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IMPROVING THE PRODUCTION CHAIN WITH LCA AND ECO-DESIGN: APPLICATION TO COSMETIC PACKAGING

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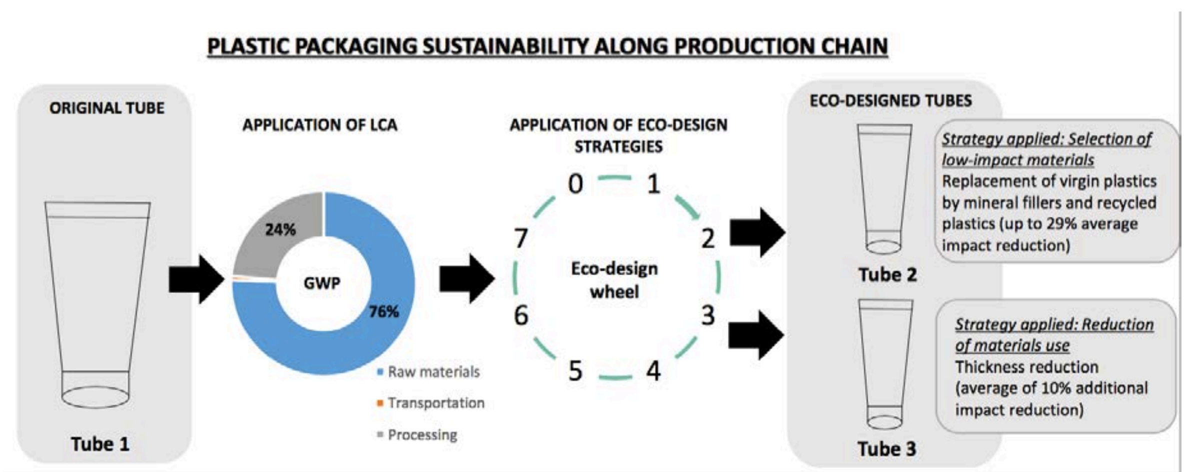


ABSTRACT

One of the main drivers for companies to perform environmental improvements is economic benefit, either by obtaining a more valuable product or gaining new customers. Circular economy combines environmental improvements with these drivers to achieve higher and quicker benefits. This paper is a case study on packaging eco-design aligned with circular economy strategy along the production chain. Life cycle assessment (LCA) was used to identify the product life cycle stages where the application of eco-design strategies would be more efficient (in this case, raw materials production from virgin petrochemicals). To improve the environmental profile of this packaging, virgin petrochemicals were partially replaced by mineral fillers (calcium carbonate based) or/and post-consumer recycled plastics. Different technically compliant cosmetic tubes were produced by collaboration between a company producing the plastic granulates with mineral fillers and a company producing the cosmetic tubes and cradle-to-gate LCA were performed. The replacement of virgin petrochemicals by mineral fillers helped to reduce the environmental impacts by an average of 12% and the use of post-consumer recycled plastic further decreased emissions up to 29% for 6 out of the 9 evaluated impact categories. The option with better environmental performance was also the one with lower economic costs.

According to the involved companies, LCA combined with ecodesign helped to achieve efficient environmental and economic savings. The findings are important for the plastic packaging sector because they tackle with prime concerns, like plastic debris, climate change and resource depletion. They are of main interest for industrial activities where brand positioning is a priority (i.e. cosmetics).

Keywords: mineral fillers; post-consumer-recycled plastic; cosmetic tubes; packaging; end of life allocation (EoL)

1. INTRODUCTION

Circular economy is a new concept aiming to guide and help the society's needed change towards a more sustainable economy. This change has to be done by re-thinking and re-designing production and consumption systems to avoid environmental emissions and maintaining natural resources as long as possible in the biosphere and technosphere (Gaustad et al., 2018; Simon, 2019). Circular economy aims to raise public and private awareness environmental problems, and combines environmental management with economic benefits to push private companies to get more easily involved (Babbitt et al., 2018).

In addition to public awareness and consumers' willingness-to-buy, if environmental concerns are to be widely and quickly spread among companies, following the principles of life cycle management (Fullana i Palmer et al., 2011), corporate strategies focusing on the more efficient and sustainable use of natural resources within the company (Rieckhof et al., 2015) and all along the supply-chain (Geissdoerfer et al., 2018) must be encouraged. This goal has to be implemented at strategic company level.

Usually, the relationship along the supply chain begins when a customer asks for environmental improvement from its supplier. To reduce efforts (and to ensure quality) associated with this collaborative relationship, third-party product sustainability certifications appeared (Chkanikova and Kogg, 2018). This is an instrument for the transfer of significant life cycle information along the production chain and a tool to facilitate corporate life cycle management.

This type of client-provider relationship can also begin with the interest of the provider to gain a new customer thanks to better environmental profile of its product or material. In this last case, third-party product environmental certification may not be enough to produce the change, and a closer collaborative relation may be needed in the beginning; thus, environmental, as well as technical and economic aspects of the new product should be evaluated to demonstrate its eco-efficiency (Laso et al., 2018). In the present paper (and up to the knowledge of the authors for the first time in the literature), a case study is presented on cosmetic packaging where a plastic granulate supplier starts a collaboration with a new customer by spreading its circular economy strategy downstream in the production chain.

The packaging industry looks for packaging solutions that are strong, hygienic, easy to handle, lightweight, and, most importantly, sustainable (Varun et al., 2016). The increased concern for environment has attracted attention to the environmental burdens of packaging (Flanigan et al., 2013; Herbes et al., 2018). As a result of this, in the recent years, production of packaging in a more sustainable way has become more of an issue, not only to improve environmental performance of the products but also to meet the requirements of green product market (González-García et al., 2016).

Many LCA studies related to packaging can be found in the literature. Some of them stress that the production stage of packaging is the major contributor to its environmental impacts (Navarro et al., 2018; Raugei et al., 2009; Roy et al., 2009). Therefore, the search of alternative materials and designs with less environmental impacts have become more important to provide sustainability for packaging products.

According to a recent review study performed on functional fillers (Civancik-Uslu et al., 2018), addition of minerals (like calcium carbonate) may help to improve the environmental profile of materials. In addition, they do not only reduce the cost, but also provide additional properties, like changes in mechanical properties (Xanthos, 2010). However, it should be noted that each case is specific, and should be investigated separately.

Life cycle assessment (LCA) is used to help policy-makers to understand the environmental impacts of packaging (Lewis et al., 2010). De Koeijer et al. (2017) define LCA as the major tool to evaluate environmental profile of a product through its life cycle. Luz et al. (2018) offered a methodological approach to integrate LCA in product development and applied it to a softener packaging in their study.

As previously said, there are many studies in the literature, in which LCA is used to identify the environmental profile of packaging (Albrecht et al., 2013; Balaguera et al., 2019; Civancik-Uslu et al., 2019a; Cleary, 2013). Some LCAs of cosmetic products focusing on the ingredients exist in the literature (Glew and Lovett, 2014; Martinez et al., 2017; Secchi et al., 2016) and evaluates packaging as a part of full life cycle of the cosmetic product (Borghi et al., 2004, 2003; Fullana and Puig, 1997; Golsteijn et al., 2018; Molander et al., 2004; Vallés et al., 2001). However, no LCAs found in the literature focusing on cosmetic packaging, despite of its growing market (Future Market Insight, 2017).

On the other hand, as suggested by some authors (Muñoz et al., 2009; Navajas et al., 2017), the use of eco-design strategies in combination with LCA helps to improve environmental profile of products.

Cosmetic tubes are a type of packaging used for semi-liquid cosmetics, which preserves its content for longer time, prevents drying and helps correct dosing. This type of tubes is difficult to recycle because, when collected as waste, they still contain some cosmetic and, in the packaging selection plant, since they are so small, they end up in the plastic-mix fraction. Thus, they are commonly landfilled or incinerated with the consequent emissions and resource losses.

Recently, the importance of developing new materials and business models which facilitate the application of circular economy in plastics industry is stated by the European Commission (EC) (Crippa et al., 2019). In addition, improving product design and boosting recycled content are also identified by the European Circular Economy Action Plan (EC, 2019) among the strategies to be promoted on plastic industries. Accordingly, in the present case study, cosmetic tubes were re-designed based on circular economy principles through the collaborative relation between a plastic-granulate provider and a cosmetic tube manufacturer, through the transmission of circular economy from the first company to the second, downstream in the production chain (opposite to the most common upstream transmission; from client to provider). LCA was used in combination with eco-design, to identify the life cycle stage environmentally most significant, where the application of eco-design strategies would be more efficient.

The goal of this study is to see if it is possible to achieve a better environmental profile of a cosmetic tube by applying LCA and eco-design strategies. The alternatively proposed cosmetic tubes, with mineral fillers and recycled plastics content, were produced and their technical properties and costs were evaluated. LCA methodology was also used to calculate the environmental profile of each tube with the aim of identifying the one with least environmental emissions. The project took place with a close collaboration between supplier and customer-to-be companies. The findings and conclusions, together with the methodological approach of the present study, will guide plastic packaging sector to achieve higher sustainability degree.

2. METHODOLOGY

The circular economy principle applied in this case study is the one dealing with resource conservation and recycling of materials. The methodology used was based on the application of the eco-design strategy wheel (Brezet and van Hemel, 1997) taking into consideration the most impacting life cycle stage (according to LCA results), to see which strategies were applicable to the cosmetic tubes. Then, we selected the strategies which the manufacturer felt comfortable with, to produce new cosmetic tubes (described in section 2.1). Finally, LCA results of the newly obtained cosmetic tubes were compared with those of the previous tube.

When performing the LCA, ISO 14040 (ISO, 2006a) and 14044 (ISO, 2006b) Standards were followed. Methodological details on the LCA study are given in sections from 2.2 to 2.6.

2.1. Eco-design methodology

The eco-design strategy wheel was checked to find which strategies were applicable to the present product (Figure 1). According to the LCA results of the original tube (Figure 4), strategies related to raw materials production were identified as the most relevant ones. Although other strategies in the wheel could be also applicable, the manufacturer of the cosmetic tubes decided to apply strategy 1 (the use of materials with lower impact) and later on, as a new improvement option, strategy 2 (reducing the amount of material) thanks to the improved mechanical properties of the tubes obtained with mineral fillers.

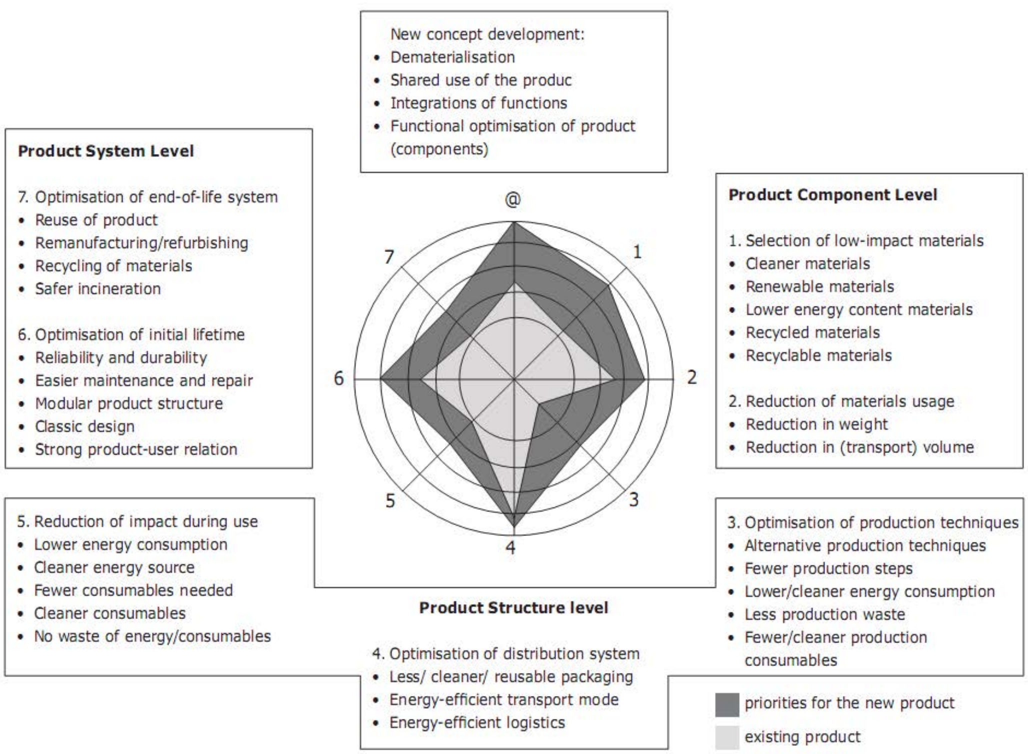


Figure 1. The eco-design strategy wheel (Brezet and van Hemel, 1997)

Materials with lower impact that can replace virgin petrochemicals are mineral fillers (based on calcium carbonate), which are present in nature in large amounts and are constantly being produced from CO_2, and recycled plastics. Therefore, the virgin petrochemicals, which are high-density polyethylene (HDPE) and linear low-density polyethylene (LLDPE), were replaced by: a) mineral fillers, which are Granic products produced by GCR, a company in Tarragona, Spain; and b) post-consumer recycled HDPE at some percentages. The proposed replacements intend to reduce resource loss (as said, mineral fillers are very common in nature and recycled plastic is re-used in the techno-sphere). Therefore, three types of cosmetic tubes were produced and their environmental impacts were evaluated.

2.2. Goal and scope

The goal of the present LCA study is to calculate the environmental impacts of three different cosmetic tubes knowing that all of them are technically possible based on the information provided by the producer of the tubes, Linhardt (Linhardt, 2019), a packaging company placed in Hambrücken, Germany. All of the tubes have the same appearance (Figure 2) and the differences in weight and composition of the tubes are presented in Table 1.

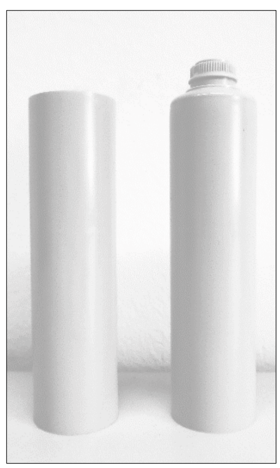


Figure 2: Cosmetic tubes without/with shoulder injected

Table 1: Weight and composition of tubes

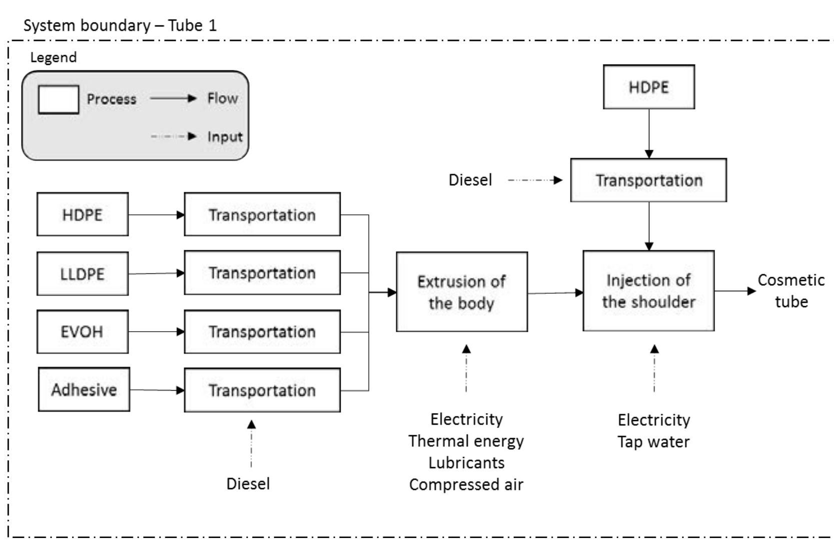
	Weight	**Body**	**Shoulder**
Tube 1 (original)	10.4 g	HDPE (40%) LLDPE (40%)	HDPE (100%)

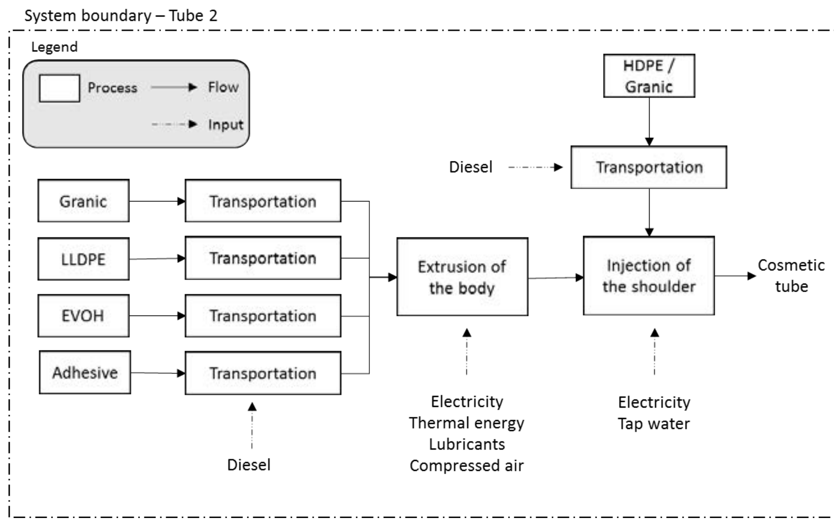
		EVOH (8%) Adhesive (12%)	
Tube 2 (with mineral filler)	11.6 g	Granic 742 (45%) LLDPE (36.7%) EVOH (7.3%) Adhesive (11%)	HDPE (70%) Granic 742 (30%)
Tube 3 (with mineral filler and recycled content)	11.6 g	Granic 742 (45%) PCR-HDPE (36.7%) EVOH (7.3%) Adhesive (11%)	PCR-HDPE (70%) Granic 742 (30%)
**Granic 742: calcium carbonate based filler* **PCR: post-consumer-recycled*			

The original tube, tube 1, was mainly composed of virgin plastics. In tube 2, HDPE was replaced by Granic 742, which is a mineral filler based on calcium carbonate (produced by GCR Group in Tarragona, Spain (GCR Group, 2018)). In addition to this change, tube 3 was made by also replacing LLDPE by post-consumer recycled (PCR) HDPE.

The functional unit of the study is: "Production of a single cosmetic tube having a 35 mm diameter and 120 mm length, and able to carry 75 mL of cosmetics".

The corresponding reference flows relate to 10.4 g, 11.6 g, and 11.6 g of tube weight, respectively.





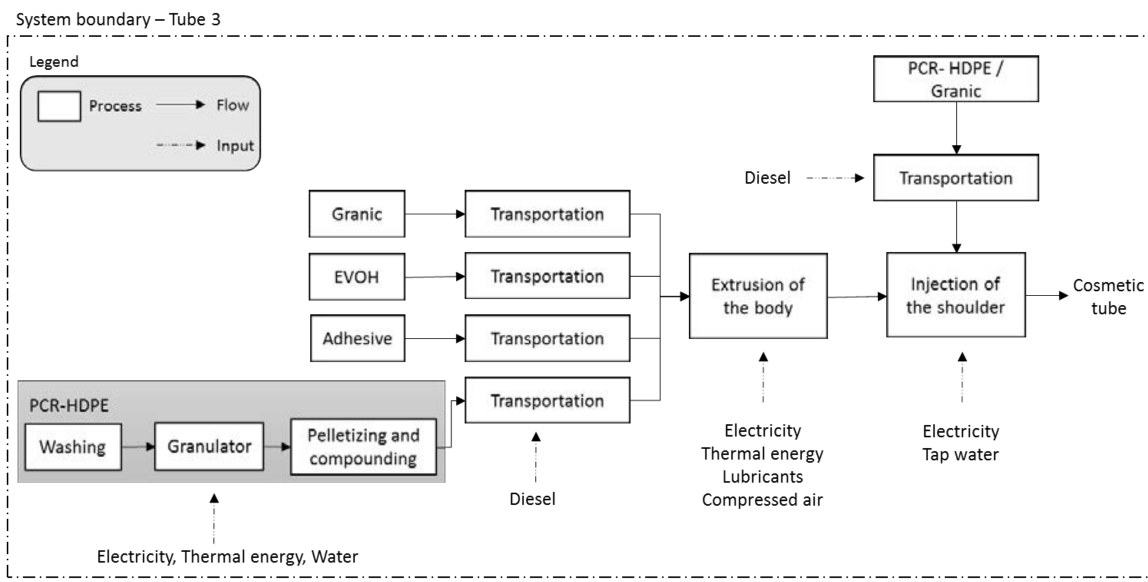


Figure 3: System boundaries of the tubes

The system boundary of the study is defined as "cradle-to-gate" (Figure 3), from the extraction of raw materials to the gate of the production facility, to obtain the environmental profile of the three alternative tubes. For tube 1 and 2, each component is transported from different suppliers to the tube production facility in Germany. They are fed to the screw machine and the body part of the tube is co-extruded. Following that, the shoulder of the tube is produced by injection molding and combined with the body of the tube.

In the case of tube 3, for the production of recycled HDPE as secondary raw material, washing, granulator, pelletizing, and compounding processes are considered. In each of the recycling processes, electricity is consumed. During the washing of the plastic waste before granulating, water and thermal energy are also used.

2.3. Data collection

LCA of the tubes was performed by using GaBi 8 software. The required data were intended to be collected from the producers of raw materials and the manufacturer of the tubes. This was for production of mineral fillers, preparation of secondary raw material, production of cosmetic tubes and transport means and distances. For the rest, the data were taken from Thinkstep Professional Database SP33 (Thinkstep, 2017). While picking the data from the database, special attention was given to select the regional representative data, which was Germany in this case as the manufacturing takes place in Germany.

Raw materials production

Life cycle inventory (LCI) data for HDPE and LLDPE were taken from the database, while the data on preparation process of post-consumer recycled HDPE were taken from the producer.

Since ethylene vinyl alcohol (EVOH) production process was not available in the LCI database, instead ethylene vinyl acetate copolymer (EVA) process was used as a proxy (Thinkstep, 2017), as EVOH is synthesized from EVA and they have similar profile (ETH Sustainability Summer School, 2011). In addition, Humbert et al. (2009) say in their study that the use of EVA as a proxy of EVOH shows minor changes in the results, which are below the defined cut-off criteria. For the adhesive, due to the lack of specific data, the closest adhesive available in the database, simple 2-component epoxy adhesive, was used as an approximation. Finally, for the mineral fillers, LCA results were taken directly from the producer.

Transportation

Distances between the supplier of each raw material and the production facility, which is located in Germany, were gathered from the manufacturer of the tubes and presented in Table 2.

Table 2: Distances between the raw material suppliers and the production facility

Raw material	**Distance (km)**
HDPE	361
LLDPE	256
Mineral filler (Granic)	1280
PCR HDPE	1175
EVOH	471
Adhesive	338

The transportation of the raw materials to the production facility was done by truck. The truck data were taken from the database for a 32 ton capacity Euro 6 truck with 85% utilization rate.

Production processes

There were no primary data for the extrusion and injection molding processes from the manufacturer. Therefore, LCI data were taken from the database. The specific data for Germany were available for injection molding process, while not for extrusion. Therefore, the process used for extrusion was a global means. However, electricity, thermal energy, and lubricants consumed during the extrusion process were selected for Germany. Only compressed air consumption was the representative of global consumption as it was not available specifically for Germany.

For the recycling of HDPE as raw material, based on the information provided by the producer, washing, granulator, pelletizing and compounding processes were considered. The processes were taken from the database. For the consumption of thermal energy and electricity, country specific data were chosen. At the washing process, European process water was used, while municipal wastewater treatment data for Germany was used.

2.4. Assumptions

The printing and final packaging processes of the tubes were excluded from the system boundary, as they are the same for all alternative tubes.

The end-of-life modeling of the tubes was not included in the LCA, as the aim of this study is to communicate the environmental profile of the tubes to the client (in this case, it was the cosmetics producer). Depending on the specific markets that the tubes may be sold in, the waste management scenario of the tubes will be different.

2.5. Impact assessment

For the estimation of the environmental impacts, ILCD/PEF recommendation (v1.09) was used. The following midpoint impact categories were estimated:

- Acidification (AP) [mole H^+ eq.]
- Climate change, excluding biogenic carbon (GWP)[kg CO_2 eq.]
- Eutrophication freshwater (EP freshwater) [kg P eq.]
- Eutrophication marine (EP marine) [kg N-eq.]
- Photochemical ozone formation, human health (PCOF)[kg NMVOC]
- Resource depletion water (Water) [m^3 eq.]
- Resource depletion, mineral, fossils and renewables (ADP) [kg Sb eq.]

In addition, the following indicators were also calculated:

- Primary energy from non-renewable sources (PE_non_ren) [MJ]
- Primary energy from renewable sources (PE_ ren) [MJ]

2.6. Allocation procedure

In the case of tube 3, the 100:0 allocation method (also known as cut-off approach), was used (Baumann and Tillman, 2004). Thus, the burdens of HDPE recycling was allocated to the tube which uses PCR-HDPE as raw material. On the other hand, knowing that end-of-life (EoL) assumptions may have important influence on the results (Civancik-Uslu, et al. 2018; Sandin et al., 2014), the use of 50:50 allocation, as being selected for the PEF methods (Allacker et al., 2017), was also considered as a sensitivity analysis in order to see the importance of the allocation method on the present results. In 50:50 allocation, impacts of virgin material production and recycling process are allocated equally between the two products of a product cascade (Nicholson et al., 2009).

3. RESULTS AND DISCUSSION

LCA combined with eco-design, as a circular economy strategy aimed at reduction of resource use, was applied downstream in the production chain. Two new cosmetic tubes (tube 2 and 3) were produced and environmentally compared with the previous one (tube 1), through LCA methodology.

In Figure 4, the LCA results of tube 1 are presented in percentages for life cycle stages: raw materials, transport, and processing. “Raw materials” stage includes all the emissions from the activities related to the raw materials preparation (HDPE, LLDPE, PCR-HDPE, Granic, EVOH and adhesive). For example, in the case of PCR-HDPE, all the activities related to the production of recycled HDPE were included in the raw materials stage: washing, granulator, pelletizing and related electricity, and water consumption. The “Transportation” stage covers the emissions from the truck and diesel consumption. Finally, all the emissions occurring during the extrusion and injection molding processes are presented as “Processing” in the figure.

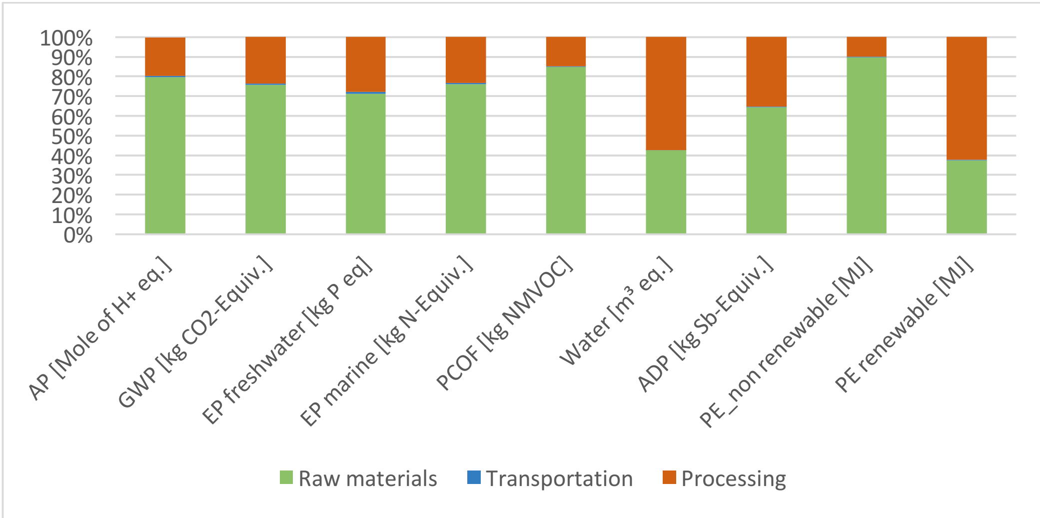


Figure 4: LCA results for tube 1

As seen in Figure 4, for the majority of the impact categories raw materials stage form more than 50% of the total impact. However, in the case of water depletion and primary energy from renewable sources, the most contributing part is the manufacturing of tubes, mainly due to the consumption of electricity.

Although the amounts of adhesive and EVOH used in the composition of the tubes are relatively small, their contribution to the impacts was identified as important. For example, in the case of freshwater eutrophication, their contribution reached to 46% of the total impact for tube 1. On the other hand, the impacts from the transportation of raw materials were found to be very low (up to 1 % of the total life cycle).

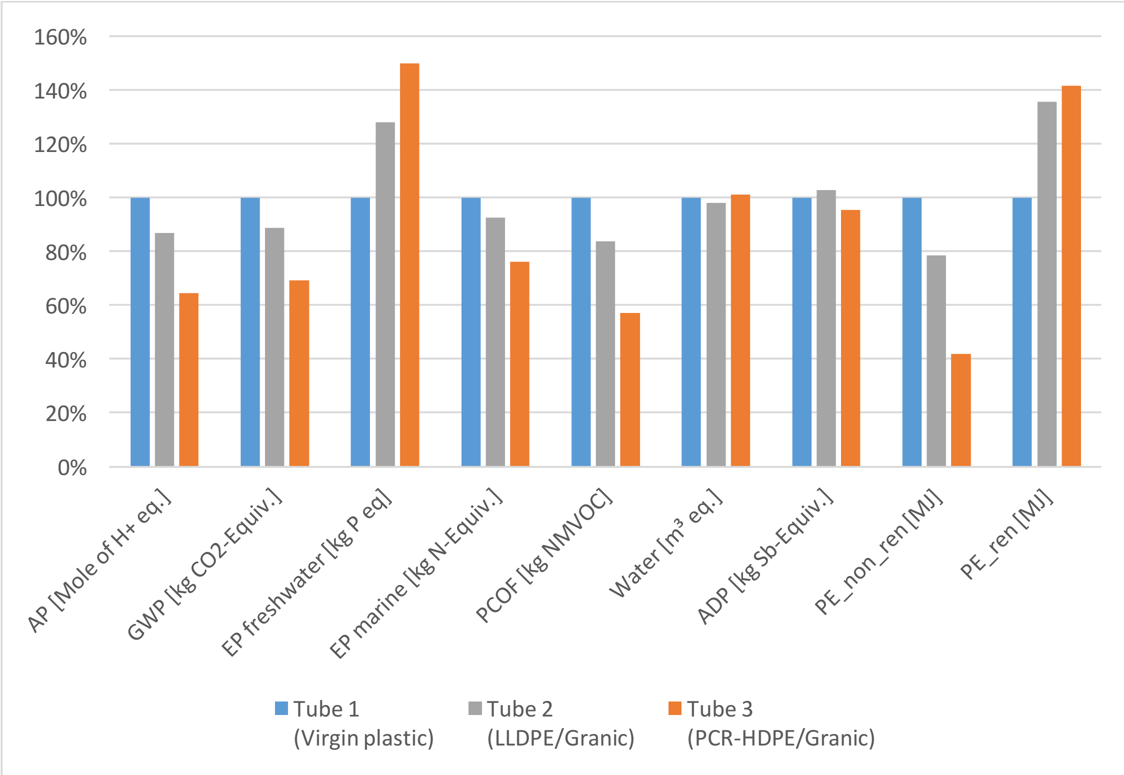


Figure 5: LCA results of cosmetic tubes

The results for the original tube (tube 1) are presented in Figure 5 in comparison to the proposed alternatives with mineral fillers and recycled content (tube 2 and tube 3, respectively). Comparing the results of tube 1 and 2, it can be observed that, when HDPE content of the original tube was replaced with mineral fillers (which is Granic 742 in this case), 6 out of the 9 evaluated environmental impacts decreased by an average of 12%. The reason for the improvement is the replacement of petrochemical-based raw materials by minerals, specifically calcium carbonate. On the other hand, 3 impact categories increased: EP freshwater (by 28%), ADP (by 3%). and PE renewable (by 35%). For EP freshwater and PE renewable, the reason for the increase was the mining of calcium carbonate, which significantly contributes to freshwater eutrophication and energy consumption. However, in the case of ADP, the slight increase happened during the manufacturing of the tubes. It is important to note that tube 1 weighs 10.4 g, while tube 2 weighs

11.6 g, due to the addition of the denser mineral fillers. This increase in weight causes higher consumption during the processing of the tube (electricity, lubricants, etc.), as the model proportionally relates electricity consumption to mass being extruded or injected, without taking into account that the filler may behave differently to heat and pressure than the plastic.

In the case of tube 3, in which LLDPE is replaced by post-consumer-recycled HDPE (PCR-HDPE) and the virgin HDPE by mineral fillers, even further reductions were achieved. In this case, for 6 of the impacts, a 29% reduction was gathered in average compared to the original tube (tube 1). The use of recycled HDPE helped to reduce the emissions further compared to the tube 2. On the other hand, the results for EP freshwater, PE renewables, and water consumption increased (by 50%, 41% and 3%, respectively). The reason for the increase in EP freshwater is the washing of post-consumer plastics during recycling and the production of calcium carbonate (used as filler). The last aspect also contributes to the PE renewables increase.

One of the main concerns of plastics nowadays is the marine littering environmental impact, which is not yet addressed through LCA methodology although first inputs have recently been published (Civancik-Uslu et al., 2019b). In the present case, the use of post-consumer recycled HDPE as raw material together with calcium carbonate as mineral filler contribute to reduce the marine littering of this packaging as less plastic-waste will be dumped and calcium carbonate will be naturally integrated in the environment.

According to the companies involved, the results of the study showed that LCA combined with ecodesign strategies (Figure 1) is an efficient way to economic and environmental savings.

3.1. Sensitivity analysis

3.1.1. Weight reduction

The use of mineral fillers instead of virgin plastics results in the increase of weight of the tubes from 10.4 g to 11.6 g (Table 1). Because of previous experiences in other products, it was known that, thanks to the improved physical properties of the polymer produced with mineral fillers, reduction of the weight for tubes 2 and 3 was possible by reducing the thickness of the tube. Therefore, a sensitivity analysis was performed to see how the environmental profile of the tubes would change by reducing the weight from 11.6 g to the original 10.4 g (see this sensitivity analysis for tube 2 in Figure 6).

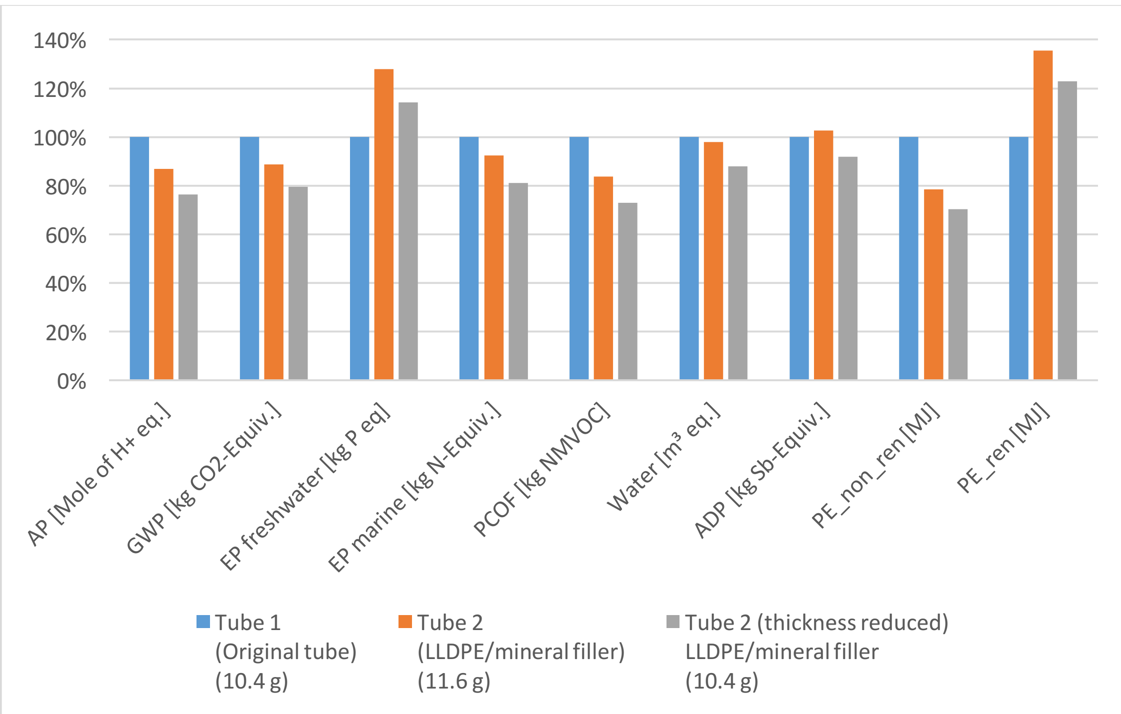


Figure 6: Sensitivity analysis on tube 2 weight

LCA results showed that the decrease in the weight caused further reductions in the overall impact results (average of 10%). Using LCA to study different possible scenarios, is a good eco-design tool for packaging. For example, the tube-weight required to have all impact categories smaller than the ones of the original design could be determined with LCA, as well.

3.1.2. EoL Allocation

For tube 3, a sensitivity analysis was performed to see what would happen if the 50:50 allocation method was used instead of 100:0 for the modeling of PCR-HDPE as secondary raw material. It means that 50% of the burdens due to the production of virgin HDPE and 50% of the burdens due to its recycling were allocated to the PCR-HDPE used as raw material in tube 3. This would also mean that, if the final user of the tube with the cosmetics inside wants to add the gate-to-grave life cycle stages, the same method should be applied to the percentage of tubes being recycled at the EoL. As this is totally unknown to the tube manufacturer, at this point it seems more adequate to use the 100:0 rule as baseline scenario.

Results of the analysis are shown in Figure 7 together with the other tubes in order to see the effect of allocation methods. As expected, due to the emissions coming from the production of virgin HDPE, the results increased between 6% and 20% when the allocation method was changed to 50:50. PE from non-renewables impact category showed the greatest increase with a 20%, since it is an impact category highly affected by the consumption of virgin petrochemicals. On the other hand, despite of the smaller increase in EP marine and ADP, the change of EoL allocation made tube 3 to have more or less the same impact as tube 2. In this study, it did not cause a significant change on the overall results; however, it may in other cases. Even though one single study is not enough to make a general conclusion, it can be a good example as the change of EoL allocation method caused 6- 20% difference in the results. As said above, if the tubes were recycled once used up, then the following system in the open-loop recycling will take the 50:50 rule as well, decreasing somehow the impacts of the tubes.

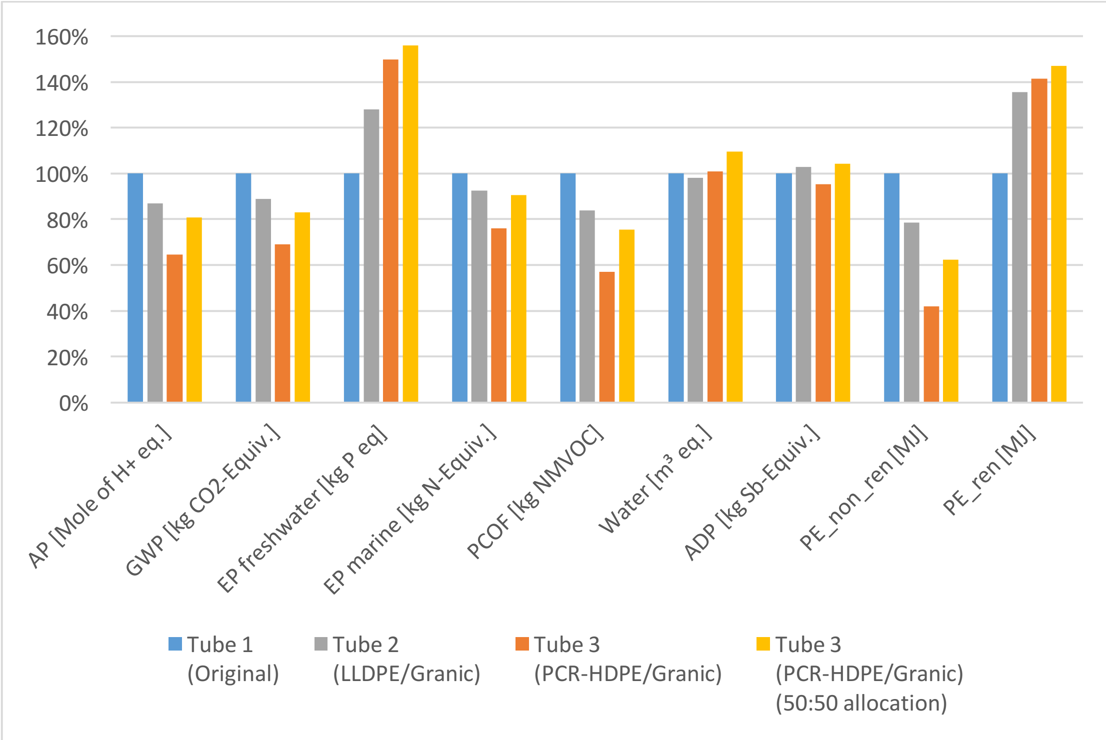


Figure 7: Results of the sensitivity analysis on EoL allocation method

4. CONCLUSION

Circular economy based on resource conservation was applied, not in-company, but along the production chain, by close-collaboration between a raw material supplier (with a strong internal circular economy strategy) and a possible customer-to-be. The product of the customer, a cosmetic tube, which is usually landfilled or incinerated at the end of its life, was eco-designed by using both mineral fillers and recycled material in order to reduce the use of virgin petrochemicals. The results of the study showed that cosmetic tubes with less environmental emissions can be obtained by changing virgin petrochemicals by these materials at some portions, while maintaining its technical feasibility and reducing costs.

The use of mineral fillers instead of virgin petrochemicals showed a clear advantage, reducing the environmental impacts by an average of 12%. In addition to that, if LLDPE was replaced by PCR-

HDPE, environmental impacts further decreased by an average of 29% for most of the impact categories.

Using mineral fillers, due to their higher density, may result in higher weight of the tubes. Nevertheless, thanks to its superior properties, weight reduction was technically possible by reducing the thickness of the tubes; which brought a 10% further reduction in the emissions.

Two different EoL allocation methods were tested in this study, the 100:0 and the 50:50, to model the PCR-HDPE in tube 3. Impact results varied between 6% and 20%. In this case study, it did not affect the comparison, as tube 3 remained the best option for the majority of impacts. However, it showed the importance of EoL allocation methods in product profiles.

LCA was used to identify the most contributing life cycle stages, and eco-design solutions were used where they could be more efficient. This showed the importance of combining LCA with eco-design. The project was a clear example on how the circular economy strategy can be transferred downstream in the production chain (from provider to customer) in a collaborative relationship, when the provider is the one pushing for the improvement instead of being the client, as it usually happens.

This study showed how to apply LCA and ecodesign as a shortcut to environmentally improve a packaging, the cosmetic tubes, which considering its growth (about 4,8% from 2017) probably achieving a market of 2.8 billions of US$ by 2022, is a significant contribution to the sustainability of the cosmetic industry. This methodology (LCA & ecodesign), accepted and implemented by both industries involved in the case study presented here, can be extended to other supply chains.

Finally, the specific findings of the present study will be useful to the plastic packaging sector because they tackle very important issues at hand: marine plastic littering, climate change and resource depletion. In addition, cosmetic industry relies very much on branding and these environmental issues may influence brand positioning.

5. ACKNOWLEDGMENT

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The authors are responsible for the choice and presentation of the information contained in this paper as well as for the opinions expressed therein, which are not necessarily those of UNESCO and do not commit this Organization.

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