Single-Use Paper Cups Circularity Improvement and Environmental Impact Mitigation Measures for Lappeenranta University of Technology Campus †

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Abstract: This study examines the generation and treatment of disposable single-use paper cups at Lappeenranta University of Technology (LUT) campus located in Finland. The study was carried out within the LUT campus considering take-away venues and the waste collection system, with the intersection of the local waste treatment system. The University was considered as a closed system where different activities and services are taking place. This work contributes to a better understanding of newly adopted circularity measures and application possibilities. The research attempted to evaluate the environmental impacts, and reduction options of disposable single-use paper cups within the Lappeenranta University of Technology (LUT) campus, and measured the circularity indicator of single-use paper cups.

Keywords: paper cups; circular economy; LCA; waste management; resources; packaging; environmental impact reduction; circularity potential; materials management

1. Introduction

The single-use paper cup is one of the attributes of a so-called throw-away society, resulting in the generation of large amounts of hardly recyclable waste and contributing to resource depletion. GreenMatch [1] counts that 16 billion disposable polyethylene coated (PE-coated) paper cups are used each year, which results in 6.5 million trees being cut down each year, 4 billion gallons of water used per year, and the energy amount equates to the amount of power required for 54,000 homes. Single-use paper cups contain a plastic liner as a liquid barrier, which makes them a complicated material for recycling on the global scale. Recycling availability differs from country to country, and impurities in single-use packaging causes even more processing issues. Many global brands are looking for alternative barrier coatings, while other offer systematic changes by delivering circular economy principles as a tool to solve single-use packaging problems. Unsustainable food and beverage supply systems need substantial systematic transformations via services transformation and circular food-beverage service models' integration. Some venues have exceptional potential for single-use packaging circularity, but are still stuck in a linear model due to a lack of measures. Circular Economy concept is represented today as a key driver towards environmental sustainability [2].

Technically, paper cups can be recycled, but the key limiting factors are the recycling technology availability in different markets, economical feasibility, and level of infrastructure. Waste management infrastructure has an important role in delivering sustainable development [3]. In order to increase resource recovery from solid waste, better sorting of household waste is needed [4]. The

main objective of the study is to evaluate the environmental impact and circularity potential of disposable single-use paper cups at a university campus setting, and suggest impact reduction measures. As different venues have different disposable single-use packaging generation amounts, sources, sorting and collecting facilities, and boundaries, the study aims to create additional understanding of venue potential for closed-loop packaging system creation. The research aims at answering five research questions as follows:

1. What are the amounts, types, and main sources of single-use paper cups generated at Lappeenranta University of Technology (LUT) campus?
2. What are the current and optional waste treatment scenarios as well as product alternatives for paper cups in LUT?
3. What are the circularity indicators of current single-use paper cups, and alternative products at LUT campus?
4. What are the environmental impacts of different paper cup scenarios and how much?
5. What measures of the environmental impacts of single-use paper cups can be reduced?

2. Materials and Methods

The research covered several research questions that were investigated by applying both quantitative and qualitative research methods. For a deeper understanding of the phenomenon of interest [5] suggests using mixed methods research, which uses both qualitative and quantitative research methods concurrently and sequentially. Starman [6] agrees that qualitative and quantitative results should complement each other to create a meaningful whole according to the object and purpose of the investigation. The research attempted to answer five research questions.

To answer the first research question (RQ1) and find out the amounts, types, and main sources of single-use paper cups generated at LUT campus, questionnaires and interviews were conducted on site.

To identify current and optional waste treatment scenarios as well as product alternatives for paper cups at LUT and answer the second research question (RQ2), questionnaires and interviews were made with the addition of a literature review.

For the third research question (RQ3), a new product circularity methodology developed by Ellen MacArthur Foundation [7] was applied to provide information on what are the circularity indicators of current single-use paper cups, and alternative products at LUT campus. As noted by the French Packaging Council [8], a **c**ircular economy model in the packaging sector handles all stages of a product's lifecycle—design, production, distribution, use, and recovery—not only recycling.

The fourth research question (RQ4) was answered by using the life cycle assessment (LCA) method and a literature review to identify the environmental impacts of different paper cup life cycle scenarios suggested by answering RQ2. Curran [9] represents Life Cycle Assessment (LCA) as an analytical environmental management tool that captures the overall environmental impacts of a product, process or human activity from raw material acquisition, through production and use, to waste management.

The ISO 14040 standard sets four main phases to perform full environmental LCA: Goal and scope definition, inventory analysis, impact assessment, and interpretation. LCA was performed using SimaPro version 8.0.3, ReCiPe impact assessment method which allows an evaluation of harmonized category indicators both at the midpoint and endpoint levels. Also, the product environmental load can be expressed in a single score. As an assessment method, RecCiPe Endpoint was used. For the calculations, data and processes were taken from the Ecoinvent v.3 database.

Four alternative paper cup waste management scenarios were suggested as potential improvements to the current paper cup scenario:

- S0 (baseline scenario)—PE coated paper cups are being incinerated;
- S1—PE coated paper cups recycling with beverage cartons (S1);
- S2—composting (PLA paper cups);
- S3—paper cup recycling with paper;
- S4—reusable cup system.

In the calculations for paper cups, bleach board paper was used. In S0 and S1, the internal lining of the cup was polyethylene (PE), which was extruded on the paper; in S2, the internal lining was polylactic acid (PLA) coated by the extrusion technique; in S3, a water based latex coating was used to form a barrier and it was dispersed on paper; and in S4, the polypropylene cup was produced by pure primary polypropylene (PP) granules by the injection molding technique. The average transportation distance for both waste treatment and the production plant was 300 km.

In order to provide clear environmental impact reduction measures for single-use paper cups (RQ5), this paper suggests guidelines that are in parallel with the literature review and the results from RQ3 and RQ4. It was assumed that S0 goes to the incineration plant, which is 20 km in distance; S1 goes to the beverage carton recycling plant, which is 100 km in distance; S2 goes to the industrial composting plant, which is 20 km in distance; S3 goes to paper recycling, which is considered to be 20 km in distance; and S4 is reused (washed and dried) at the place.

3. Results

3.1. Types, Amounts, and Sources of Single-Use Paper Cups

The results reveal the amounts, types, and main sources of single-use paper cups generated at LUT campus as well as the current and optional waste treatment scenarios for paper cups at the university. Lappeenranta University of Technology consists of seven buildings, and is connected with Saimaa University of Applied Sciences, and contains seven venues for take-away beverages. The collected data shows that the total approximate amount of single wall take away paper cups generated on campus is 1224 cups per day and vary in size and materials (Table 1). The consumption rate of reusable cups differs from site to site from 10% to 40% of total beverage sales.

Table 1. Paper cup sizes, amounts, and types used at Lappeenranta University of Technology (LUT) campus.

	PE Coated Cups	PLA Coated Cups
8.5 oz/250 mL cup, 11 g	915	-
12 oz/350 mL cup, 12 g	207	60
16 oz/450 mL cup, 14 g	27	15
Total	**1224 cups per day at LUT campus**	

3.2. Current and Optional Waste Treatment Scenarios

The study revealed that waste is sorted in three bins: Dry waste, waste to energy, and compostable waste. The results reveal that both dry waste and waste to energy are being incinerated, and biodegradable waste is being transported to an aerobic digestion plant. As a result, the university waste management system is inefficient, does not support waste management hierarchy, and the sorting system does not perform its function. Four alternatives are suggested with respect to materials' circularity. In addition, the environmental impacts of different paper cup life cycle scenarios are presented and their circularity indicators are investigated.

3.3. Environmental Impact Assessment and Circularity Potential

Environmental impact assessment was applied for four scenarios (see Figure 1b). The functional unit for this method was 1000 cups to serve 250 mL of hot drink per use at LUT campus per day. The scenarios that perform best in terms environmental impacts and circularity were further investigated and impact reduction measures are suggested (see Figure 2).

The midpoint results show that polypropylene (PP) reusable cup production causes the biggest impact on all impact categories, as well as PE coated paper cups and water based coating paper cup production (see Figure 3).
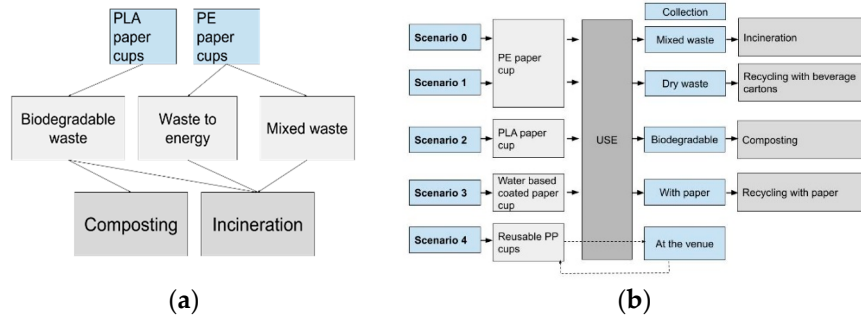
Figure 1. Current and optional waste treatment scenarios: (**a**) Current paper cup sorting and waste treatment at LUT campus; (**b**) alternative paper cup waste management scenarios.
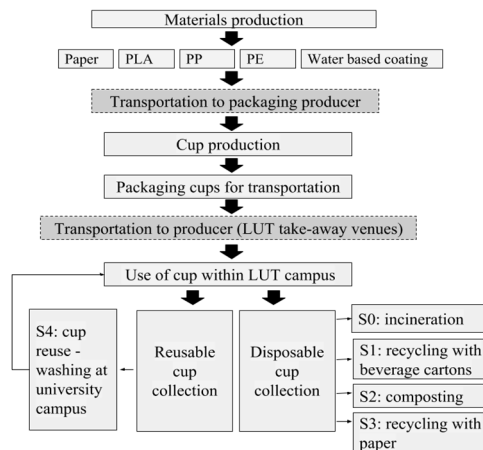

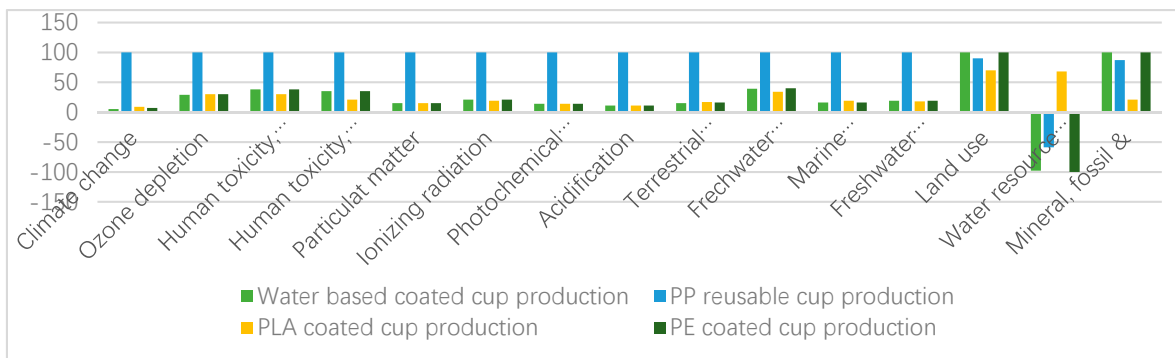**Figure 2.** General process flow diagram.

Figure 3. Midpoint results of five different cup production scenarios.

Comparing both the production and waste treatment (reuse) of different scenarios, the midpoint results reveal that S2 (composting) and S4 (reuse) have the lowest impact on the environment, while S0 (incineration) has the greatest negative impact on all impact categories (see Figure 4).

In S0, it was considered that 100% of PE coated paper cups are being incinerated with the municipal waste stream, while in S4, it was considered that 100% of PP cups are being reused, causing no waste.

Furthermore, S1, S2, and S3 were analyzed separately to find out the second scenario with the lowest environmental impact. As showed in Figure 5, the single score results indicate that the second best alternative is the composting of PLA coated paper cups (S2), while the recycling with beverage cartons has the biggest environmental impact on all categories.
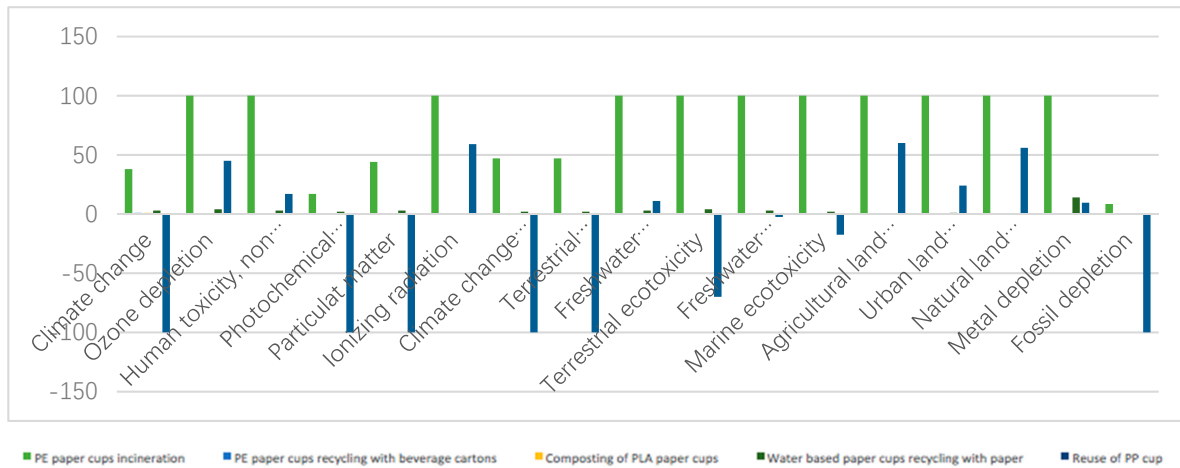
Figure 4. Midpoint results of five different cup scenarios for production and waste treatment.
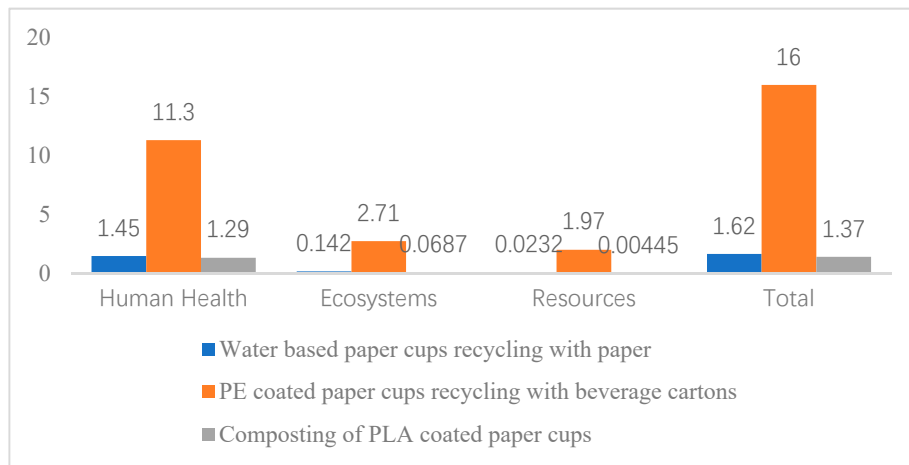

Figure 5. Single score results of three paper cup scenarios (S1, S2, and S3).

However, more precise data was needed for LCA calculations in order to evaluate the very precise impacts of each category—there can be some deviations and inexactitudes.

For the further circularity evaluation, two best scenarios (S2 and S4) were investigated under Ellen MacArthur Circularity Indicators Methodology. The PLA paper cup material circularity indicator (MCI) was 0.12; and the MCI of the PP reusable cup was 0.975 (see Figure 6). The calculations show that the PP cup reuse has a higher MCI (material circularity indicator) than the PLA paper cup composting. On the other hand, the calculations should be revised in a more accurate manner. Also, the calculation methods did not provide deeper process analysis and choices, so deviations and inaccuracies are plausible.

According to the Ellen MacArthur Circularity Indicators Methodology, the MCI assigns a score between 0 and 1 to a product to assess how restorative or linear the flow of the materials is for the product. A linear product equals 0, while a fully circular product is 1.
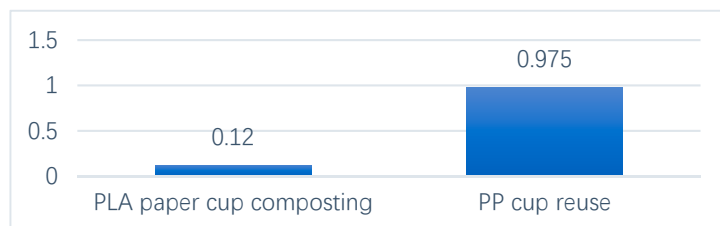

Figure 6. Material circularity indicator (MCI) of the polylactic acid (PLA) paper cup and polypropylene (PP) reusable cup.

4. Conclusions

Single-use paper cups are widely used in different venues, such as universities. These results can be utilized in other venues as well, at least in Finland with similar waste treatment methods available. Thus, the environmental burden related to single-use paper cups could be reduced also outside the LUT campus. Further research is being performed in order to obtain the whole picture of this study. The final results reveal that the PP reusable cup is more circular to the PLA paper cup. As a suggestion, a reusable beverage cup system could be good alternative to the current single-use beverage packaging system at LUT campus.

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