# Identification of Environmentally Friendly Alternative for Laundry Detergent Packaging

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## ABSTRACT

**Purpose:** The objective of the study was to analyse and evaluate two alternative liquid detergent packaging systems from the point of view of their overall environmental impact. Using the LCA method, we have come to the conclusion that cardboard packaging is an alternative with a lower negative impact on the environment than an HDPE bottle.

**Methodology/Approach:** The study is based on the LCA method implemented through the software openLCA, including available databases.

**Findings:** The environmentally friendlier alternative of the detergent packaging is identified. The decisions about individual stages during LCA must be made with caution and well documented to ensure credibility of the results.

**Research Limitation/Implication:** The findings of the presented study are limited by the available data used for the environmental impact assessment. The inventory analysis was performed for the conditions of the central European region.

**Originality/Value of paper:** This study applies LCA methodology to present the details of a decision process involved in selecting better environmental alternative of the product. The information generated by the study is directly applicable in the industry.

**Category:** Case study

**Keywords:** packaging material; environmental aspect; environmental impact; life cycle assessment

## 1 INTRODUCTION

Over the last hundred years, there has been a sharp increase in the types and amounts of pollutants, some of which are synthetic substances, which long-term consequences for our planet we do not know, yet (Hill, 2017). Along with the development of science and technology after the Industrial Revolution, the population grew, resulting in increased demands on natural resources, an increase in produced waste triggering a series of subsequent serious problems such as climate change, soil and water contamination.

In order for humanity to be able to meet all the requirements of the sustainability and thus create a way of functioning of a society with a high emphasis on environmental responsibility, it is necessary to create a suitable economic environment. The level of sustainability may be assessed according to criteria like: level of process management, the quality and quantity as an optimum, acceptance by customers (Slimák and Zgodavova, 2011).

At present, the Slovak economy, as well as that of many other countries, is based on a linear model. The linear economy works on the principle "extract – produce – throw away". This means that we extract the raw materials needed for production, turn them into a specific products and, after using these products, throw them in a landfill and do not deal with its recyclability, renewability or recovery (Lacy, Longen and Spindler, 2020). In the circular/circulatory model, the fundamental idea is product reuse, while the objective is to minimize or eliminate waste. In this type of economy, two types of materials are used – biological (renewable) and technical (non-renewable but recyclable materials, which constantly move between production and consumption with minimal loss of quality or value). The circular economy sees waste materials as a resource (Lacy and Rutqvist, 2015).

At present, the trend towards the circular economy becomes ever more notable. This change requires the cooperation of all parts of society, from consumers, through developers to politicians. Regulations within member states or the European Union are also important – if there are no economic incentives for eco-business, the transition will not be easy (Sillanpää and Ncibi, 2019).

Directive 94/62/EC of the European Parliament and of the Council of 20 December 1994 on packaging and packaging waste lays down European Union rules on the management of packaging and packaging waste. The Directive aims to harmonize national measures concerning the management of packaging and the waste from packaging and increase the quality of the environment prevention and elimination of the impact of packaging and waste from them. The scope of the directive covers all packaging that is placed on the European market, as well as all packaging waste, whether used at industrial level, in shops, households, regardless of the material used. The directive requires EU countries to take measures and use economic instruments to prevent the generation of packaging waste and to minimize the environmental impact of packaging.

The directive sets a limit for at least 60% of waste to be recovered (including incineration), 55% to 80% of packaging waste recycled, where the minimum values for individual materials are set as follows: 60% for glass, paper and cardboard, 50% for metal, 22.5% for plastics, 15% for wood. This goal was best met by Finland in 2018 with a recovery of up to 114.6% (a rate of more than 100% can be explained by the storage and subsequent recovery of waste generated in previous years). Slovakia has reached the set limits – the share of recovered packaging waste was 69.1% and that of recycled packaging waste 66.6% (Smernica Európskeho Parlamentu A Rady 94/62/ES z 20. decembr... - EUR-Lex, 2020). EU countries are required to increase the share of reusable packaging and systems in a way that is environmentally acceptable without compromising food safety or consumer safety, including repayable advance schemes or even economic incentives. Member States are also obligated to take the necessary measures to meet the recycling targets: at least 65% of all packaging waste must be recycled by 31 December 2025 and 70% by 31 December 2030, at the latest.

According to the Statistical Office of the European Communities, published on 10 December 2020, the packaging waste generated in 2018 averaged around 174 kg per capita in the European Union. The published data represented data made available by individual EU Member States between 2008 and 2018. The total amount of packaging materials produced has increased by 6.7 million tonnes since 2008, or about 9.4%. Packaging waste produced in 2018 alone accounted for 77.7 million tonnes, of which 40.9% was paper and board, 19% plastic, 18.7% glass, 16.1% wood and 5% metal – these materials are the most widespread packaging materials in the EU. Other materials accounted for less than 0.3% (Packaging waste statistics, 2021). In Slovakia, according to the latest available data from the years 2017/2018, the amount of waste produced was 13 million tonnes, of which about 350,000 tonnes accounted for packaging and waste from packaging (Lieskovská, and Lényiová, 2019).

The packaging is defined as a means or set of means that protect the product from damage or loss, caused by adverse events that could occur during handling, transport, storage, sale or use (Pernica, 1994). At present, the most widespread packaging material for laundry detergents is a plastic bottle. This study presents a cradle-to-grave quantitative assessment of two different packaging for liquid laundry detergent. The proposed alternative is to pack and sell the liquid detergent in a paper container. Life cycle assessment (LCA) is a quantitative method that focuses on the entire product life cycle. LCA is one of the most frequently employed approaches for an environmental evaluation of products and processes. The purpose of this work is to present an alternative packaging system and characterize its environmental aspects and their impacts using the LCA method. The main goal of this study is the environmental evaluation of plastic bottle and paper packaging, to decide which option has lower negative impact on the environment.

The packaging system represents the goods, packaging and packaging process. It is necessary to approach the packaging system comprehensively in order to achieve a functional and economic optimum with the given means. The choice of packaging method must help to integrate packaging technology with production technology into a continuous material flow with a link to a continuous flow outside the production organization (Sixta and Macat, 2005).

Each part of the packaging life cycle, from raw material recovery to disposal, has its own specific requirements. These individual requirements may be compatible with each other, e.g. the packaging should be solid and watertight, or they may be in conflict with each other, e.g. the cover should be strong but at the same time light.

## 1.1 Product Life Cycle Assessment

A product life cycle is defined as all stages of a product's life from the extraction of the raw materials needed for its production, through the production of the product itself, its use and finally, disposal (Jolliet et al., 2015). Product LCA is the process of collecting and evaluating the inputs, outputs and potential environmental impacts of a product throughout its life cycle (Hauschild, Olsen and Rosenbaum, 2018). The International Organization for Standardization (ISO) has issued a series of standards and technical regulations for LCA – ISO 14040 listed in Table 1, which constitute a very important tool for environmental assessment.

*Table 1 – Overview of the ISO Standards for LCA*

| **Designation** | **Title** |
|---|---|
| ISO 14040:2006 | Life cycle assessment — Principles and framework |
| ISO 14044:2006 | Life cycle assessment — Requirements and guidelines |
| ISO 14045:2012 | Eco-efficiency assessment of product systems — Principles, requirements and guidelines |
| ISO 14046:2014 | Water footprint — Principles, requirements and guidelines |
| ISO/TR 14047:2012 | Life cycle assessment — Illustrative examples on how to apply ISO 14044 to impact assessment situations |
| ISO/TS 14048:2002 | Life cycle assessment — Data documentation format |
| ISO/TR 14049:2012 | Life cycle assessment — Illustrative examples on how to apply ISO 14044 to goal and scope definition and inventory analysis |
| ISO/TS 14071:2014 | Life cycle assessment — Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006 |

LCA covers a wide range of environmental issues, not just single specific one. The main reason for considering several environmental aspects is to avoid the so-called "Burden shifting", which means that if we focus on reducing only one impact, we may inadvertently ultimately increase other types of environmental impacts (Hauschild and Huijbregts, 2015).

LCA is a quantitative method. It answers the question: “How much can a product system affect the environment?” Being quantitative means that this method can be used to compare the environmental impacts of different processes and products, for example to assess, which products or systems are more suitable for environment, or to point out the processes that contribute most to the overall impact and should therefore be given more attention. We obtain the result by mapping all used sources and emissions (if possible, taking into account the geographical location of the factors) and using mathematical models to calculate the potential impacts of all factors (Jolliet et al., 2015).

## 1.2 Advantages and Disadvantages of LCA

The main advantage of this method is its comprehensiveness, as it deals with the whole life cycle and all kinds of environmental aspects. This makes it possible to compare the environmental impacts of product systems, which consist of hundreds of processes representing thousands of used sources and emissions. This complexity is also a disadvantage of this method, as it requires simplification and generalization when modelling the product system and its impacts, which hampers the calculation of real and accurate environmental impacts. More precisely, therefore, the LCA calculates their potential impact (Hauschild, Olsen and Rosenbaum, 2018).

Strength of the comparative LCA method is that it follows the principle of best estimate. This generally allows for an objective comparison, as the same level of caution is applied throughout the impact assessment. The disadvantage of the method being guided by the principle of best estimate is that LCA models are created on the basis of average process performance, without taking into account the probability of the occurrence of an adverse event. For example, according to the LCA, nuclear energy is considered to be environmentally friendly because it does not take into account the small chance of an accident that would have a catastrophic impact on the environment. The disadvantage of this method is that while it can tell us which system has a lower environmental impact, it cannot tell us whether the system is sufficiently environmentally friendly (Hauschild and Huijbregts, 2015).

## 2 METHODOLOGY

The LCA method consists of 4 main phases: definition of objectives and scope, inventory analysis, impact assessment, and life cycle interpretation (Curran, 1996).

Definition of objectives and scope

The first step is to clearly and unambiguously define the goals of the method. This step serves to define how much of the life cycle will be included in the evaluation and what the evaluation will be used for. It describes the criteria for comparing systems and the timeframe in which the evaluation will take place.

Inventory analysis

This phase is also called LCI – Life Cycle Inventory. At this stage, the inputs and outputs of the product are summarized throughout its life cycle. Quantitative data and calculations are a key element of this step. The first step is to write down all the material and energy flows that enter the processes. The data must be consistent and in relation to the functional unit. The result is a system that provides information on all inputs and outputs in the form of an elementary environmental flow from a functional unit of a given process, with each input/output quantified (Hauschild, Olsen and Rosenbaum, 2018).

Life cycle impact assessment

This phase is also called LCIA – Life Cycle Impact Assessment. It is focused on assessing the significance of potential environmental impacts. ISO has defined mandatory steps that must be followed:

- Selection of impact categories, indicators and model characteristics;
- Classification – to assign the results obtained from the inventory analysis to specific categories;
- Characterization – in this step the emissions are recalculated in units of mass or volume, i.e. the potential environmental impacts in a specific category are quantified (for all categories it is necessary to select a unit that will express the degree of possible damage – category indicator) (Curran, 2012);
- Interpretation – in the final stage there is a summarization and evaluation of the results of the inventory and evaluation phases with respect to a predefined purpose. It is a process in which the main environmental aspects are identified and ways are sought to reduce the environmental impacts of the system. This phase should provide the clear and practically applicable information needed to make the right decision (Jolliet et al., 2015).

## 2.1 LCA of Detergent Packaging Systems

The objective of this work is to quantify and compare the environmental performance of two types of product packaging that are used as primary containers for liquid detergent. At present, the most widely used packaging material is plastic bottle. The body and neck of the plastic bottle are made of high-density polyethylene (HDPE), the lid is made of polypropylene (PP). The proposed alternative to a plastic bottle is a cardboard package. The body of the package consists of one layer of cardboard paper and three layers of polyethylene (PE). The neck and lid are made of bio HDPE, which was obtained by processing sugar cane.

## 2.2 The Scope of the Study

The life cycle of both products is divided into 4 phases: raw material extraction, production, transport and waste disposal.

The performed analysis includes:

- extraction/sourcing of raw materials for the production of primary packaging materials (body and lids) and sourcing of raw materials for the production of secondary packaging materials (low-density polyethylene (LDPE) foil, cardboard boxes), which will be used during transport,
- production of primary and secondary packaging,
- transport of packaging materials to the place where they will be filled with liquid detergent,
- recycling, landfilling and incineration of primary and secondary packaging materials.

The performed analysis does not include:

- production, filling process, environmental aspects and effects of liquid detergent, as the aim of the study is to analyse the packaging system,
- transport of already filled packaging materials to the point of sale and to the consumer due to lack of data,
- environmental impacts caused by accidents or incidents during the manufacture or transport of detergent,
- tertiary packaging – pallets used in transport, we assume that they are used repeatedly,
- production, disposal and maintenance of infrastructure in the life cycle of products such as machinery, trucks, roads, etc.,
- loss of detergent during its production, use and transport. It is difficult to identify these losses and data to calculate their impact are not available,

- production and printing of packaging materials labels,
- life cycle of secondary products in the production of individual components.

## 2.3 Functional Unit

We define a functional unit as the quantitative performance of the product system that will be used as a reference unit for the LCA study. The selected functional unit for presented LCA is packaging for 10,000 liters of product, as described in Table 2.

*Table 2 – Quantitative Definition of the Functional Unit*

| | **Weight per 1 pc [kg]** | **Weight per 10 000 pcs [kg]** | **Total [kg]** |
|---|---|---|---|
| HDPE bottle body | 0.07 | 700 | 820 |
| lid + neck HDPE bottle | 0.012 | 120 | |
| paper packaging | 0.0292 | 292 | 320 |
| lid + neck for paper packaging | 0.0028 | 28 | |

## 2.4 Data

The data used to assess the life cycle of packaging products were obtained through OpenLCA software. The data is in line with European emission limits. From the geographical point of view, we focus on the production, transport and disposal of packaging systems in the EU-28 + EFTA. We worked with average data that were obtained over a period of 8 years (2012-2020).

## 2.5 Primary Packaging Materials

### 2.5.1 HDPE bottle

A plastic bottle is made of two types of plastic: the body of the bottle is made of polyethylene of high density and the cap is made of polypropylene. The basic raw materials for the production of plastics are mainly oil and natural gas. The selected product is made 100% of oil. After the oil is extracted, it needs to be cleaned and desalted – this is done by distilling the oil at the refinery. By refining the oil, we obtain oil, which we then treat by steam cracking. Cracking is the process by which high molecular weight substances are converted into low molecular weight substances. By cracking we obtain ethylene, propylene and higher alkenes. The individual components have different boiling points, so it is possible to separate them from each other by distillation. After obtaining ethylene and propylene, polymerization takes place and thus we obtain plastic granulate (Polypropylene (PP), no date; Spracovanie ropy na primárne produkty | petroleum.sk, no date).

The individual methods of converting granulate into a specific product differ depending on the intended the use of the product. A plastic bottle is formed from the HDPE granulate by the blow moulding, and a lid is produced from the PP granulate by the injection moulding. The finished product is transported to a place where it will be filled with detergent. From there, it is transported to the point of sale and to consumers. In a process of making a plastic bottle and a lid 1.61 kg of oil must be used to produce 1 kg of plastic. The bottle analysed in this work has a volume of 1 l and dimensions 214x84x84 mm.

### 2.5.2 Cardboard packaging

The cardboard packaging consists of a body and a lid. The body consists of four layers. One layer is unbleached kraft paper and three layers are polyethylene. Unlike cardboard packaging for food and beverages, the alternative we choose does not contain an aluminum layer, which protects food from direct sunlight, oxygen and bacteria. This type of carton is called non-aseptic. The neck and lid of the package are made of bio HDPE, which is obtained by processing sugar cane.

Cardboard makes up about 70-80% of the entire packaging, polyethylene 20-25%. The analysed cardboard package has a volume of 1 l and dimensions 230x70x70 mm. Non-recycled paper was assumed for production the paper part of the packaging. After harvesting the wood, and before its processing, it is necessary to debark, clean, cut and mechanically split the wood. In order to make paper out of wood, we need to convert it into pulp. The pulping method differs according to required paper properties. We generally recognize three types of pulping: Kraft pulping, acid sulfite, and neutral sulfite semichemical pulping. Sulfide pulping is used to produce kraft paper. This type of pulping uses a solution of NaOH and $Na_2S$. The result is a solid pulp with long fibers. The pulp is then cleaned and travels to a mill and a paper machine. The result is kraft paper (Twede, 2014). The production of the polyethylene layer is similar to the production of HDPE bottles – polymerization of ethylene. The connection of the paper and plastic layer takes place by extrusion lamination.

Bio HDPE for the lid and neck are obtained from sugar cane. The first step in the production of organic HDPE, after growing sugar cane is its cleaning, slicing, grinding, which releases glucose in the form of fibers and juice. Anaerobic fermentation of glucose decomposes it to give a mixture of ethanol and dregs. After distillation, bio-ethanol is dehydrated to obtain bio-ethylene. Polymerization of ethylene produces a bio-polymer that is identical in chemical, physical, and mechanical properties to the petroleum-derived polymer. The final step is injection moulding, which results in a lid and a neck (Siracusa and Blanco, 2020).

## 2.6 Secondary Packaging Materials

### 2.6.1 Cardboard box

The cardboard box serves as a secondary packaging for the primary packaging materials stored therein for transport to the place of filling. The box consists of two types of paper – two layers of plain paper and corrugated three-ply cardboard. Non-recycled wood was assumed to make the cardboard box (Twede, 2014).

### 2.6.2 LDPE foil

Classic LDPE foil is used for product transport. The production of foil is similar to the production of all plastic products. The foil is made in 100% of oil. The LDPE granulate is extruded into a foil. LDPE foil covers the cardboard boxes, in which the primary packaging materials are placed.

## 2.7 Environmental Impacts of Products

A detailed examination of all environmental impacts is not possible, whereas it depends on several factors, such as the quality of the data obtained or the availability of the data. At present, one of the biggest problems is air pollution, therefore in this study focused on the three main indicators, namely global warming, acidification and photochemical smog (these impact data exist for almost every product). The fourth selected impact is eutrophication, which is caused by water pollution. Another most common aspect is energy consumption, which is included in all data throughout the product life cycle.

## 2.8 Characteristics of Selected Impacts

### 2.8.1 Eutrophication

Eutrophication is caused by the excessive presence of inorganic nutrients, especially nitrogen and phosphorus, in the water. This results in increased growth of cyanobacteria and algae. Due to the increased production of biomass and its subsequent decomposition, there is a lack of oxygen in the aquatic environment. Lack of oxygen causes the death of organisms that live in or near water – a reduction in biodiversity. The main causes of eutrophication are wastewater, intensification of livestock farming, energy and fossil fuel consumption, increased fertilizer consumption, land use (Ansari and Gill, 2014).

The indicator for this category is kg $PO_4$ equivalent. $PO_4$-eq. is a value expressing the degree of eutrophication potential of substances.

### 2.8.2 Acidification

Acidification is the process by which the components of the environment are acidified. The result of acidification leads to forest degradation, deterioration of buildings, climate change, the loss of nutrients from the soil, extinction of animal and plant species (acidifikácia, 1999).

The indicator for this category is kg $SO_2$ equivalent. $SO_2$-eq. is a value expressing the degree of acidification potential of the substances.

### 2.8.3 Global arming

The result of global warming is the gradual increase in temperature of the Earth surface, oceans and atmosphere (Bradford and Pappas, 2017).

The indicator for this category is kg $CO_2$ equivalent. $CO_2$-eq. is a value expressing the rate of global warming potential of substances.

### 2.8.4 Photochemical smog

Air pollution by photochemical smog, is the result of the interaction of photo-sensitive substances in the atmosphere with UV part of the solar radiation – especially ozone (smog | Causes, Effects, & Types | Britannica, 2019).

The indicator of this category is kg ethylene equivalent. Ethylene-eq. is a value expressing the degree of photochemical potential of the substances.

## 2.9 Interpretation of Results

### 2.9.1 Obtaining raw materials

In the phase of raw materials sourcing, we focus on oil extraction, logging and sugar cane cultivation. The data also include the transport of individual raw materials to the place where they will be further processed, including energy.

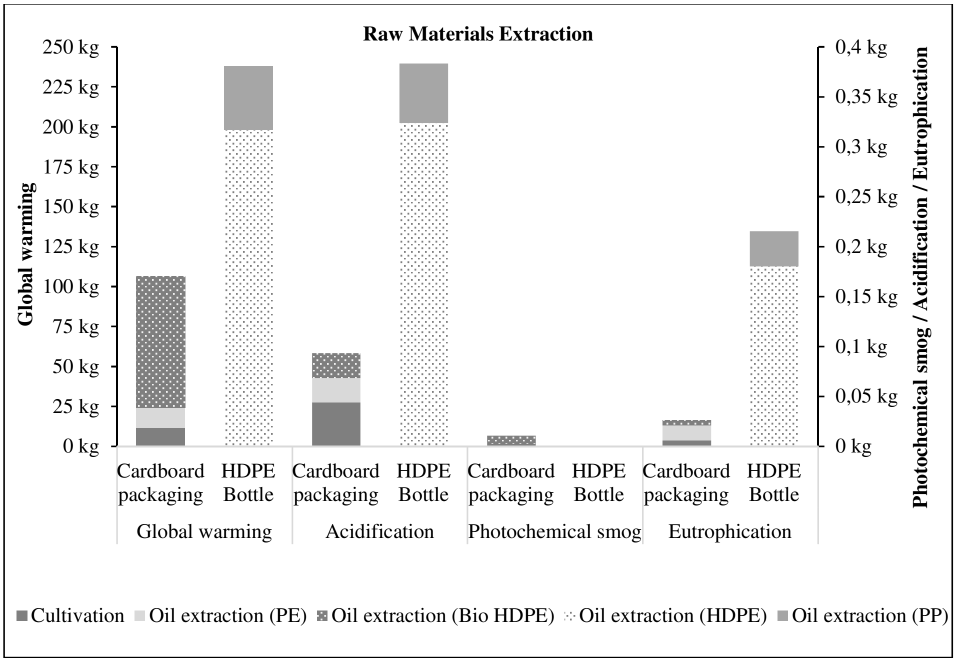

*Figure 1 – Impacts of Raw Materials Extraction*

The graph in Figure 1 shows that in the raw material recovery phase, paper packaging has a less negative impact on the environment in three categories – global warming, acidification and eutrophication. The biggest burden on the environment is the extraction of oil, which is needed to produce the entire plastic bottle.

### 2.9.2 Production

The production phase includes the complete process of converting the basic raw material into the final product. The data also include the transport of products between individual production companies, including energy. As shown in Figure 2, the biggest burden on the environment is the production of HDPE bottles. Compared to the paper packaging, the HDPE bottle entails significantly higher emissions, for example in the category of global warming it is up to about 1,640 kg $CO_2$-eq. more. On the contrary, in the photochemical smog category, the production of HDPE bottles represents a lower environmental burden than the production of paper packaging by about 0.8 kg ethylene-eq. less. As far as paper packaging is concerned, the production of kraft paper has the highest emissions of all three packaging components.

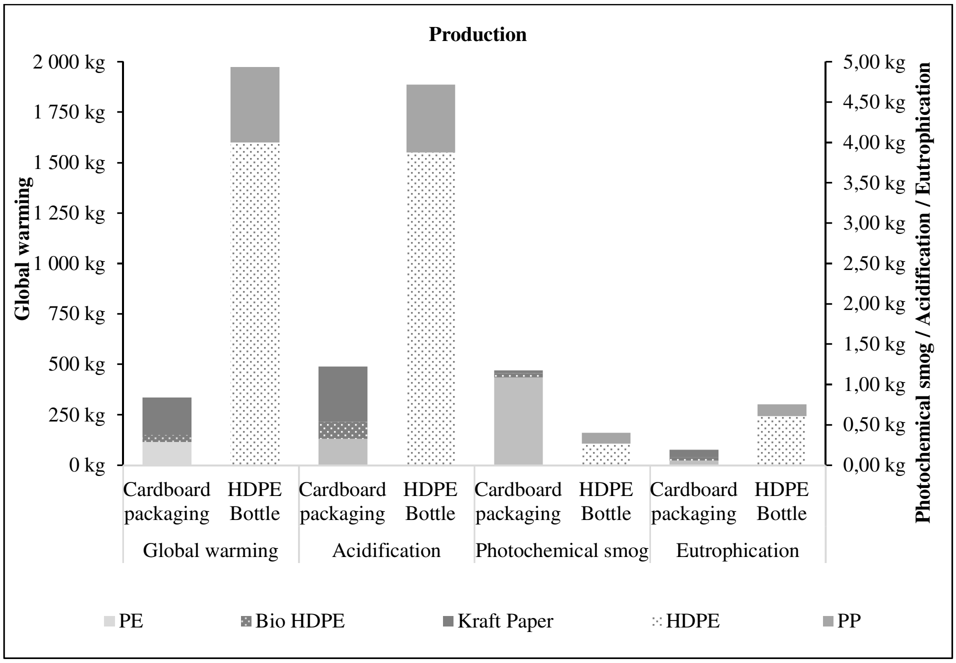

*Figure 2 – Impacts of Production*

### 2.9.3 Transport

The data used represent the regional mix of EU-28 + EFTA countries. We assume that a truck with a payload capacity of 5 tonnes will be used for the transport. We assume that 59% of the total route will be on the highway, 28% in the country and 13% in the city. The data also includes fuel – diesel. The data do not include the production and disposal of the truck. We use cardboard boxes and LDPE foil as secondary packaging for transport. Emissions of secondary packaging materials are included in the data. The comparison of impacts in transport phase is shown in Figure 3.

For the purposes of this work, the city of Košice was chosen as the place of filling, the place of production of cardboard packaging is Gornji Milanovac, Serbia and the place of production of HDPE bottles is Kralovice, Czech Republic. The distance between Gornji Milanovac and Košice is 730 km and the distance between Kralovice and Košice is 760 km. When transporting materials from the place of production to the place of filling, the HDPE bottle again represents a significantly higher burden on the environment than cardboard packaging in all 4 categories. This might be explained by the fact that the HDPE bottle is bulkier than the cardboard packaging. In terms of secondary packaging, the life cycle of LDPE film has a greater impact on the environment (especially in terms of air emissions) than a cardboard box.

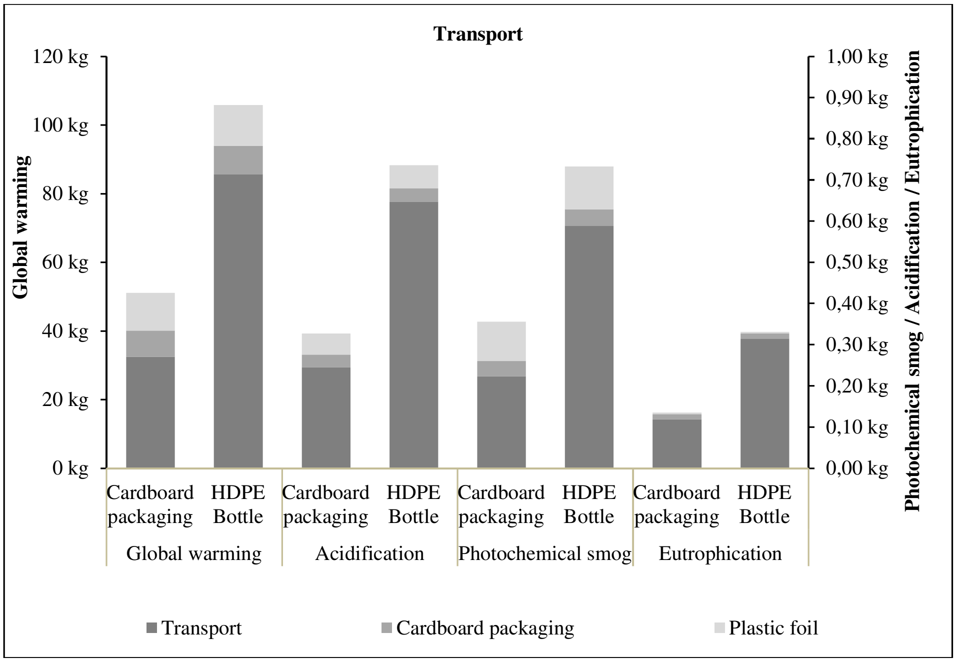

*Figure 3 – Impacts of Transport*

### 2.9.4 Waste Disposal

In the phase of packaging materials disposal, we have focused on three basic types of waste disposal, namely recycling, incineration and landfilling.

Recycling

Recycling means repeated recovery of materials. It is the most preferred method of waste treatment. The data used include the transport of waste to the recycling site, cleaning, sorting, separation, granulation and palletisation of waste. The method of recycling differs from material to material. The sources of energy in recycling are coal, oil, natural gas, uranium. All energy recovery data are also included.

Assessing the environmental impacts of recycling in the waste disposal phase is relatively complicated. In general, there are several approaches that can be applied in the evaluation, for example we will consider that the input to the production process is made from already recycled material or we estimate how many times the material can be recycled and so we will count specific values as 1/N-th of functional units. The second approach was chosen in the work. We assume that the paper can be recycled 7x, bio HDPE and HDPE 2x, LDPE 4x, PP 5x, so we assume that the paper has 8 life cycles, bio HDPE and HDPE 3, LDPE 5 and PP 6. Negative values are actually positive – they represent the amount of emissions not released into the environment. For example, if we recycled an HDPE bottle twice, we would save up to 300 kg CO2 eq. than, if we burned the bottle or landfilled it. However, if we look at the photochemical smog category, it is more environmentally friendly to burn an HDPE bottle than to recycle it twice.

Incineration

Incineration takes place in waste-to-energy plants – in the heat treatment of municipal waste, dry flue gas cleaning takes place and NOX is removed by selective catalytic reduction or selective non-catalytic reduction. The incineration plant consists of a combustion chamber equipped with a steam generator. The recovered energy is either returned to the combustion process, used for energy production or exported as heat to industry or households. The resulting bottom ash is extinguished, ferrous scrap and non-ferrous metals are selected from the ash, followed by three-month ash aging process. Part of the ash thus obtained is used as a building material. The rest is deposited in the ground. The used data include waste transport and pre-treatment.

Landfilling

Landfilling as waste disposal is used when no other method of disposal is possible. However, it is the least preferred method of waste disposal. The used data represent a typical municipal waste landfill with a basic surface sealing that meets European emission limits. The data do not include pre-treatment of waste, as we assume that the waste is pre-treated before it is landfilled. The data include the cleaning and treatment of landfill gases and leachates. The data also include the individual life cycles of the materials used to seal the landfill. The materials used to seal the landfill are gravel, sand, clay, PE film. Gravel and sand are used as filter layers. PE film is used as a waterproof seal, clay as a base seal and a mineral layer. Gravel, sand and clay are mined from the dry quarry. PE is made from oil. All production processes of sealing materials are included. The sealing efficiency is 70%. The height of the landfill is 30 m, the landfill area is 40,000 m$^2$.

The graph in Figure 4 shows that incineration is the biggest burden on the environment. The best option is recycling. At this stage, an HDPE bottle is a better alternative due to the amount of emissions in 3 categories – acidification, photochemical smog and eutrophication. For the global warming category, cardboard packaging is a more appropriate option if the waste is disposed of by incineration. However, if the waste was recycled, a more suitable alternative is an HDPE bottle again.

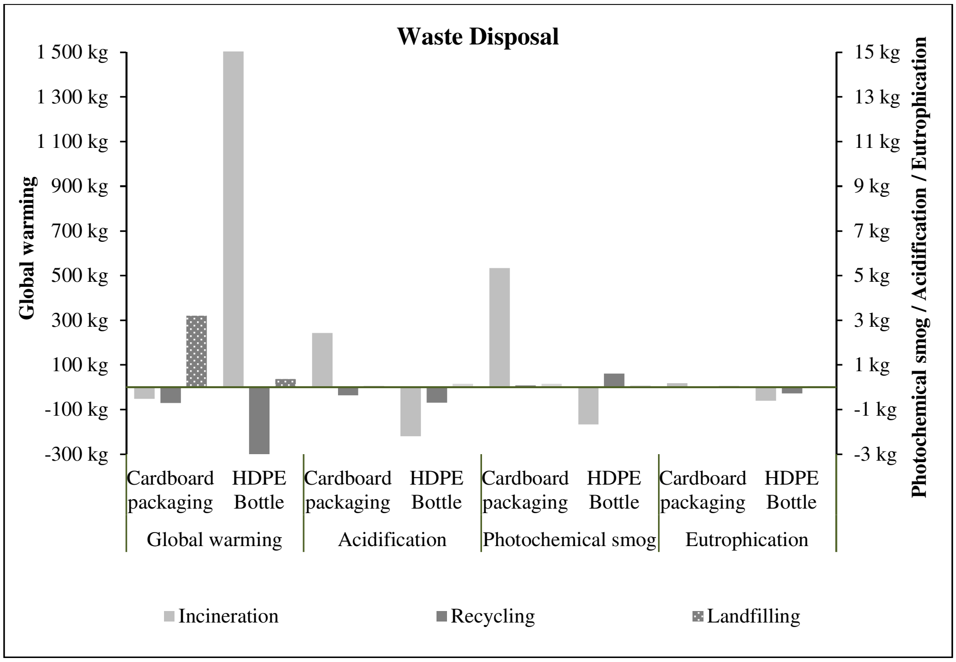

*Figure 4 – Impacts of Waste Disposal*

## 3 DISCUSSION

Using LCA method we have found that paper packaging is a more suitable alternative for the environment. The summary results are shown in Figure 5. In the raw materials extraction phase, cardboard packaging had a smaller negative impact on the environment in three of the four categories – global warming, acidification and eutrophication.

The biggest burden on the environment in the raw material extraction phase is the extraction of oil, which is needed for both products. The life-cycle stage that produces the most emissions is the materials production phase.

Production is a complicated process that consists of a large number of technological operations, which a large amount of materials enters and a large amount of emissions and secondary products leaves. Even at this stage, the paper packaging represented a lower environmental burden. However, the photochemical smog values in both phases of the paper were higher than those of the HDPE bottle.

In the transport phase, we focused on the transport of containers from the place of production to the place where they will be filled with detergent. Both products cover approximately the same distance of 750 km. The results of this phase also include the values of the effects of secondary packaging materials – LDPE foil and cardboard box during their entire life cycle.

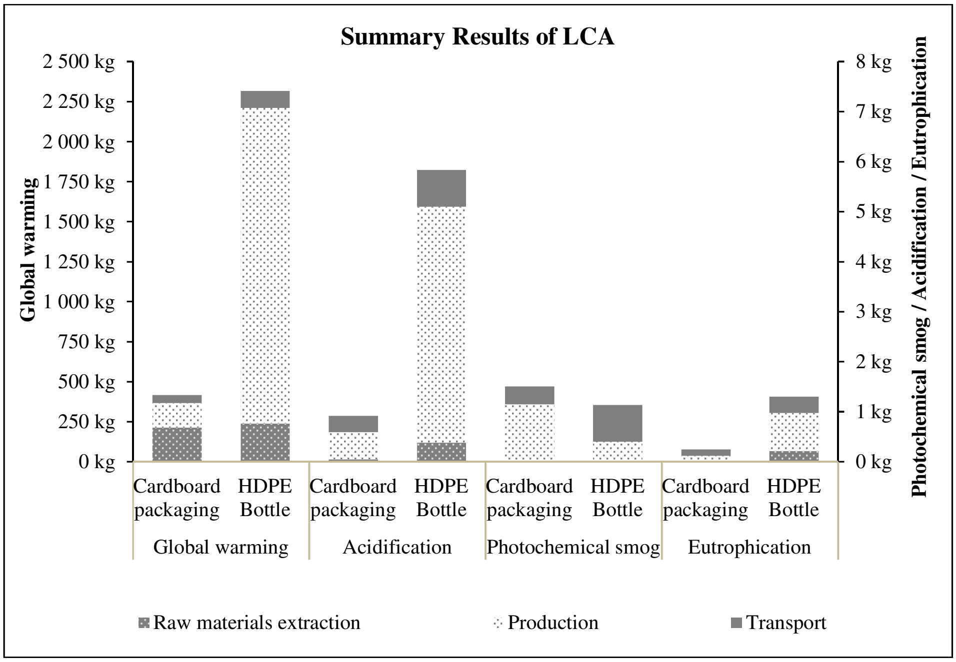

*Figure 5 – Overall Environmental Impacts*

At this stage, the cardboard packaging also had a more favourable impact on the environment. This can be explained by the fact that the HDPE bottle is heavier and we need more secondary packaging materials to transport it. The HDPE bottle had a significantly lower environmental impact when disposing of packaging waste, except for incineration in the global warming category, than paper packaging. However, this does not change the fact that paper packaging is a more suitable alternative for the environment, because despite subtracting the individual values of the effects of disposal from the summary results, the HDPE bottle has much higher emissions in the previous three phases.

## 4 CONCLUSION

The LCA method was chosen mainly because of its complexity, as it allows us to evaluate and compare all processes, inputs and outputs related to the production of packaging from the acquisition of raw materials to their disposal. This makes it possible to focus on a wide range of environmental issues, not just single specific one.

The problem seems to be that the LCA provides an answer, which of the analysed systems has a potentially lower impact on the environment, but does not provide an answer as to whether a particular system is really environmentally friendly enough. However, it helps us identify, which phase of product's life cycle poses the greatest environmental burden; where we need to focus in order to be able to produce environmentally friendly product.

This method is very costly and time consuming. In order to be able to perform a truly detailed analysis that will cover all environmental issues, a large amount of finance, capable software, availability and high data quality are needed.

Using the LCA method, we have come to the conclusion that cardboard packaging is an alternative that has a more favourable impact on the environment than an HDPE bottle. The presented work provides a reason for the decision on a more detailed examination of the issue of packaging for liquid detergent and the consideration of cardboard packaging as an alternative to HDPE bottles.

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## CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.