Comparative Life Cycle Assessment of Alternative Packaging Materials for Beverages

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Abstract The study assesses the potential environmental impact of several widely used packaging systems: polyethylene terephthalate bottles, glass bottles and aluminium cans. The functional unit was defined as packaging necessary for distribution of 1000 L of beverage. The reference flow also included labels and closures, transport packaging (corrugated cardboard, trays, disposable foil and wooden EUR pallets). Data were sourced from Ecoinvent 3.2 and ELCD 3.2 databases as well as beverage manufacturers. OpenLCA software was used for LCA modelling. The environmental impacts were estimated using the CML 2001 method. Under the assumptions made in this study, drinks packaged in PET bottles have the lowest environmental impact, followed by aluminium cans. Extraction of raw materials for primary packaging has the highest environmental impact, while the end-of-life and transport phases affect the results less than expected.

Keywords: life cycle assessment, packaging materials, beverage, environmental impacts, OpenLCA.

University of Maribor Press

DOI https://doi.org/10.18690/978-961-286-353-1.21
ISBN 978-961-286-353-1

1 Introduction

Packaging contributes significantly to the environmental impact of product manufacturing. The packaging life cycle is often longer than the product itself and it often has greater environmental impact than the product does. Packaging is thus one of the most intensely studied areas of Life Cycle Assessments (LCA). LCA enables us to evaluate the environmental impacts of packaging throughout the life cycle of production, from raw material extraction through material processing, production, distribution, use, repair and maintenance, to eventual disposal or recovery. Using LCA, it is possible to identify key process stages of manufacturing that have the greatest environmental impact. Since this analysis focuses on the entire life cycle, it prevents shifting the environmental burden from one stage of the life cycle to another (i.e. from production to raw material production).

In the research cooperation of our university with Slovenian companies, there is growing interest in performing LCA of selected products, or even the entire company. LCAs are increasingly being recognized as a tool for improvement and innovation, and a way of reducing environmental impact. In line with these trends, we expect that the use of life cycle thinking in leading Slovenian companies will intensify in coming years. Those companies that have already set out to perform an LCA analysis often face many practical questions about approaching practical life cycle assessment.

Therefore, we aim to promote LCA analysis as currently the most suitable method for assessing environmental impacts. There is extensive research on the environmental assessment of different packaging systems for different products (Saleh Y., 2016; Hischier *et al.*, 2010; Pagani *et al.*, 2015; Amienyo *et al.*, 2013; Navajas *et al.*, 2017). However, the purpose of this study is to assess the potential environmental impact of disposable beverage packaging available on the Slovenian market. It provides a practical example of evaluating the packaging systems of polyethylene terephthalate bottles (PET), glass bottles (GL) and aluminium cans (ALU). The value of this research is not only in the results of the analysis; it is also intended to provide supporting information for easier and more intensive use of LCA analysis. This will provide businesses with a tool to support decision making on environmental policy and make it easier to choose from different production options with comparable characteristics. In case of interest, we will present this study and similar examples as part of a professional training workshop on LCA using the OpenLCA software tool.

2 Materials and methods

2.1 Aim and scope of the study

Our aim is to evaluate the environmental impact of the following packaging systems: polyethylene terephthalate bottles (PET), glass bottles (GL) and aluminium cans (ALU). The analysis was performed on some of the most commonly used 0.500 L containers.

Six indicators of potential environmental impacts were considered in the analysis: global warming potential (IPCC, 2013), ozone depletion (WMO, 2006), acidification (Hauschild and Wenzel, 1998) and eutrophication (Heijungs *et al.*, 1992). The reference units concerned are kg CO_2 equivalent, g CFC-11 eq., g SO_2 eq. and g PO_4 eq.

The environmental impact assessment of packaging was carried out using OpenLCA 1.9.0 software. The study was conducted according to the methodology of life cycle assessment ISO 14044: 2006 (ISO, 2006).

2.2 Functional unit

The functional unit was defined as the packaging required to fill and distribute 1000 L of beverage to the point of sale. The reference flow of the production system included beverage packaging (aluminium can, glass and PET bottles, labels and closures) as well as transport packaging (corrugated cardboard, trays, disposable foil, wooden EUR pallets) required for filling and distribution of 1000 L of drink.

2.3 System boundaries

The geographical boundary of the study is within the typically used production processes and waste management practices within the EU. We assessed the potential environmental impacts of the entire life cycle of each packaging system approach (cradle-to-grave). This means that the packaging systems included all stages from raw material extraction to final waste processing. The waste management processes evaluated were disposal, recycling and incineration. Due to lack of data, the following activities were excluded from the system boundary:

- production and packaging of the beverage and its ingredients,
- mass flows contributing less than 1 % to total mass flows,
- transportation of consumers to buy drinks.
- The life cycle of the beverages is shown in Figure 1. The systemic boundary of the study includes the following stages of the life cycle:
- production of primary packaging, including bottles, aluminium cans, PET bottles, aluminium and polymer caps (HDPE), Kraft paper and polypropylene (PP) labels; production of secondary packaging materials, including corrugated cardboard, Kraft paper, low density polyethylene (LDPE) and wooden pallets,
- waste management: recycling and disposal,
- transport of raw materials, packaging materials and transport of the beverage to the retailer along the life cycle.

The product itself, i.e. drink, was not included in the analysis. This means that the filling process was also not studied.

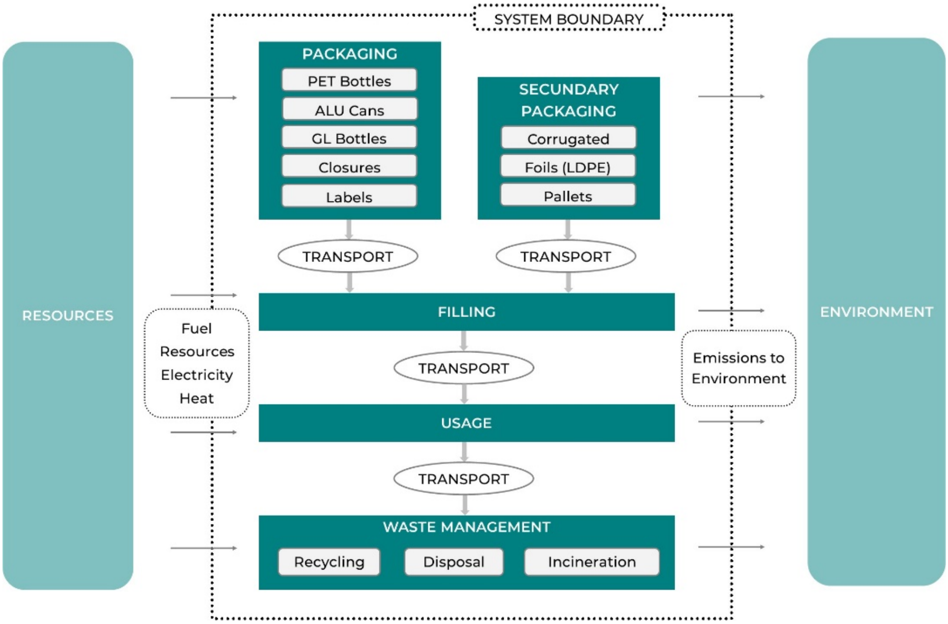

Figure 1: System boundaries.

3 Life cycle inventory

The LCI (Life Cycle Inventory) quantifies the use of resources (energy and materials) and environmental emissions associated with a specific product life cycle.

3.1 Process diagrams

This section presents process diagrams created with OpenLCA 1.9. Figure 2 shows the process diagram of the life cycle of aluminium packaging, Figure 3, the diagram of glass packaging and Figure 4, the diagram of production of PET packaging.

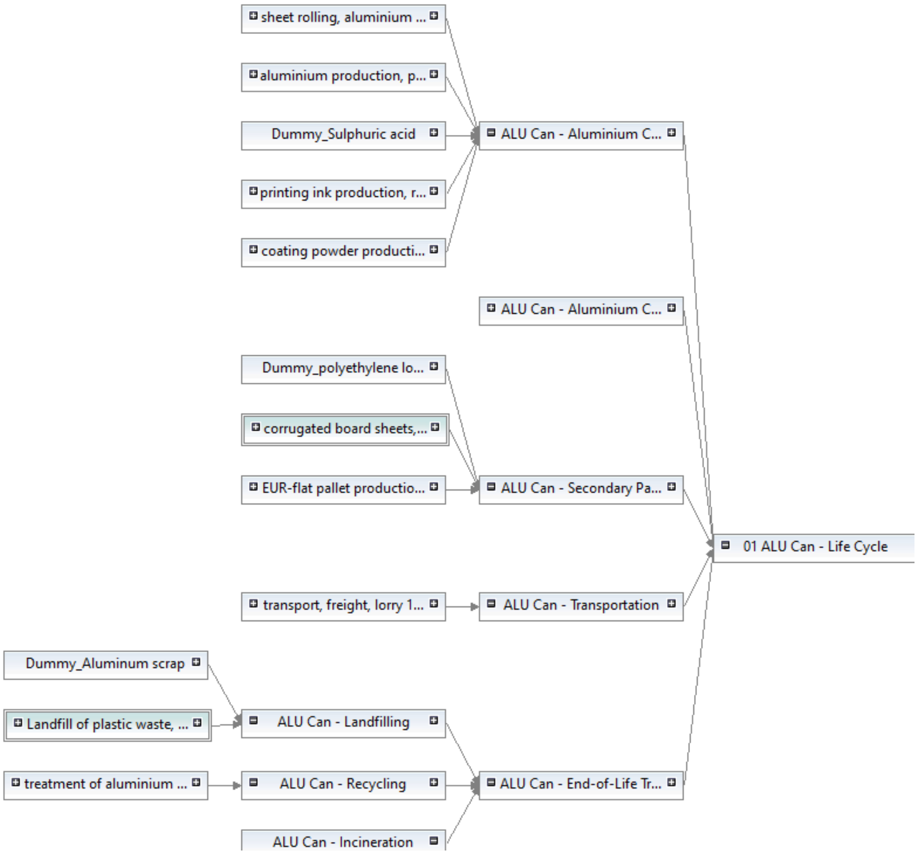

Figure 2: Process diagram of the life cycle of aluminium packaging.

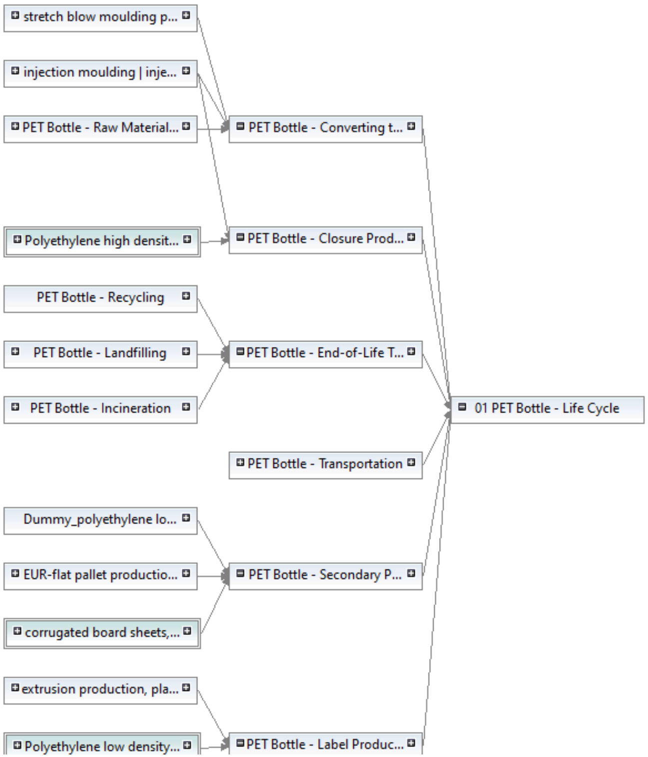

Figure 4: Process diagram of the life cycle of PET

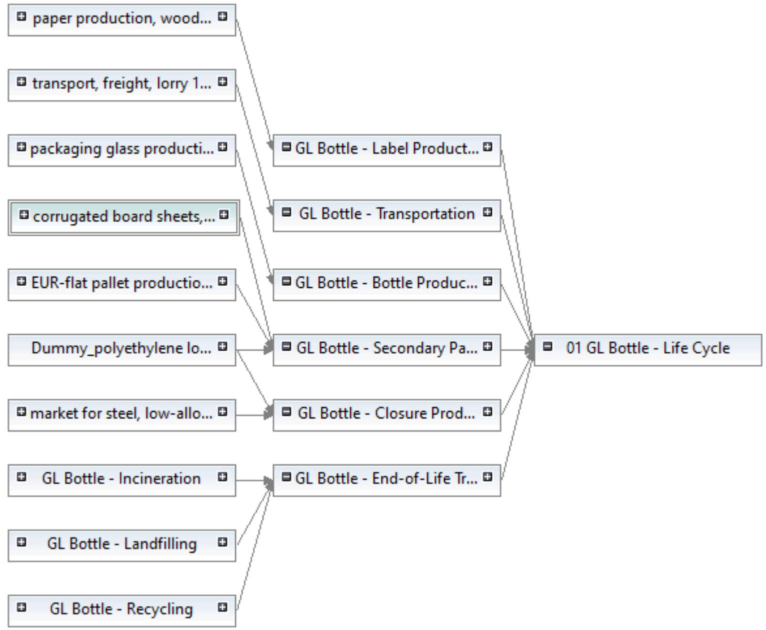

Figure 3: Process diagram of the life cycle of glass.

3.2 Inventory data and assumptions

Inventory data were obtained from the Ecoinvent 3.2 databases (Ecoinvent, 2016) and the European reference Life Cycle Database of the Joint Research Center, Version 3.2 (ELCD, 2015) and beverage manufacturers.

Primary production data were obtained from the literature, including quantities of primary and secondary packaging materials (Amienyo *et al.*, 2013; Klöpffer *et al.*, 2011). The types and quantities of primary and secondary packaging are summarized in Table 2. Bottle closures are made of 84 % aluminium alloy and 16 % low density polyethylene (LDPE) (Amienyo *et al.*, 2013). Green packaging glass made from a mixture of primary and secondary raw materials (average European situation based on the BAT document EU-IPPC on BAT on the Glass Industry (Scalet *et al.* 2013) was considered for the analysis of the bottles. Aluminium cans are made of primary and secondary aluminium.

PET bottles are made from 80 % virgin material and the rest from recycled PET fibres, as is the case with Zala water (Pivovarna Lasko Union, 2019). The stoppers are made of high-density polyethylene (HDPE) and the LDPE label.

As shown in Table 2, secondary packaging includes various materials and systems such as cardboard, LDPE foil and wooden EUR pallets.

The analysis considered the transport routes (Table 1) for individual transportation stages/sections. The distances considered were chosen according to our own assumptions and they do not represent the real case distances. However, they were included in the analysis to determine the indicative contribution of transport to the overall environmental impacts of the analysed system. The analysis considered transport by 16-32 ton trucks, EURO 5.

Table 1: Considered transport routes for individual transportation stages/sections.

Transportation routes	Segment	Distance [km]
Level 1	from raw material production to production site	230
Level 2	from the production site to the filling of the drink	30
Level 3	from central warehouse to point of sale	133
Level 4	from the point of sale to the waste centre	20
	TOTAL:	**413**

Table 2: Specifications of the estimated aluminium (ALU), glass (GL) and plastic (PET) packaging system.

Packaging components	Amount [kg/FU] ALU	Packaging components	Amount [kg/FU] GL	Packaging components	Amount [kg/FU] PET
PRIMARY PACKAGING	**34.19**	**PRIMARY PACKAGING**	**966.04**	**PRIMARY PACKAGING**	**56.95**
Body (52 % recycl. ALU)	26.60	Glass (35 % recycl. green GL)	960.00	Bottle (PET)	49.3
Closure (ALU)	5.70	Closure (84 % alu alloy and 16 % LDPE)	4.04	Closure (HDPE)	6.03
Coatings	1.83	Labels (Kraft paper)	2.10	Labels (LDPE)	1.62
Inks	0.06				
Sulfuric acid	0.40				
SECONDARY PACKAGING	**14.31**	**SECONDARY PACKAGING**	**28.79**	**SECONDARY PACKAGING**	**9.61**
Corrugated cardboard	13.60	Corrugated cardboard	25.20	Corrugated cardboard	8.90
Foil (LDPE)	0.71	Foil (LDPE)	3.59	Foil (LDPE)	0.71
Pallets (mass in kg)	25.0	Pallets (mass in kg)	25.0	Pallets (mass in kg)	25.0
Pallet type	EUR	Pallet type	EUR	Pallet type	EUR
Number of bottles per pallet	**1848**	**Number of bottles per pallet**	**320**	**Number of bottles per pallet**	**960**
Number of pallets per FU	**0.54**	**Number of pallets per FU**	**3.13**	**Number of pallets per FU**	**1.04**

4 Life cycle impact assessment

The aim of this phase is to transform inventory results into different types of environmental impacts. Impact categories considered in the Life Cycle Impact Assessment (LCIA) include acidification, eutrophication, global warming and ozone depletion. LCI-derived emissions and resources were assigned to each of these impact categories. They were then converted to indicators using factors calculated from EIA models (EC, JRC and IES, 2011). The OpenLCA software tool was used to model the LCA. Environmental impacts were assessed using the CML 2001 method.

4.1 Results

Table 3 shows a comparison of the packaging systems analysed for each environmental category. Figure 5 shows a comparison of the packaging systems analysed for different environmental categories. Bottle production contributes most to the impacts in virtually all the estimated impact categories (except in the ozone depletion category, where can production has a greater impact). This is because of the higher mass of bottles and the energy-intensive process to maintain the high temperatures required in the furnaces. Bauxite, used as a source of aluminium in cans, is a major contributor to the ozone depletion indicator. PET bottles show the least environmental impact in all categories. Their lower impact can be attributed to the lower impacts of material and production and their mass. This also reduces the effects of transport and end-of-life disposal.

Based on these results, it can be concluded that the glass bottle making process has the greatest environmental impact, since it contributes most to almost all categories of environmental impacts. This is followed by the production of aluminium cans.

Table 3: Comparison of analysed packaging systems for individual environmental categories.

Impact Category	ALU	GL	PET	Unit
Acidification Potential	2.72	7.56	1.27	kg SO_2 eq.
Eutrophication Potential	0.77	1.08	0.17	kg PO^{4-} eq.
Global Warming Potential	419.30	930.32	245.50	kg CO_2 eq.
Ozone Depletion Potential	0.17	0.12	0.02	g CFC-11 eq.

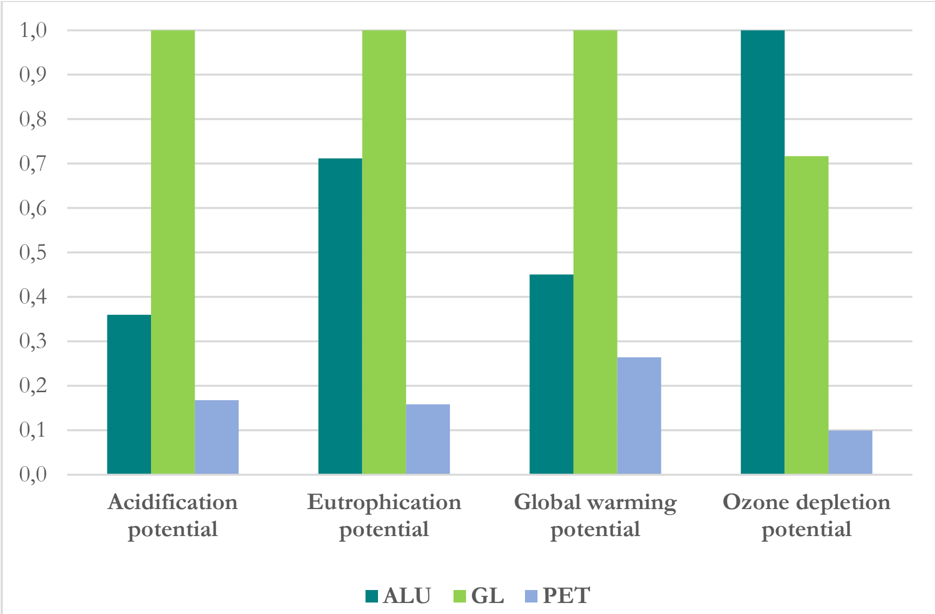

Figure 5: Comparison of the analysed packaging systems for individual environmental categories (relative result).

Figure 6 shows the contributions of each process phase to the global warming potential (GWP). The individual phases are divided into the production of packaging, closures, secondary packaging, labels, transport and waste management (GWP is used as an example as one of the impact categories).

Extraction of raw materials and their transformation into primary packaging contributes most to the environmental profile of beverage packaging systems. Therefore, attention must be paid to the selection of packaging material in the environmental planning of packaging. Nevertheless, the production of secondary packaging is also important. Further, it can be observed that the end of life and the transport phase affect the final values of the indicators less than would be expected.

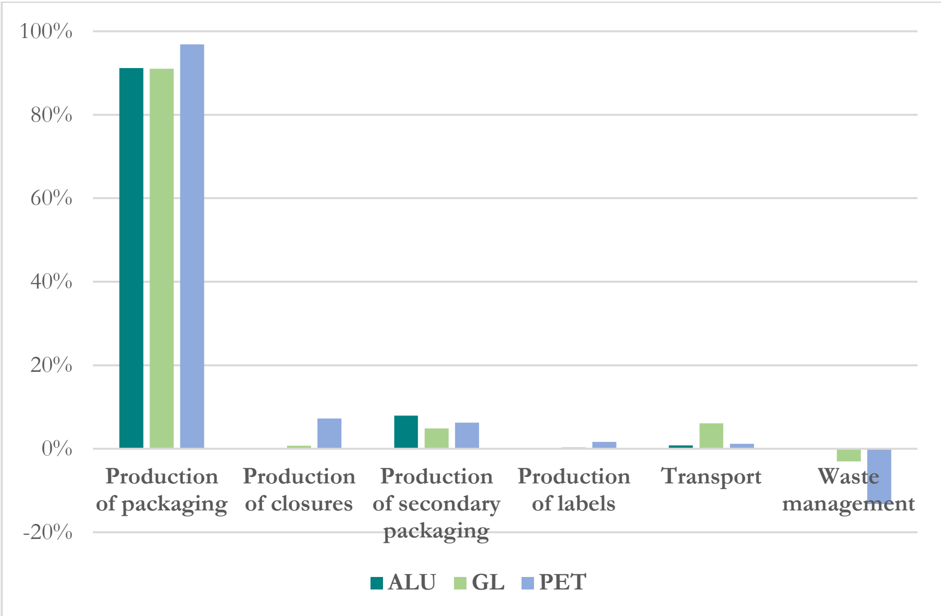

Figure 6: Contributions of individual process phases to global warming potential (GWP).

5 Conclusion

We evaluated the impact of three packaging systems for the distribution of 1000 L of pre-filled beverage (cans, plastic and glass with a single unit filled with 0.5 L).

The results show that the production phase contributes most to the overall environmental impacts of global warming potential (around 90 %). Therefore, this phase needs to be addressed most and packaging should be designed according to eco-design guidelines. The main factors behind this result are the type and amount of material used. There is a likely correlation between bottle weight and environmental impact. However, this is not true for aluminium cans, which are the lightest in weight but nevertheless have a greater environmental impact than PET bottles. It should be noted that the single use system has been evaluated as one of the most common practices. Considering the bottle return system, glass bottles are likely to exhibit lower environmental impact, but additional bottle cleaning processes, return transport etc. would have to be considered in this case.

Our analysis shows that PET bottles are the least burdensome among the systems evaluated, followed by aluminium cans and finally non-returnable glass bottles.

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