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ASSESSMENT OF THE ENVIRONMENTAL IMPACT OF SINGLE-USE PACKAGING

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Abstract: In recent years, there has been an increase in the consumption of disposable packaging, which has led to overloading landfills. These problems have become widely noticeable and dominant in a wide range of packaging issues in terms of environmental protection. The development of knowledge in the field of environmental protection, which has taken place in recent years, has shown that the impact of packaging should be considered throughout its life cycle, taking into account many factors that constitute environmental burdens and threats. Many companies operating in the world markets, using the standardized Life Cycle Assessment (LCA) method, conduct tests in terms of technical and material solutions with the lowest environmental impact. Therefore, this publication was to conduct environmental analysis of the life cycle of disposable food packaging based on the method of LCA. The subject of the research were bottles, caps and labels made mainly of polymeric materials: polyethylene terephthalate, polypropylene and LDPE. Eco-indicator 99 was used as the calculation procedure. The impact of the analysis objects on human health, ecosystem quality and resources was assessed. Among the examined objects, the highest level of negative influence on the environment was characteristic for the life cycle of a polyethylene terephthalate (PET) bottle. The use of recycling processes reduce the environmental impact by about 25%.

Keywords: LCA, bottle, label, nap, Eco-indicator 99

1. INTRODUCTION

In the countries of the European Union, already in the 1980s, the increase in the consumption of single-use packaging, as well as their diversity of materials constituting a barrier to recycling, overloaded landfills and highlighted the need to implement industrial methods of using the growing mass of packaging waste (Lewandowska 2011). In the following years, these problems became commonly noticeable and dominant in a wide range of packaging issues in terms of environmental protection. However, it should be emphasized that the issues related to packaging in terms of the environment have a broader scope than waste management (Bałdowska-Witos et al., 2019).

Many companies operating in the world markets, using the standardized Life Cycle Assessment (LCA) method, conduct tests in terms of technical and material solutions with the lowest environmental impact (Lewandowska, 2011). By using the LCA method, enterprises declare that they reduce their environmental impact to a greater extent than the competition, and the results of the assessment shape new directions of production, taking into account such factors as: sources of material origin, recyclability and use of recycled raw materials, reduction of greenhouse gas emission rates (Bałdowska-Witos et al., 2020).

In the world literature one can find analyzes concerning mainly comprehensive assessment of environmental impacts of raw materials used in the production of disposable bottles. Santosh Madival et al. made a comparison of thermoformed clamshell containers made of polylactide (PLA), PET and polystyrene (PS) for the packaging of fresh strawberries. Demonstrating that PET contributed the highest in almost all the impact categories (Santosh Madival et al., 2009). Krystyna Czaplicka-Kolarz et al. proposed an environmental assessment of the process of obtaining polymers such as: polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), PS and PET. The conducted analysis included damage to human health, the quality of the ecosystem and resource consumption, the global warming emission index and cumulative energy consumption were determined. On the basis of the obtained research results, it was found that polypropylene has potentially the greatest negative impact on human health and the quality of the natural environment (Krystyna Czaplicka-Kolarz et al., 2013). By contrast, Li Shen et al. assessed the environmental impact of PET bottle-to-fiber recycling using the methodology of Life Cycle Assessment (LCA). Four recycling cases, including mechanical recycling, semi-mechanical recycling, back-to-oligomer recycling and back-to-monomer recycling were analysed. The obtained results of environmental impact show that recycled PET fibers have a better influence on the condition of the natural environment than virgin PET fiber (Li Shen et al., 2010). On this basis, it was considered important from the point of view of environmental protection to carry out a life cycle assessment of disposable beverage bottles. It is also worth emphasizing that the actual input data from the enterprise is accepted for research.

The aim of the publication is to assess the environmental impact of the process of shaping the PET bottle, the cap made of polypropylene and the LDPE (Low Density Polyethylene) label for their further development and recycling.

2. RESEARCH METHODOLOGY

The study used the Life Cycle Assessment technique to assess and assess the potential environmental impact of the beverage bottle design process. The technique used covers the flows of materials and energy within the system boundaries and calculates the respective impacts generated by each unit process, indicating negative impacts on human health, ecosystem quality and resources (Bałdowska-Witos et al., 2019).

1000 bottles with a capacity of 1 l were adopted as the functional unit of the study. The boundary of the system covered the production phase of the bottles and their subsequent post-use / recycling.

Characterization

Characterization consists in calculating the value of the category indicator for the LCI result and thus allows to assess the degree of their participation in the values relating to a given impact category. The result is the numerical value of the summary indicator. The result is the value of an indicator for the greenhouse effect, for example, expressed as a carbon dioxide equivalent (Lewandowska, 2011).

Grouping

Grouping is the assignment of an impact category to one or more sets according to the purpose and scope of the research, it may include sorting the ranking according to a specific hierarchy. Grouping is the ordering and ranking of the categories of influence (Lewandowska, 2011).

Weighting

In the LCIA impact assessment phase, the different values of the impact category indicator can be considered and summed to obtain the weighting of the environmental effect (Fuc et al., 2016). For example, it indicates how many times more harmful is the environmental impact of the greenhouse effect than toxicity. Weighing is about assigning a weight to each impact category so that these categories can be comparable with each other. The most significant impact is given the greatest importance and is considered first (Kuczenski et al., 2011).

Eco-indicator 99 method

The Eco-indicator 99 method belongs to the group of methods modeling the environmental impact at the endpoints level of the environmental mechanism. The characterization process takes place for eleven impact categories, which fall into three larger groups known as areas of influence (Piasecka et al. 2020). The following areas of influence are distinguished: human health, ecosystem quality, resources. The results of the areas of influence indicators are further aggregated in the Ecolabel final by normalization, grouping and weighting.

Human health is one of the areas of influence in the Eco-indicator 99 method, which in turn consists of six impact categories: carcinogens, resp. Organics, resp. Inorganics, climate change, radiation and ozone layer. By determining the area of influence indicator from the endpoints of the environmental mechanism, it is possible to adopt a common unit for all impact categories within human health. Each of them can cause the same type of impact, i.e. health disorders in humans and animals. The ecosystem quality distinguishes three impact categories: ecotoxicity, acidification / eutrophication and land use (Piasecka et al., 2020).

Modeling in the third area of influence - resources consists of resource analysis and damage analysis. Only two impact categories from this area are considered in Eco-indicator 99: minerals and fossil fuels. A special injury indicator was developed, analogous to DALY, PAF and PDF, which is surplus energy expressed in MJ. During resource analysis, a decrease in the content of the useful component in the deposit or complete depletion of the deposit is modeled (as potential production effects) (Piasecka et al., 2020).

3. ANALYSIS OF RESULTS

The results of the analyzes carried out as part of the Life Cycle Impact Assessment (LCIA) were summarized in three phases developed for one adopted Eco-indicator 99 method. The modeling results with Eco-indicator 99 were divided into two steps. The first step shows the results at the characterization level, the second step shows the data at the grouping and weighting level (Bałdowska-Witos et al., 2020).

Influence of factors that may adversely affect human health (table 1), the group of inorganic compounds causing respiratory diseases was characterized by the highest level of harmful effects 0,052446517 DALY. During the production of disposable bottles, significant amounts of, among others, nitrogen oxides and sulfur dioxide. The use of recycling processes in this case would result in a significant reduction of the adverse environmental impact in the considered impact category o -0,04 DALY. In the group of factors influencing the reduction of the quality of the environment, the ecotoxicity category is of key importance 33488,61 PAF*m2yr, for which the recycling rate is equal to 7649.11 PAF*m2yr, and landfill 51915.62 PAF*m2yr. In contrast, when considering the impact of factors related to fossil resource depletion, by far the most detrimental impact is associated with fossil fuel extraction 216123,55 MJ. Applying the recycling process would reduce the potential negative impact to a level of approx 46% (Fig. 1).

Table 1
Characterization results of the environmental consequences occurring in the PET bottle shaping cycle

Impact category	Unit	Production	Recycling	Landfill
Carcinogens	DALY	0.009952825	0.002960579	0.020508937
Resp. organics	DALY	0.000101179	-0.001169289	0.000007242
Resp. inorganics	DALY	0.052446517	-0.045082988	0.000502783
Climate change	DALY	0.021276286	-0.001703711	0.003021902
Radiation	DALY	0.000321794	0	0.000004228
Ozone layer	DALY	0.000003564	-0.00000980	0.000000083
Ecotoxicity	PAF*m2yr	33488.61157	7649.115698	51915.62382
Acidification/ Eutrophication	PDF*m2yr	1298.12928	-2047.534383	17.52044668
Land use	PDF*m2yr	758.0142935	0	41.20689827
Minerals	MJ surplus	3966.66548	-3.479175	14.761984
Fossil fuels	MJ surplus	216123.5593	-188090.9238	937.4121012

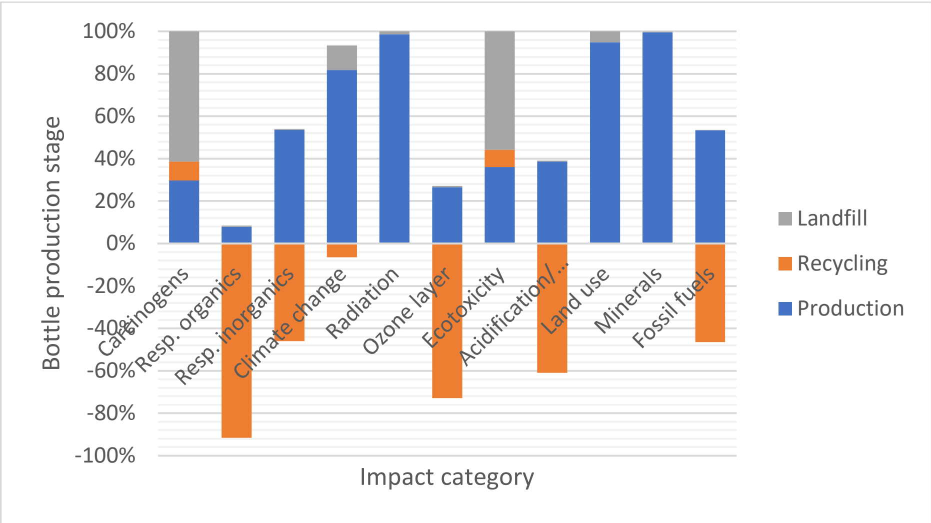

Fig. 1. Characterization results for environmental impacts covering all impact categories that occur during the PET bottle shaping process

It was noticed that the highest level of potential harmful effects on human health was the process of shaping the PET 2190.02 Pt bottle, which is the result of high demand for electricity in production processes and directly related to them, extremely energy-consuming processes of extracting non-renewable raw materials necessary in individual processes during the production of raw materials. The use of recycling processes to some extent allows to reduce the emissions of selected compounds by the value of -1171.94 Pt. The processes related to their extraction of fossil fuels significantly reduce the quality of the environment. The highest level of potential negative impact in this category was recorded at the stage of the production process of 5,238.15 Pt. However, the use of the recycling process allows to effectively limit the depletion of non-renewable resources, but also to significantly reduce environmental degradation. Recycling processes during bottle shaping allow the greatest possible reduction in the level of potential harmful effects of processes related to the extraction of fossil fuels by the value of -4476.65 Pt (Fig. 2).

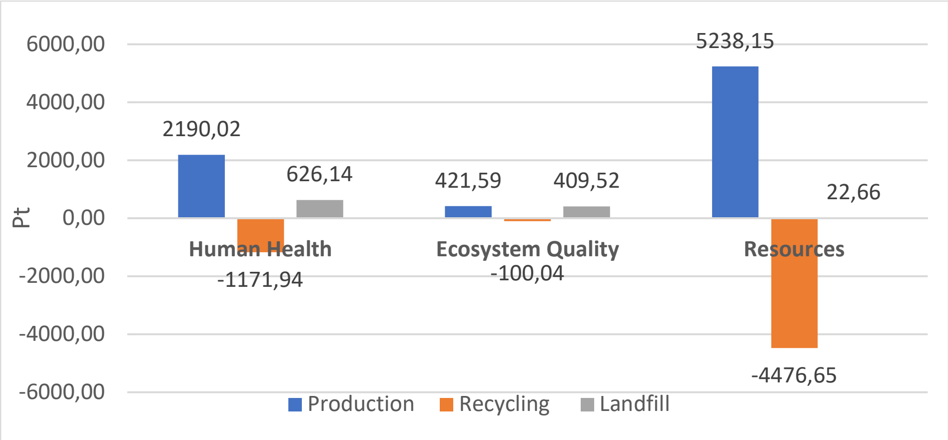

Fig. 2 Grouping and weighting results of environmental impacts covering all categories of damage occurring during the PET bottle shaping process

Table 2 presents the results of characterizing the environmental consequences occurring during the production of polypropylene caps, taking into account the impact categories. Among the substances affecting human health, the resp category was indicated with the highest negative impact. inorganics 5.06623E-06 DALY. Recycling processes would reduce such harmful impacts over the entire life cycle of the cap by a total of 16% (Fig. 3). Among the compounds that have a harmful effect on plants and animals, Ecotoxicity 0.206377841 PAF*m2yr substances are the most dangerous to their health and life. Recycling at the end of the life cycle would minimize the negative impact under consideration to a total level of 0.597736 PAF*m2yr. The highest level of adverse impact in this respect was recorded for processes related to the extraction of fossil fuels, which is 25.59611594 MJ. Recycling processes would allow a total saving of energy needed to extract raw materials for the caps making process of -0.00025 MJ.

Table 2
Characterization results of environmental consequences occurring during the process of making polypropylene caps

Impact category	Unit	Production	Recycling	Landfill
Carcinogens	DALY	0.000000455	0.000000229	0.00000992
Resp. organics	DALY	0.000000012	-0.000000032	1.12E-10
Resp. inorganics	DALY	0.000005066	-0.00000071	2.95E-08
Climate change	DALY	0.000002147	-0.00000013	3.02E-08
Radiation	DALY	0.725138E-10	0	1.01E-10

Ozone layer	DALY	1.97097E-11	-8.5E-10	5.84E-12
Ecotoxicity	PAF*m2yr	0.206377841	0.597736	1.680037
Acidification/ Eutrophication	PDF*m2yr	0.146370386	-0.0575	0.001091
Land use	PDF*m2yr	0.014349158	0	0.003127
Minerals	MJ surplus	0.008117747	-0.00025	0.000819
Fossil fuels	MJ surplus	25.59611594	-15.493	0.069713

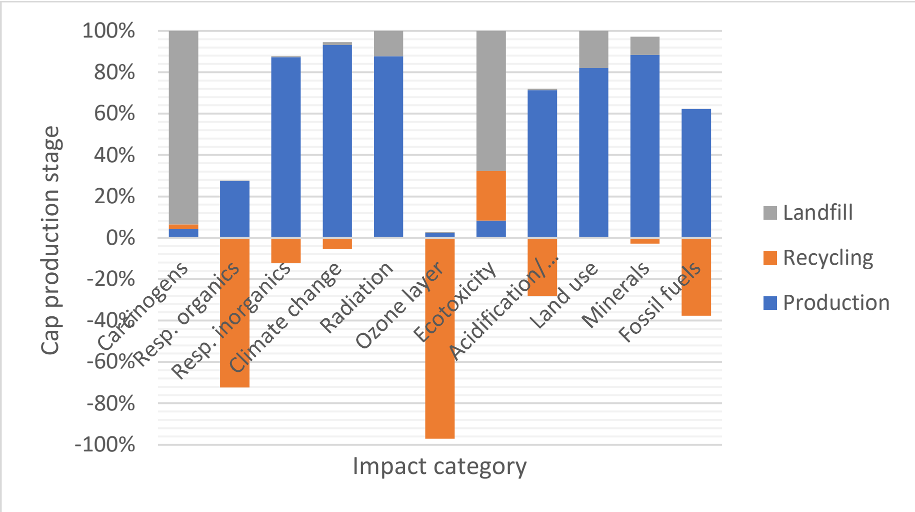

Fig. 3. Results of the characterization of environmental consequences covering all impact categories that occur during the process of making a polypropylene caps

Figure 4 shows the results of grouping and weighing of environmental consequences occurring during the process of making the polypropylene cap. At the stage of the production process, the negative impact on human health was 0.20 Pt. The main fossil fuels used in the production of polymers include, among others crude oil, coal and natural gas. Increasing use of crude oil, natural gas and coal leads not only to the depletion of these non-renewable energy sources - their exploitation is also associated with many environmental degradation problems. In the case of the assessment of the process of creating polypropylene caps, the level of potential negative impact in this category was 0.26 Pt.

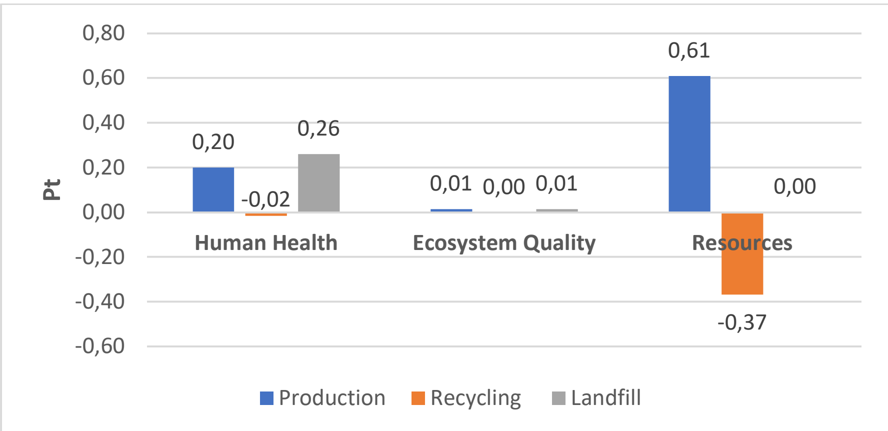

Fig. 4 Grouping and weighting results of environmental impacts covering all categories of damage occurring during the polypropylene screw cap making process

Table 3 presents the results of characterizing the environmental consequences occurring in the process of creating LDPE labels for disposable bottles. Among the substances affecting human health, the Resp category was the highest negative impact. Inorganics 3,37575E-06 DALY causing respiratory diseases. Recycling processes would reduce this type of harmful impact over the entire life cycle of the label by a total of -5.1E-07 DALY. Ecotoxic substances 0.143433719 PDF*m2yr are among the compounds that adversely affect the quality of the natural environment, including vegetation and animals. The last type of impact analyzed was related to the potential increased energy consumption necessary during the extraction of raw materials. The highest level of harmful impact in this respect was recorded for processes related to the extraction of fossil fuels. The energy expenditure was 15.73927487 MJ. Recycling processes would allow for a total life cycle energy saving of -11.1894 MJ (42%) (Fig. 5).

Table 3
Characterization results of environmental consequences occurring during the LDPE label development process for disposable bottles

Impact category	Unit	Production	Recycling	Landfill
Carcinogens	DALY	0.0000003106	0.000000165	0.0000033
Resp. organics	DALY	9.49068E-09	-0.000000023	9.34E-11
Resp. inorganics	DALY	0.0000033757	-0.00000051	2.12E-08
Climate change	DALY	0.0000012151	-9E-08	2.72E-08
Radiation	DALY	8.74434E-10	0	6.23E-11
Ozone layer	DALY	1.47287E-11	-6.2E-10	4.21E-12
Ecotoxicity	PAF*m2yr	0.143433719	0.431698	0.358381
Acidification/ Eutrophication	PDF*m2yr	0.089233331	-0.04153	0.000775
Land use	PDF*m2yr	0.009893334	0	0.002257
Minerals	MJ surplus	0.007120048	-0.00018	0.000578
Fossil fuels	MJ surplus	15.73927487	-11.1894	0.050275

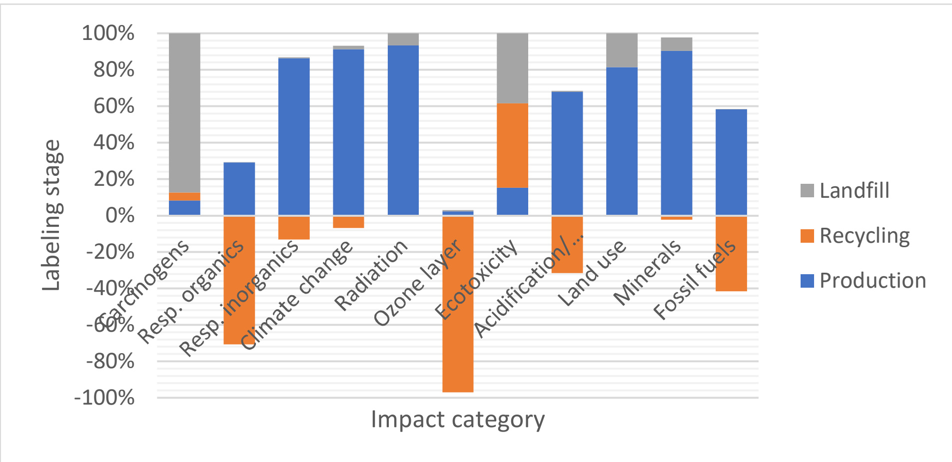

Fig. 5. Results for the characterization of environmental impacts covering all impact categories during the LDPE label development process for disposable bottles

Figure 6 presents the results of grouping and weighing environmental consequences in relation to human Health, ecosystem quality and resources. Among all damage categories, the resource category of 0.37 Pt was characterized by the highest level of harmful effect. The use of recycling would reduce the total negative impact by a total of -0.27 Pt.

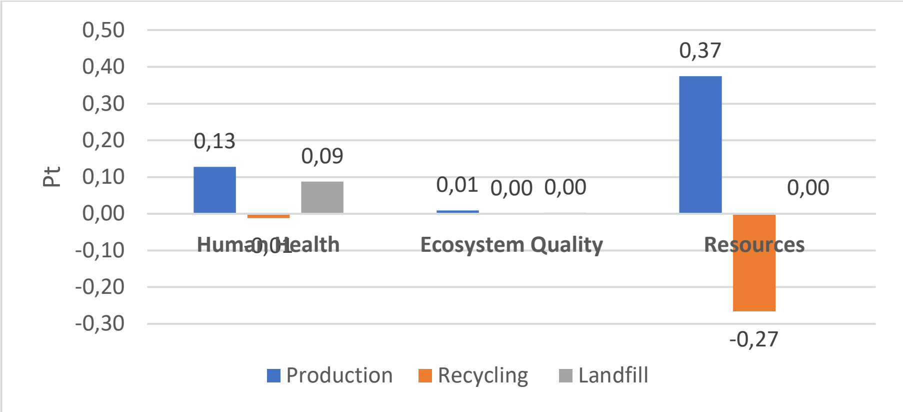

Fig. 6 Grouping and weighting results of environmental impacts covering all damage categories that occur during the LDPE labeling process for single-use bottles

4. CONCLUSION

The main goal of the study was achieved by conducting an environmental analysis of the life cycle of a single-use bottle. The analysis was carried out on the basis of the Life Cycle Assessment (LCA) method using the Eco-indicator 99 calculation procedure. Among the factors harmful to human health, the highest emission levels were observed for the bottle life cycle in the Resp. Inorganics category (0.054 DALY). The recycling process allows to reduce the level of potential harmful effects of the processes related to the influence of Resp. Inorganics on human health, in the perspective of the entire life cycle of the analyzed research object (in total by -0.045 DALY). In the group of factors reducing the quality of the environment, the greatest number of potential negative environmental consequences related to the emission of ecotoxicity compounds is distinguished by the life cycle of a PET bottle (33,488,611 PAF*m2yr), followed by a caps (0.206 PAF*m2yr) and a labels LDPE (0.143 PAF*m2yr). As for the factors of resource depletion, the maximum negative impact processes characterized by fossil fuel plants during the production of PET bottles (MJ 216123), a caps (MJ 25596), and labels LDPE (MJ 15739). Applying the recycling process can reduce the negative environmental impacts for the bottle by about 87%, for the cap by about 60% and for the label by about 73%. The presented data is only a kind of estimate that may be helpful at the product design stage. Moreover, the conducted research has shown that energy consumption is the factor determining all impact categories at the production stage. In the course of further research, more attention should be paid to the processes related to the eco-design of packaging, as the main source of environmental pollution is energy consumption. Furthermore, taking into account other environmental pollution, should develop appropriate management after use.

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