LCA Case Studies

Environmental Evaluation of Single-Use and Reusable Cups

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Abstract

Goal, Scope and Background. The objective of the study was to determine the environmental effects of the reusable cup used during a major event (which took place in Barcelona, Universal Forum of Cultures, 2004), compared with a single-use cup of the same composition (polypropylene) but with different physical characteristics such as mass, shape and capacity.

Methods. To perform the environmental evaluations and the comparison of both types of cups, the SimaPro software developed and marketed by PRé Consultants was used. The environmental evaluation of the reusable cup was compared with that of a single-use cup using the LCA methodology [6]. The functional unit used was: 'Serving 1000 liters of draught beverages'. The objective of the study was to find the minimum number of cycles the reusable cup has to do so that its environmental impact is smaller than that of the single-use cup.

Results and Conclusions. Taking into account all the hypotheses put forward, the study drew the conclusion that the minimum number of uses of the reusable cup necessary for it to have a smaller environmental impact than the single-use cup is 10.
The contribution of each process taking part in the entire life cycle of the cups was also studied in detail. In the case of the single-use cup, the most important contribution to all the impact categories is due to the production of polypropylene and the fabrication of the cup, except for the heavy metals category where it is due to the management of the waste coming from the cup's use.
In the case of the reusable cup being used 10 times, the contribution to the different impact categories of the waste generated by the cup's use is negligible compared to the contribution of the fabrication and washing processes. In addition, the washing process is the one which contributes most to the ozone layer depletion, heavy metals and carcinogens categories.
As the number of uses of the reusable cup increases, the contribution to all the environmental impact categories decreases. However, this reduction is not as significant for the ozone layer depletion, heavy metals and carcinogens categories. This is due to the washing process and the fact that the electrical consumption associated with it increases with the number of washing s and, consequently, of uses.

Recommendations and Perspectives. From the environmental point of view, the reusable cup must be used at least 10 times to have less impact than the single-use cup. This is mainly due to the higher weight of the reusable cup and, therefore, the greater amount of raw material needed for its fabrication. If the LCA methodology had been introduced during the design of the reusable cup, its weight would have been lower. This modification would have resulted in a reduction of the environmental impact associated with the use of the reusable cup and, consequently, a smaller number of uses would have been necessary to attain the same level of impact as the single-use cup.

Keywords: Environmental impact; life cycle assessment; polypropylene; reusable cups; single-use cups

Introduction

One of the most important challenges brought by the new sustainability culture is to develop production and consumption habits more respectful of the environment and, by doing so, to move towards a more responsible consumption model based on efficient use of natural resources during their extraction, transport, processing, use and disposal phases. Among the types of waste that have increased most over the last years, containers and container waste require major attention because of their weight, volume and the aspects associated with their fabrication and disposal. One possible way to reduce waste creation is to use reusable cups in large events.

In this paper the environmental evaluation of the reusable cup is performed and it is compared with a single-use cup, using the Life Cycle Assessment (LCA) methodology [6].

Using LCA methodology, some authors compare or analyze different packaging materials used for distribution of consumer goods [4,11,13]. Other studies assess the reuse and recycling environmental advantages of the plastic packaging materials [10], or the environmental advantages of the reuse versus one-way glass packages [12]

It is difficult to find studies that analyze the environmental benefits of a product like the Forum cup. This kind of cup is only used for a short time period, that is only used during a specific event.

A project funded by the European Commission under the Life Program called 'Smash events' recommends supplying the drinks and food with reusable crockery in order to significantly reduce the amount of waste created during the event. On this project there is not any LCA study in which we can observe the real environmental benefit of this action [3].

1 Description of the Systems and Limits

The system of study for the single-use cup is, practically, of a linear type, which means it does not contain internal loops. The system's steps are: extraction of raw material and its processing, fabrication of the product, delivery, use and elimination. It must be taken into consideration, since they are cups intended for food consumption, that it is impossible to use recycled polypropylene for their fabrication.

The system on study for the reusable cup has an internal loop located at the use step, where the possibility of reusing the previously cleaned cups is considered.

Different scenarios will be considered depending on the work hypotheses that will be seen in section 2 of this paper.

The subsystems being studied are:

- The polypropylene's (PP) production processes.
- The cups' fabrication processes, including facilities' consumption for producing the cups.
- Transport from the factory to the store located in the village of Sant Esteve Sesrovires.
- The use of the cup, taking into consideration different scenarios concerning the reuse of the reusable cup.
- Waste management.

In the case of reusable cups, the acid engraving phase was not taken into consideration because no data were available. If we would have considered this phase, a larger environmental impact associated with the fabrication of reusable cups would be obtained. This fact would imply a greater number of reusable cup uses to have less impact than the singe use cup.

A priori, the number of uses or cycles of the reusable cup are not known. That is why different scenarios will be studied. The objective of this study is to determine at which number of cycles of the reusable cup it starts to have a lesser environmental impact than the single-use cup.

1.2 Definition of the system's function and functional unit

The only function developed by the system is to contain beverages. The basic difference between the two types of cups studied is the reusable character of the cup used at Forum 2004.

The functional unit has to be the same for both systems in order to be able to compare them. The functional unit is '**serving 1,000 l of beverage**' and this means a different number of cups for each specific type of cup.

In **Table 1**, the physical characteristics of the two PP cups are shown.

2 Methodology of the Study

The impact of the two types of cups will be studied, with different numbers of cycles for the reusable cup. In **Table 2**, the studied scenarios are shown.

Next, the data associated with the fabrication subsystem for the cups needed to distribute 1,000 l of draught beverages (5,000 cups = 5,000 uses), as well as the data associated with the fabrication of the reusable cups needed to serve 1,000 l of draught beverages (3,333 uses) are shown (**Table 3**).

Table 1: Physical characteristics of the cups

Physical characteristics	Single-use cup	Forum cup
Capacity (ml)	200	300
Height (cm)	9	15
Weight of a cup (g)	3.20	44.89
Number of cups needed to serve 1,000 liters of draught beverages	5,000	3,333
Weight of cups (kg) equivalent to 1,000 l beverage distribution	16.00	149.63

Table 2: Scenarios studied for the Forum cup

Scenario 1	Scenario 2	Scenario 3	Scenario 4
2 uses (1 cleaning)	9 uses (8 cleanings)	10 uses (9 cleanings)	14 uses (13 cleanings)

Table 3: Inventory table associated with the fabrication of the cups to distribute 1000 l of beverage assuming one use by cup

		Single-use cup	Forum cup
Inputs			
Energy (kWh)		21.03	97.2
Water (l)		0.00	0.00
Raw material (kg)	PP	16.50	166.67
	Cardboard boxes [a]	1.45	7.00
	PP sheet	0.31	0.00
	Colorant	0.00	2.67
Outputs			
Product (kg)		16.00	149.63
Emissions into the air (kg C)	VOC	0.63	5.95 [b]
Emissions into the water (mg)	**Not being considered [c]**		
Residues (kg)	Paper/cardboard	0.023	0.00
	PP	0.010	0.00

[a] Since there is a great variety of models for this type of cup, one of the most standard was taken. Cardboard boxes with dimensions (cm): 35.9 x 28.8 x 58.5 (length x width x height) and with a delivery capacity for the boxes of 2000 units of cups.
[b] Since there is no value of VOC emission for the Forum cup, it was estimated from data of the single-use cup.
[c] There is no water consumption during the fabrication and the only waste waters are the sanitary ones. Since the volume of that type of water depends basically on the number of workers, i.e. the size of the company, it was assumed that both cups are fabricated by companies with an equal number of workers.

The data associated with the fabrication of the single-use cups were provided by a company specialized in the fabrication of, among others, single-use cups, by extrusion and thermoforming.

The data associated with the fabrication of the reusable cup were provided by the company in charge of its fabrication. The process used was mould injection.

Concerning the delivery subsystem, the following data hypotheses have been considered:

- It is assumed that the type of transport used for the delivery to the Forum of both types of cups is the same.
- It is assumed that the distance to travel for each trip (going and coming back) for both types of cups is the same and equal to 15.2 km (Distance between Sant Esteve Sesrovires and Barcelona), for a total distance to travel of 30.4 km.
- It has been assumed that the delivery to the Forum is carried out with 3.5 tons trucks, with a load of 100% when going and 0% when coming back.

Since the delivery is done in cardboard boxes, the weight and environmental effects associated with their production, as well as the waste management of the boxes, were taken into account.

In the case of the reusable cup, the following consideration was taken: All the inputs and outputs of the delivery subsystem were divided by the number of uses of the reusable cup studied in each scenario.

The washing of the reusable cups has to be taken into consideration. In **Table 4**, the real data associated with the washing of 1,500 reusable cups can be seen.

Concerning the use system, the following data hypotheses have been considered:

- The multiple uses of the reusable cup which could be performed without returning it to a food stand will not be taken into consideration. Thus, it is assumed that the cup will be cleaned each time it is used again. Of course, this can not be certain and the cup can sometimes be refilled without being washed, this fact would result in reduced environmental effects for the reusable cup.
- Since there was not any data concerning the quantity of soap used, nor about the emissions into the water, these were not taken into consideration. The number of washing s of each scenario is: Number of uses – 1.

Table 4: Inventory table for the cleaning of 1500 Forum cups

Inputs		
Energy (kWh)		30
Water (l/ cup)		0.27
Material (kg)	Soap	ND
Outputs		
Emissions into the water (mg)		ND
ND: No data available		

Concerning the management of the waste generated by the single-use cups, the following considerations were taken:

- 6.7% of the cups that will not be used anymore are collected separately through recycling bins and will be recovered [7].
- 93.3% of the cups that will not be used anymore are sent to the waste container. Of these, 85% go to the landfill and 15% go to incineration [7].

Concerning the management of the reusable cup waste, it is supposed that:

- 20% of the cups are returned[1]
- 80% of the cups are not returned, of which: 5% will end up in the waste within the precincts of the Forum and 95% continue being used outside the precincts of the Forum (and, therefore, outside the limits of the system studied) [1].

Concerning the waste management of the cardboard coming from the boxes used for the delivery of both types of cups, the following considerations were taken:

- 16.2% is collected separately [7].
- 83.8% of the waste is divided according to the following distribution: 85% goes to the landfill and 15% goes to incineration [7].

It is important to say that recovery and/or recycling of both types of cups result in a reduction of resources consumption for other processes. The study of that saving of resources was not taken into consideration because it goes out of the limits of the system studied. The impact caused by the recycling of the parts collected separately, in any case, was not taken into consideration.

To perform the environmental evaluations and the comparison of both types of cups, the SimaPro software developed and marketed by PRé Consultants was used with the BUWAL 250, IDEMAT 96, RPRé databases [9] The environmental evaluation of the reusable cup was compared with that of a single-use cup using the Life Cycle Assessment (LCA) methodology. The principles and framework of the ISO 14040: 1997 'Environmental management – Life Cycle Assessment' standard were applied [6]

In order to know the real number of reuses carried out with the reusable cup, **Eq.** (**1**) has been used:

$$\text{Real Uses} = \frac{V_b}{(N_s - N_R)\,0.3} \qquad (1)$$

where

V_b, N_S and N_R are the weekly dates of volume of beverages sold expressed in liters, the number of reusable cups sold and the number of cups returned, respectively, and

0.3 is the capacity of reusable cup in liters

The comparison between the real and theoretical number of reuses will show up to the reusable cup's benefit.

[1] Real data coming from DEMAF (Environmental Department of FORUM).

3 Results and Discussion

3.1 Characterization

Taking into consideration the entire life cycle of both types of cups and the different scenarios studied, **Fig. 1** is obtained where the contribution (in percentage) to every impact category of each cup and their reuse scenarios can be seen.

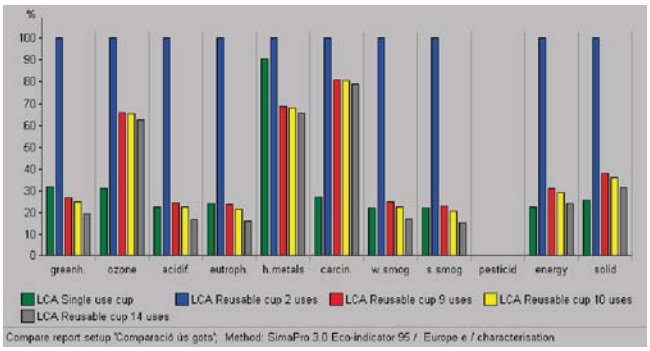


Fig. 1: Comparison characterization LCA cups

The LCA concept includes:

- Fabrication of the cup plus production of raw material,
- delivery of the cup,
- fabrication and waste management of the cardboard boxes,
- washing,
- management of the waste generated during the entire life cycle.

It can be seen that the magnitude of all the environmental impacts decreases as the number of uses by the Reusable cup increases. This reduction is not as significant for the impacts: Ozone layer depletion, heavy metals, carcinogenic compounds. This fact is due to the washing process. It is obvious that the electrical consumption of the washing process increases with the number of washings and therefore with the number of uses. Because of the characteristics of the Catalan energy mix (practically 65% is generated in nuclear power plants [5] the most important impacts are the ones associated with ozone layer depletion, heavy metals and carcinogenic compounds. On one hand, the energy consumption associated with the fabrication of the cups decreases with the number of uses, but, on the other hand, the energy consumption associated with the washing process increases with the number of uses. Still, the decrease due to fabrication is more important than the increase due to washing. This is why the global effect is that the magnitude of the impacts decreases, although slower than the remainder of impacts.

In **Fig. 2**, the contribution of each subsystem to the global life cycle for the Reusable cup 2 uses and Reusable cup 14 uses can be seen. It can also be noticed how, with the number of uses, the washing process gains importance in the impact categories mentioned previously.

The most important contribution to the cup's global impact is due to the production of PP and fabrication of the cup subsystem (green color in Fig. 2). As the number of uses increases, and therefore the number of washings, the washing process gains importance.

3.2 Normalization

The objective of normalization is to put the impacts into perspective by taking a unifying parameter called 'equivalent inhabitant'. The equivalent inhabitant is a parameter used to compare the values from the characterization with the environmental effects a European person would cause in a year. The normalization values are based on average European data from different sources [2,8].

Fig. 3 shows that the impact categories 'carcinogens', 'ozone layer depletion' and 'solids' do not have as much significance anymore.

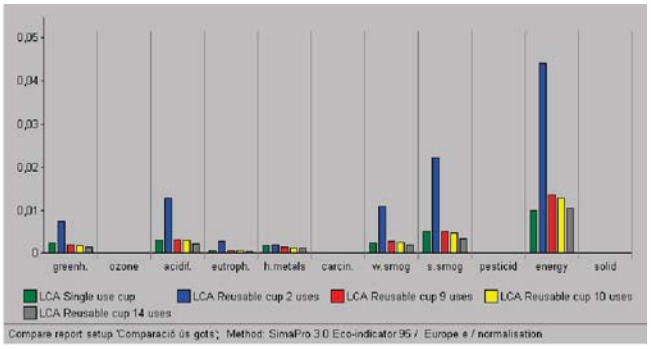
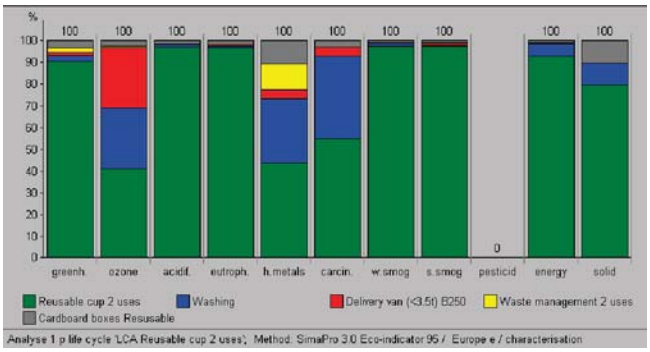


Fig. 3: Comparison of the normalization of the LCA for the different cups



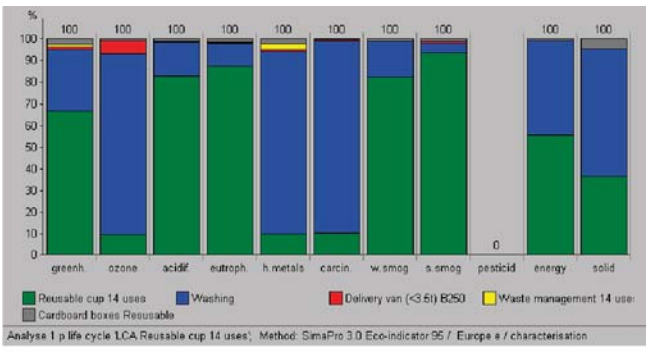


Fig. 2: Contribution of subsystems to the emissions of the Forum cup with 2 uses and 14 uses

3.3 Evaluation

In the normalization, as has been noted in the previous point, the results are calculated in relative terms, but the relative importance of the effects is not taken into consideration.

The indicator (Eco95) [8] is a general name for the result of an evaluation method that produces a single figure for environmental impact. SimaPro can add together all the different environmental effects from the evaluation stage to give a total impact for each material and process in the assembly. The indicator (Eco95) [8,9] for each scenario studied is calculated with **Eq. (2)**:

$$Eco95 = \sum_{i=1}^{n} f_i c_i \qquad (2)$$

where:

C_i is the value calculated in the normalization stage for each impact category considered, and

f_i is the weighting factor for each impact category considered

An impact category could be more significant than another one depending on the region in which it was studied. For that reason, it would be interesting to know the specific data of our geographical area of study in order to be even closer to reality, but due to the absence of such data, the ones provided by Sima-Pro will be used [9] The results are shown in **Fig. 4**.

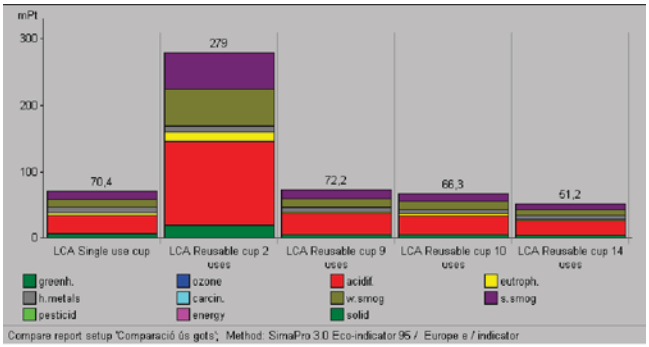


Fig. 4: Eco95 of the LCA of the different scenarios studied

Taking into account all the hypotheses put forward and all that was taken into consideration in the course of this study, the following conclusion can be drawn: the number of uses of the reusable cup necessary for it to have a reduced environmental impact than the single-use cup is 10.

4 Conclusions

Concerning the environmental aspects, the following conclusions stand out as the most important:

- Taking into consideration the entire life cycle of both types of cups, the conclusion can be drawn that the minimum number of reuses of the reusable cup to make the associated environmental impact smaller than that associated with the single-use cup is 10 uses.
- The biggest contribution, for the majority of impact categories, of both types of cups is made by the 'production of PP and fabrication of the cup' subsystems. As the number of uses of the reusable cup increases, the washing process gains importance in the impact categories associated with electrical consumption (considering the Catalan energy mix), i.e. ozone layer depletion, heavy metals and carcinogens.

According to the real data delivered by Forum organization and equation 2, the number of reuses of reusable cups was 1.7. It can be observed that 1.7 reuses are far from the minimum necessary to have a smaller environmental impact than the single-use cup (10 reuses). The difference between the real cup reuses and the theoretically necessary reuses call into question the real benefit of this designed, reusable cup.

5 Recommendations and Perspectives

From the environmental point of view, the reusable cup must be used at least 10 times to have less impact than the single-use cup. This is mainly due to the higher weight of the reusable cup and, therefore, the greater amount of raw material needed for its fabrication. If the LCA methodology had been introduced during the design of the reusable cup, its weight would have been lower. This modification would have resulted in a reduction of the environmental impact associated with the use of the reusable cup and, consequently, a smaller number of uses would have been necessary to attain the same level of impact as the single-use cup.

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