

Life cycle assessment of recyclable, reusable and dematerialised plastic cosmetic packages

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Abstract. Design for Recycling and Design for Reuse are two different approaches which can be employed separately or concurrently. When designed for reuse, products are typically more robust in order to increase their probability to be used more than once. If reuse is not possible, it is essential that dematerialisation and recycling are applied. This study assessed the environmental impacts resulting from reusable, recyclable and dematerialised plastic cosmetic packages. Life cycle assessments of different versions were conducted, to identify what features are responsible for such impacts. Findings showed that removing components which are made from resourceful materials, and which render the package to be reusable, resulted in a 74% reduction in environmental impacts only when the packaging materials are fully recycled. Hence this study concludes that in such cases, reuse should be given prominence, as recycling would only depend on the user and the infrastructure in place.

Keywords: Life Cycle Analysis, Recyclability, Reusability, Cosmetic Packaging, Sustainability.

1. Introduction

The term sustainability has never been given as much importance and acknowledgment as it has been given in the last few years. It has become a trend to associate many aspects of our everyday life to sustainability, and awareness has increased significantly [1]. Additionally, when considering the drastic increase in human population over the last 50 years, from around 3 billion to today's 7.8 billion [2], an increase in demand for goods and services is also expected. This in turn leads to larger economies and increased prosperity around the world. However, this factor has also negatively affected the environment due to the increased rate of emissions, and increased depletion of resources [3]. The environmental issues worsen when we consider that packaging amounts for a large quantity of the generated waste, the most common of which is plastic. Packaging is necessary for protecting and distributing products worldwide, however, particularly secondary and tertiary packaging only serve their purpose until the product reaches its use phase, at which point such packaging turns into waste and is considered as an environmental issue [4].



1.1. The Cosmetics Industry

One of the industries which heavily uses packaging is the cosmetic industry. Globally, the cosmetic industry was valued at approximately USD 532 billion in 2017, with predicted forecasts expected to reach USD 863 billion by 2024 [5]. From this global value, approximately USD 25 billion are reflected in product packaging [6]. These values make the cosmetic industry extremely important and relevant. However, the drastic rise in this industry has also skyrocketed plastic use, and consequently has led to negative environmental impacts. With global plastic usage set to increase from 1.5 million tonnes/year in 1950 to 322 million tonnes/year in 2015, it is very evident to see just how dire the situation is [7]. Both primary packaging (the container holding the cosmetic product) and secondary packaging, are commonly found in significantly high quantities and sometimes even excessive quantities in such a luxury industry. Packaging helps create a more premium experience, such as by including thick ribbons, having individually packed items, or including lots of paper separation packaging. In 2018, more than 120 billion units of cosmetic packaging were recorded to be produced globally [8]. This is worsened when realising that studies show a significant lack of recycling. A recent EU investigation showed that in 2014 less than a third of the generated plastic waste was recycled in Europe, with the other two thirds being either deposited in landfills or being solely used to recover energy from them [9].

There are a number of existing case studies showcasing cosmetic companies which managed to improve their sustainability efforts by applying design changes and by carrying out sustainability assessments. One such company is LUSH cosmetics, which improved its environmental footprint by implementing design changes such as reducing product thickness and replacing the standard wrapping paper with reusable fabric wrapping, which comes from recycled plastic [10]. LUSH also claim that 35% of their physical outlet product range do not need any packaging whatsoever, whilst products purchased from their online outlet are shipped in biodegradable bags, cushioned by compostable renatured peanuts, and packaged in 100% recyclable cardboard boxes. When secondary packaging of the product itself is necessary, LUSH have switched to using reusable product packaging by using aesthetic and durable plastic boxes. These can be reused by either using them to resend another gift in them, or to organise jewellery or small items. Another study carried out by LCA Centre showed that if all cosmetic manufacturers worldwide adopted a reuse-refill system for their cosmetic products, the cosmetic industry overall would eliminate 70% of its total CO₂ emissions [11]. This is a very significant statistic and bodes well for companies who would like to increase their efforts towards sustainable product development.

2. Materials and methods

The main objective of this study is to quantify and compare the different environmental life cycle impacts resulting from recycling and reusing plastic cosmetic packages, and to identify the best solution for the manufacturing of such products. In order to determine these objectives, an extensive LCA study was carried out, based on a case study product produced by Toly Group.

2.1. LCA Methodology

2.1.1. Goal and Scope Definition. The main goal for carrying out this LCA, was to study the environmental impacts of different variations of plastic cosmetic packages and propose environmentally conscious possibilities. The scope of this study is to show how the defined goals can be met with the limitations that are in place. In summary the proposed main takeaways for this analysis were:

- To compare the total life cycle environmental impacts of reusable and recyclable cosmetic packages,
- To consider how the environmental footprint varies with regards to all phases of the plastic cosmetic product's life cycle, i.e. raw material extraction, manufacturing, transportation, use, and end of life,

- To create multiple scenarios by varying different parameters, in order to evaluate how different variables compare with each other, and decide what the most environmentally conscious option would be.

A case study cosmetic package (blush compact) which is shown in Figure 1, was selected and used for the analysis. This product is a small blush powder makeup compact, intended for portable everyday use. The design is relatively simple with the product possessing a circular shape and a pinned hinge design. The main parts that constitute the case are the lid, mirror, base, base plate, and pin. The circular mirror is glued to the inside of the case's lid, and the pin constrains the rest of the components together. The main materials include acrylonitrile butadiene styrene (ABS) for the main housing of the case (i.e. lid, base, and base plate), glass for the mirror, and stainless-steel for the pin that acts as the pivoting hinge. The cosmetic powder itself is contained in a circular aluminium container defined as the pan. This factor makes the product reusable, and users can easily purchase additional pans from retailers once their existing pan has been used up and swap out the old with the new refill whilst keeping the same compact case. An important clarification that shall be defined for the reader's ease of understanding, and that will be used throughout, is the difference between case and compact. The term case refers to the full assembly of the cosmetic case but without housing the pan (i.e. one empty case). On the other hand, the term compact refers to the final end product which is sold to consumers (i.e. one case + one pan). The cosmetic powder itself was excluded from the analysis as this study is only focussing on the packaging components.



Figure 1. *Tivoli cosmetic blush compact.*

2.1.2. Functional Unit. It is critical to establish a clear functional unit when carrying out an LCA study, as this is a quantitative measure of the function of the system being studied and allows for fair 'like with like' comparisons [12]. In this case, the cosmetic blush powder is estimated to last around 18 - 24 months from when it is first opened. Through surveying 20 cosmetic blush users, it was found that a 3.5g cosmetic pan approximately lasts for around 100 uses [13]. If the user uses the blush once a day (i.e. 1 day = 1 use), the user will require approximately four cosmetic pans in one year (365 days). Moreover, the probability that the user will not keep buying pan refills or may wish to change brand increases after 1 year. Therefore, the functional unit for this study was taken to be the usage of cosmetic powder in the period of one year, thus defining the functional unit as the usage of 14g (3.5g x 4 uses) of cosmetic blush powder. This will allow the output quantity of cosmetic powder to always remain constant, whilst being able to compare different versions of compact cases in a fair method.

2.1.3. Inventory Analysis. In the inventory analysis stage, all the required data necessary to model the LCA was researched and/or calculated. The full bill of materials of the existing blush compact is tabulated in Table 1, along with the relevant manufacturing processes utilised for each part. It should be clarified that the cosmetic blush powder was not assessed from an LCA point of view, as this was not

within the scope of this study. It was only inputted in the Bill of Materials to account for its weight during transportation and maintain a higher level of data accuracy.

Table 1. Compact Bill of Materials.

Part	Raw Material	Manufacturing Process	Mass (g)
Lid	ABS HI121H (25% regrind)	Injection Moulding	5.52
	Adhesive Resin	Stock Part	0.05
	Aluminium Foil	Hot Stamping	0.05
Mirror	Silver Coated Glass	CNC Diamond Cutting	5.94
	Adhesive Resin	Stock Part	0.5
Base	ABS P2HAT/792 (25% regrind)	Injection Moulding	2.47
Base Plate	ABS P2HAT/792 (25% regrind)	Injection Moulding	4.17
Pin	AISI304 Stainless Steel	Deep Drawing	0.1
Pan (Full)	Cosmetic Blush Powder	Stock Part	3.5
	Aluminium Alloy (Pan)	Stock Part	2.3
Total			24.6

2.1.4. Impact Assessment. The LCA software used in this study was SimaPro 8.4 [14]. The Life Cycle Inventory database used was Ecoinvent 3, and the chosen method was the ReCiPe 2016 endpoint method (Hierarchist version), which is the default ReCiPe endpoint method [15]. The main impacts which were assessed in this LCA study will resolve around two of the primary ReCiPe endpoints, which are the Human health and Ecosystems endpoints. To better understand what the chosen endpoints represent, it is important to understand how these endpoints are formulated [16]. The Human health endpoint covers the impacts associated with several diseases and malnutrition, while the Ecosystems endpoint covers damage associated to freshwater species, terrestrial species, and marine ecotoxicity amongst others.

2.1.5. Interpretation of Results. The generated results are shown and reviewed in detail in Section 3, along with a detailed discussion of the extracted takeaways from this LCA study.

2.2. Parameters and Scenarios Review

Three primary parameters were analysed in this study. The first parameter is the Number of Case Reuses which relates to the reusability aspect, as by continuing to reuse the existing case and utilising pan refills to reuse the cosmetic compact, the use phase is extended. In the default scenario (Reuse 3 in Table 2), it is assumed that the case detailed in Table 1 is used 4 times (first use and three reuses). In the Reuse 1 scenario, the case was dematerialised by 7% which led to a less robust product, and in turn allowed for less reusability. This concept was also applied to the reuse 0 scenario (single use product), the mass of which was reduced by 17% when compared to the default scenario. It should be clarified that the dematerialisation was applied to all plastic parts, i.e. lid, base, and base plate, and that the percentages were generated by assuming the lowest part thickness possible all around to be that of 1.4mm and 1.25mm respectively (as opposed to the benchmark thickness of 1.5mm). The other two parameters deal with the case and pan disposal scenarios respectively. To summarise, the proposed parameters along with the defined scenarios are listed in Table 2. For all the scenarios, the manufacturing country and

End-of-Life (EOL) country parameters were kept constant as Malta, and the European Union respectively. The terminology (a), (b) and (c) refer to the three different recycling rates of 0%, 50% and 100% recycling respectively. It is assumed that the pan which would be contaminated with cosmetic powder and the glass mirror are landfilled.

Table 2. List of Methodology Parameters and Scenarios.
(LF: Landfilling, REC: Recycling)

Scenario	Values
No. of Case Reuses	0 (17% Dematerialisation)
	1 (7% Dematerialisation)
	3 (0% Dematerialisation)
Case Disposal Scenarios	(a) 100% LF, 0% REC
	(b) 50% LF, 50% REC
	(c) 0% LF, 100% REC
Pan Disposal Scenarios	100% LF, 0% REC

2.3. Methodology Versions Review

The scenarios defined in Table 2, were grouped according to the different versions that they are related to. Version V1(a), is the existing cosmetic blush product with an assumed reuse capability of 3 times, i.e. 4 uses in total. This version shall be considered as the main benchmark against which other versions shall be compared. Version V1A, builds upon the existing product design, but applies 7% dematerialisation to all plastic ABS parts, i.e. the lid, base and baseplate. This reduces its maximum reuse capability, allowing only for the potential of one reuse. Hence, when considering the functional unit, 2 cases and 4 pans were required. Version V2 also builds upon the benchmark cosmetic blush product design, with the main difference being the 17% dematerialisation to all plastic ABS parts. Consequently, this completely eliminated all potential reuse capability, making it a single-use product that is neither reusable nor recyclable, since it houses a pin hinge mechanism making it difficult to disassemble, as well as utilising adhesive which is considered as a contaminant. Version V3, is the single use, fully recyclable scenario. This scenario differs significantly from the rest since this is the only scenario eliminating the use of the aluminium pan and allows blush powder to be added directly into the case. Moreover, this scenario can be recycled due to the assumed design changes taking place, such as by changing the steel pin to a plastic ABS pin, in order to ease sorting difficulties when disassembling. Finally, Version V3E can be considered as the eco-friendly version prioritising sustainability over build quality by trading the standard pin hinge mechanism to a clip-on hinge, which is deemed as poor quality from a consumer point of view. This version has the maximum dematerialisation rate of 17% applied with no reuse capability, as well as being recyclable. A summary of the proposed versions can be observed in Table 3.

Table 3. List of Methodology Versions.

	V1 (a)	V1 (b) (c)	V1A (a)	V1A (b) (c)	V2	V3 (a)	V3 (b) (c)	V3E (a)	V3E (b) (c)
Features	Reusable	Reusable + Recyclable	Reusable + Demat.	Reusable + Recyclable	Single Use + Demat.	Single Use	Single Use + Recyclable	Single Use	Single Use + Recyclable
Case Dematerialisation	/	/	-7%	-7%	-17%	/	/	-17%	-17%
Reuse Capability	3	3	1	1	0	0	0	0	0
Hinge	Steel Pin	Plastic Pin	Steel Pin	Plastic Pin	Steel Pin	Plastic Pin	Plastic Pin	Clip-on Hinge	Clip-on Hinge
% Plastic Recycle	0%	50%, 100%	0%	50%, 100%	0%	0%	50%, 100%	0%	50%, 100%
Pan Design	Reusable	Reusable	Reusable	Reusable	Glued Pan	No Pan	No Pan	Non- Reusable	Non- Reusable

3. Results and Discussion

This section will review the results generated from the LCA study, following the methodology above. It should be noted that the presented results all represent the environmental effects of the functional unit defined previously.

3.1. LCA Results

The resulting comparisons of all seven versions along with their respective recycling subcategories are shown in Figure 2. The results were normalised with respect to the existing version, V1(a), for both endpoints, as this was treated as the benchmark. It should also be noted that similar to other LCA studies carried out, there is a level of inaccuracy in the generated results. A 10% margin of error is overlaid on the results in Figure 2.

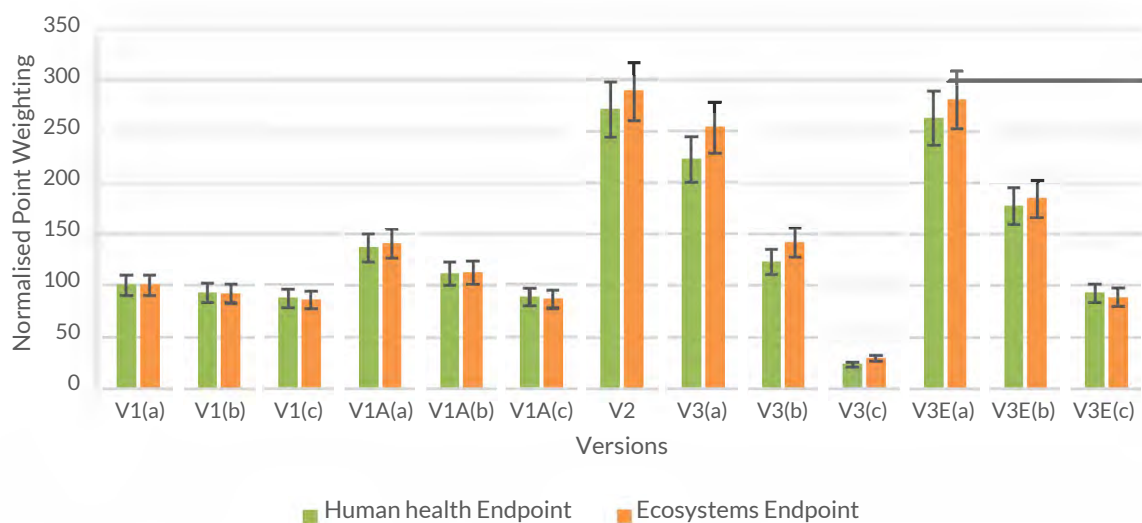


Figure 2. Normalised endpoint life cycle impacts of the different versions (V1(a) = 100).

One primary result that can be observed, is that the positive effect of reusability out ways by far the effects of dematerialisation by 171% when considering the human health endpoint (versions V1(a) vs V2). Another observation is that applying recyclability to a product that is already reusable, does not reduce the environmental impact by a significant amount, as indicated by only a 13% decrease when considering the human health endpoint (versions V1(a) vs V1(c)). In contrast, applying recycling to a single use product, resulted in very large environmental savings of 92% when considering the human health endpoint, and 90% when considering the Ecosystems endpoint (versions V2 vs V3(c)). It can therefore be concluded that the existing cosmetic blush compact performed extremely well when compared to the studied versions. The only argument that should be made when comparing the obtained results of V1(a) and V1(c), is that the recycling aspect throughout the entire study was considered only for plastic parts. This indicates that if the glass mirror and the aluminium pan could be recycled, the results would be far more significant than those registered in this study, especially when considering the large environmental discrepancy between ABS and aluminium, with aluminium having a 48% higher embodied energy and a 73% higher CO₂ footprint than ABS plastic [17]. The only version which performed significantly better than the current scenario (V1) is the recyclable single-use version V3(c). In this scenario, the aluminium pan which enables the case to be reused was eliminated. The environmental benefits resulting from the removed pan and the recycling counteract for the lack of reusability of the product. However, had the modified compact not been recycled entirely at its End-of-Life, the positive effects of the removed pan would be counteractive. In fact, V3(a-b) perform much worse than the benchmark scenarios V1(a-c).

4. Conclusions

There are a number of key takeaways which can be extracted from the LCA carried out in this study. The main takeaway is that the reusable version currently being manufactured, is very well suited when compared to the versions proposed in this research, even if the plastic waste is not recycled. Moreover, any potential improvements on the existing version, such as making the product recyclable in conjunction with it already being reusable, were found to yield very little benefits. However, it was found that if the existing product is not reused, the impacts increase by 171% and 189% for the two respective endpoints (versions V1(a) vs V2).

Only plastic recycling was considered in the study. If the other components (more specifically the aluminium pan) were to be recycled as well, the generated results are expected to be significantly different. Cosmetic packaging manufacturers should research this possibility, as well as study how realistic it is to setup an efficient circular economy recycling infrastructure. Moreover, there is a potential to increase environmental benefits by an average of 74% across both endpoints when compared to the existing product, should the compact design be altered in such a way that the use of the pan is eliminated altogether, i.e. V3(c). This is due to the fact that the pan is made from aluminium, which has significant negative environmental impacts. The main difficulty here is that this change impacts the filler company the most, since with this proposed design it will not pack the cosmetic blush powder in the pan like previously, and instead will have to find a way how to insert the blush powder directly into the case or change the material to a more durable plastic. This raises strength and quality issues since the manufactured case would need to be extremely rigid and durable to withstand the cosmetic blush packing process. This scenario does not really fall within the plastic manufacturer's remit. However, this should be researched further and potentially trialled in collaboration with the powder filler companies, in order to identify if it would actually be viable and feasible to do so. Finally, it can also be concluded that attempting to recycle the plastic case, but not recycling the aluminium pan due to contamination, proves to be almost ineffective due to the fact that aluminium has a high embodied energy and carbon footprint. Therefore, manufacturers should attempt to use materials with less harmful impacts and move towards reusable products comprising recyclable mono-materials.

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