, boxes, foils (Gómez et al., 2009). Contribution of packaging material to the entire environmental impact of the food value chain might be up to 45% depending on the sort of food and packaging material (Del Borghi et al., 2014; Meneses et al., 2012). That shows the significant role of packaging not only from sanitary point of view, but also with respect to environmental burdens and sustainability.

The European Commission obligates the member states to harmonise the waste management and implement the waste hierarchy in national regulation (EC, 2008a). It means to prefer the waste prevention, re-use and material recycling to incineration or landfill. Furthermore, the directive on packaging wastes requires the recycling of packaging materials by up to 45% (EC, 1994). Considering that the above-mentioned EC/98/2008 directive stresses the importance of human health protection in waste

Abbreviations: GHG, greenhouse gases; DCB, dichlorobiphenyl; LCA, life cycle assessment; Al, aluminium; PET, polyethylene terephthalate; PLA, polylactic acid; Gl, glass (glass-bottle).

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management, a comprehensive life cycle assessment (LCA) might be necessary to find environmental hot-spots in the packaging value chain.

The environmental impacts of beverage packaging depend on bottle characteristics and it is always a fundamental question from the environmental analysis point of view. In some relations, the one-way PET (polyethylene terephthalate) bottles have the most advantageous environmental performance relating to production and usage (Almeida et al., 2010; Diakoulaki and Koumoutsos, 1990). The one-way glass bottles are considered by many studies as the most unfavourable packaging in term of associated environmental burdens, which either originates in higher specific weight (necessary material mass per packed volume) or energy consumption during the entire life cycle (Cleary, 2013; Diakoulaki and Koumoutsos, 1990; Huang and Ma, 2004).

The following factors show high sensitivity considering the potential environmental impacts of packaging materials (Coelho et al., 2011):

- The weight of the container (necessary raw materials);
- The recycling ratio of used containers in case of one-way bottles;
- The recycled material content in new bottles;
- The quality of the recycling routes like closed-loop recycling, open-loop recycling, down-cycling or up-cycling.

The following "sensitive" parameters are furthermore important for the refillable bottles (Cleary, 2013; Detzel and Mönckert, 2009):

- The number of refills;
- The transport distance from filler to point-of-sale;
- The energy (and water) efficiency of bottle and crate cleaning.

The environmental burden of bottles logistic depends on different variables of the assessed system, such as the transport distance, the collection area and the collection method. For example, the glass bottle shows high sensitivity with respect to the distribution distance, which is the result of high specific weight (i.e. kg bottle per litre of beverage). The disadvantage of high weight may be improved by multiple refills of bottles and their distribution on a local scale (Detzel and Mönckert, 2009). Decreasing production demand originating in the reuse of bottles has a reductive effect on the overall environmental burden of bottles (Zabaniotu and Kassidi, 2003). However, one has to notice that reducing the bottle weight does not necessary lead to a significant reduction of the environmental impacts, for example in the case of the aluminium can (Al-can). Lightweight packaging shows some benefits particularly in transportation (Detzel and Mönckert, 2009), but benefits from weight reduction can considerably decline due to increased energy demand and harmful emissions during the primary aluminium production (Choate, 2007; Huang and Ma, 2004). However, this statement is rather true of system without recycling activity (Ding et al., 2012).

As Ding et al. (2012) reported, the use of high recyclable materials can support the mitigation of overall environmental burden by saving primary raw materials and production energy. However, a recycling rate of 100% might not result in emission reduction in all cases, because in some situations, collecting and recycling systems can cause higher environmental burden than which could be avoided by the production and use of secondary materials (Chilton et al., 2010; Ding et al., 2012; Romero-Hernández et al., 2009). Recycling has other advantages besides the production of secondary raw materials. Using end of life (EoL) technologies approx. 5–6 folds more energy could be saved as compared to commercial incineration (Almeida et al., 2010; Finnveden and Ekvall, 1998; Morris, 1996). Consequently, fossil resources can be saved, intensive land use and higher emission rates could be avoided (Pasqualino et al., 2011) or more workplaces can be established (Coelho et al., 2011; Pasqualino et al., 2011).

Conclusions of reviewed papers are akin to each other. These often give preference to plastic packaging materials over Al-can or glass, although sometimes they exclude some parameters allowing a comprehensive comparison or evaluate in a not holistic manner. Summary can be found in Table S1 based on Almeida et al. (2010), Chilton et al. (2010), Coelho et al. (2011), Detzel and Mönckert (2009), Diakoulaki and Koumoutsos (1990), Falkenstein et al. (2010), Foolmaun and Ramjeeawon (2012), Gironi and Piemonte (2011), Huang and Ma (2004), Millock (1994), Papong et al. (2014), Pasqualino et al. (2011), Romero-Hernández et al. (2009), Vellini and Savioli (2009). Main goals of studies are often narrowed down to one or only few materials, or describe a specific geographical system boundary and fixed system boundaries like fixed ratios of different EoL technologies, fixed relative composition of post-consumer packaging mix (Almeida et al., 2010; Cleary, 2013; Coelho et al., 2011; Romero-Hernández et al., 2009). Some papers like Huang and Ma (2004), are considering less detailed system boundary, concentrating mainly on production stage. Furthermore, in few cases description of reverse logistic is missing or simplified (Diakoulaki and Koumoutsos, 1990; Huang and Ma, 2004)), in spite of the fact, that it might be an important activity. Reverse logistic includes processes from collection to recycling as well as it affects significantly the quality of secondary material and the preventable environmental impacts (Almeida et al., 2010; Rogers and Tibben-Lembke, 1998).

The aim of present study is manifold. First, as it was mentioned above recent studies are examining beverage bottles in a case-specific context (see Table S1). A comprehensive study on wide range of materials focussing on collection solutions, as a life cycle stage with direct impact on human population, would provide a holistic view of environmental and human health implications of beverage packaging materials.

In order to meet the requirement of above-mentioned comprehensiveness, present paper described a general system boundary and an environmental analysis includes the whole "cradle to grave" life cycle of five widely used beverage packaging materials such as aluminium-can, PET-bottle, PLA-bottle, beverage carton and glass with different volumes. Although the production exhibits the main environmental impact of beverage packaging (Huang and Ma, 2004), we assumed that the post-consumer bottle collection is an important life cycle stage as well, due to the direct emissions in highly populated areas.

Collection is an important life cycle stage from policy making point of view, as well, in order to mitigate the negative effects on human health as a first objective of EU directive 2008/98/EC (EC, 2008a). European Directive on packaging wastes priors the implementations of waste hierarchy in waste management (EC, 1994), which stresses the prevention and the reuse and the recycling. To realise waste hierarchy with minimal impact on human health the collection become important and the conduction of a comprehensive life cycle assessment is essential.

Therefore, in order to identify potential hot-spots in collection systems supporting the policy makers to find potential solutions with low environmental burdens in accordance with the related European directives, present paper made a case for examining the potential impacts of different collection strategies of post-consumer bottles and also taking into consideration their whole life cycle. The impacts of collection scenarios were analysed by photochemical ozone creation potential (POCP) as well as human toxicity potential (HTP) as important local impact from transportation system. Analysis of greenhouse gas emissions (GHG) was used to define the global warming effect of the whole life cycle of