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ASSESSMENT AND ANALYSIS OF THE ENVIRONMENTAL IMPACT OF THE THERMO-SHRINKABLE PACKAGING PROCESS ON THE WAY THE PACKAGING MACHINE IS POWERED BASED ON LCA

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Abstract:
Increasing requirements in the field of monitoring the impact of machines contributes to the analysis of production processes in order to verify their environmental loads. The research carried out in this area is aimed at identifying the negative impact of the tested object to be able to introduce changes in the consumption of raw materials and energy while limiting the negative impact on the environment. The article will present the results of the life cycle assessment (LCA) of the process of mass, thermo-shrinkable packaging of beverage bags depending on the change in the way the packaging machine is powered. In addition, as part of the analysis, it was indicated which stage of the process has the biggest negative impact on the environment. LCA results are presented at the stage of endpoint characterization.

Key words: *effective management, humanistic management, manager, technological support, technologies*

INTRODUCTION

Each technological process has a bigger or less impact on the natural environment through the accompanying emissions in the form of harmful substances, noise or heat [1]. With the increase in pollution coming directly from these processes, including the processes of mass packaging of bottles using thermo-shrinkable foil, there is an increasing interest of researchers in the search for innovative ways to reduce them [2, 3]. The life cycle analysis (LCA) is very popular among the methods that allow to determine the extent of the negative impact of a given process on its system environment [4, 5]. Due to its complexity and multifaceted nature, this method is popular among tools used to determine the impact of the analyzed research object [5, 6]. Both gaseous and particulate pollutants have a significant impact on human health, the quality of ecosystems and climate change. Excessive presence of greenhouse gases contributes to respiratory diseases and human blood. In addition, they affect the acidification of soils and waters and the eutrophication of aquatic ecosystems [7, 8]. The phenomenon of acidification is a consequence of the presence of acidifying substances in the air, which include sulfur dioxide, ammonia and nitric oxide. The process of packaging bottles, like any process, affects the environment, therefore it is advisable to conduct research in the field of its impact on the environment [9, 10].

LITERATURE REVIEW

Every human's activity has an impact on the environment, therefore it is important to monitor and report these impacts both during extraction of raw materials, production periods or transport. This information should be included in financial and non-financial reports prepared by e.g. transport sector entities. To implement sustainable development, it is necessary to carry out audits and prepare emission reports [11, 12]. During production processes, in addition to the consumption of energy and raw materials to produce the final product, there is an emission of undesirable substances in the form of greenhouse gases and waste [13, 14]. Therefore, the important implementation of activities aimed at the development of the economy with the simultaneous reduction of excessive

consumption of natural resources, which leads to the commonly used term of eco-development [15, 16].
The main purpose of technological processes is to strive for the correct production of the final product while monitoring the amount of emissions and their impact on the environment of the technical system [17, 18]. Management, logistics and production systems existing in enterprises are the basis for the creation of an area where the goals of production plants are implemented [19]. It should be emphasized that every human activity, including economic activity, plays an important role in maintaining environmental balance. All entities, including industries based on packaging machines, are responsible for implementation and the spread of sustainable practices as they work directly together with many entities having a direct impact on the environment [20, 21].
The article will present the results of the life cycle assessment (LCA) of the process of mass, thermo-shrinkable packaging of beverage bags depending on the change in the way the packaging machine is powered. In addition, as part of the analysis, it was indicated which stage of the process has the biggest negative impact on the environment. LCA results are presented at the stage of endpoint characterization. The work will present the damage values of the two tested variants of the process on human health, ecosystems and resources. The analysis will also show how changing the power supply of the machine will affect its overall impact on the environment.

METHEDOLOGY OF RESEARCH

LCA is a comprehensive tool responsible for estimating the interaction that occurs between the research object, e.g. a technological process, and the environment. A properly conducted analysis should consist of four stages: defining the goal and scope, analyzing the set, assessing the impact and interpreting the results. In the first step, the purpose of the research is determined, it is also important to define the product system, the boundaries of the adopted system and the functional unit [22, 23]. The second stage involves collecting and analyzing a set of inputs in the form of media and materials and outputs, which include noise, heat or emission of substances to the environment [23, 24]. The third stage of the analysis includes the assessment of the environmental impact of the individual stages of the process in accordance with the adopted method. The most popular methods used by people conducting this type of research is ReCiPe 2016, in which there are two main ways to obtain characteristics, i.e. at the midpoint level and at the endpoint level. In this method, 18 midpoint indicators or 3 endpoint indicators are determined. The last stage of the LCA concerns the interpretation of the results and the formulation of conclusions [25, 26]. Based on the results, the direction of changes in the examined process is determined, which contributes to the reduction of negative impacts [27, 28]. Based on the identification of individual stages of the examined process and the inputs and outputs associated with them, it is also possible to introduce actions that will lead to a reduction in the consumption of utilities and materials in the process [29, 30].
As part of the research, an analysis of the impact of the mass packaging process on the environment was carried out using the SimaPro program, depending on the method of powering the processing machines. Life cycle analysis will allow to indicate the impact of the process on three categories of impact: human health, resources and ecosystem [31, 32]. In the first step of the LCA, the scope and purpose of the analysis were defined, which was to compare the environmental impact of the process in two different variants, which differed in the way the machines were powered (variant 1 – energy from gas and mix electricity, variant 2 – energy from mix electricity). In the process of mass packaging of bottles, its stages were specified: collecting the raw material, wrapping a group of products with foil, shrinking the foil, cooling packs and additional drives. All exclusions and limitations were made simultaneously for both types of processes. The boundaries of the studied system included only the previously mentioned process steps. In order to compare the environmental impact of two variants of the packaging process, the analyzes were related to the same functional unit in the form of 1000 packs. Environmental analysis was performed using the ReCiPe Endpoint method.

RESULTS

The work uses data from a food industry company that in 2021 packed bottles in heat-shrinkable film on two packing machines. Data calculated for the functional unit adopted in the analysis is presented in the Table 1. Analysis shows that to produce 1000 packs (functional unit) by packing machine in process A consumes more energy than process B.

Table 1
Media and raw material consumption during the process of mass packaging of bottles – consumption for 1000 packs

Parameters	Process A	Process B
all: gas [kWh]	58.93	0
all: electrical energy [kWh]	6.33	46.10
all: heat-shrinkable film [kg]	35.35	35.35
ENERGY CONSUMPTION [kWh]		
collecting the raw material	3.99	4.52
wrapping a group of products with foil	1.14	1.48
shrinking the foil	58.93	34.58
cooling of the resulting packs	0.57	0.46
additional drives	0.63	5.07
FOIL CONSUMPTION [kg]		
0rLDPE/100LDPE	31.52	31.52
50rLDPE/50LDPE	3.83	3.83

For the tested variants of the mass packaging process, process trees were prepared, including the media and raw materials used in the process within the previously established system boundaries (Fig. 1, 2).

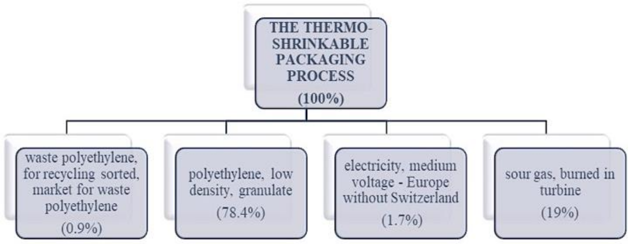

Fig. 1 Tree of raw materials and utilities for the mass packaging process with the use of packaging machine A in 2021
Source: (own elaboration by SimaPro).

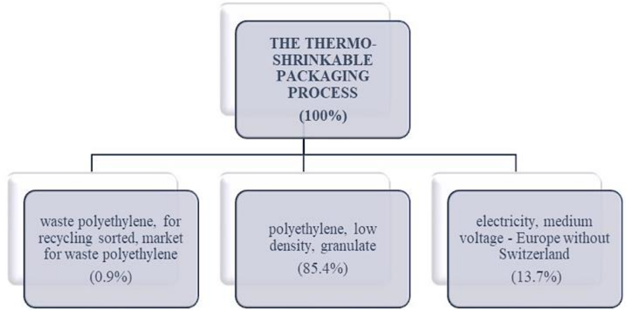

Fig. 2 Tree of raw materials and media for the mass packaging process with the use of packaging machine B in 2021
Source: own elaboration by SimaPro.

Based on the results of the analyzes, it can be concluded that in the process of mass packaging of bottles, the biggest potential impact on the environment has both the first (78.4%) and the second (85.4%) polyethylene low density. Low impact values in both cases were recorded for sorted polyethylene for recycling, for the first variant at the level of 0.9%, for the second 0.9%. In addition, the potential impact of the individual stages of the packaging process was also determined in two variants on three categories of impact: ecosystems, human health and resources. For resources (9.89 $) and human health (2.20E-04 DALY), the first variant (Tab. 2) achieves higher impact values. While for ecosystems the second variant has the greatest harmfulness (7.54E-06 species.yr).

Table 2
Values of impacts of each variant of the examined process on three categories of impacts

damage category	unit	variant of the process	total
resources	$	Variant 1	**9.89**
		Variant 2	9.77
human health	DALY	Variant 1	**2.20E-04**
		Variant 2	1.77E-04
ecosystems	species.yr	Variant 1	7.40E-06
		Variant 2	**7.54E-06**

In both variants of the process of mass packaging of bottles, the biggest impact in the category of resources is characterized by the stage of shrinking the film (Fig. 3), the impact of which is at the level of 21.4% and 21.0%, for the remaining stages, the potential impact on this category is lower than 20% (Fig. 3).

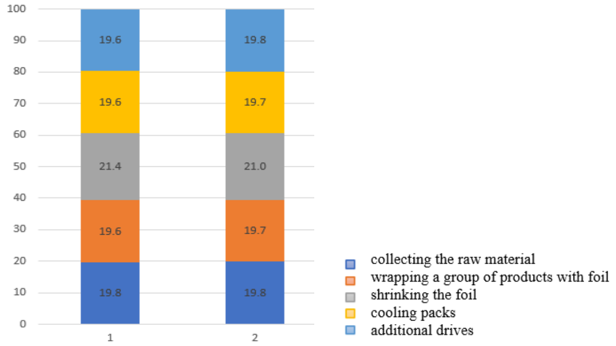

Fig. 3 Percentage impact of individual stages of the mass packaging process on the category of resources depending on the variant

In the category of impact on human health, the highest values are the same as above for the foil shrinking stage (23.1-27.8%) in both cases. For the other stages of collecting the raw material, the impacts were 18.0% and 19.5%, wrapping a group of products with foil 18.0% and 19.1%, cooling packs 17.9% and 18.9% and additional drives 18.3% and 19.4% (Fig. 4).

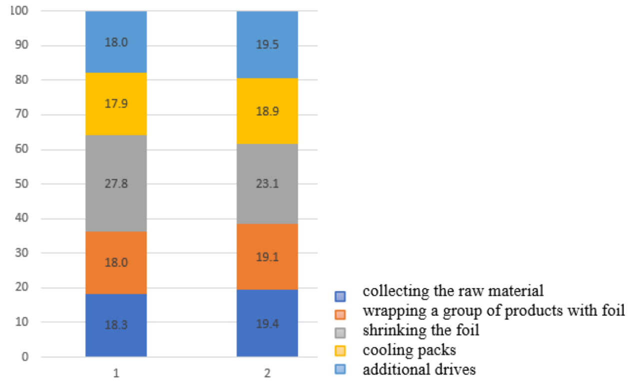

Fig. 4 Percentage impact of individual stages of the mass packaging process on the human health category depending on the variant

In the impact on ecosystems, the same situation is noticeable as for the two previously discussed types of impacts. For all variants, the film sealing step achieves the highest impact values at the level of 22.9% (Fig. 5). For both variants, the impact values at the welding stage are comparable to the impact levels of the remaining stages of the process.

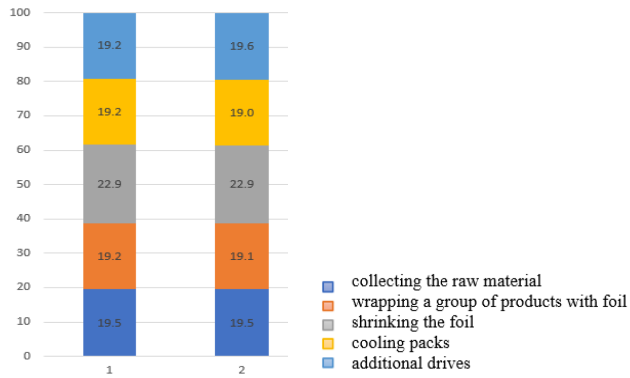

Fig. 5 Percentage impact of individual stages of the mass packaging process on the category of ecosystems depending on the variant

Based on the analysis, it was found that the total environmental index for the mass packaging process in the first variant is 61.006 Pt, including the resource consumption index is 37.260 Pt, the impact on human health is 22.396 Pt and the impact on ecosystems is 1.350 Pt (Tab. 3). However, for the second type of process, where the heating tunnel is not supplied with energy from gas, the total index is 59.751 Pt, including 37.200 Pt for resources, 21.191 Pt for human health and for ecosystems 1.360 Pt. In the analyzed variants of the process, the differences in harmfulness for the three examined categories are small. The highest noticeable difference at the level of 1.2 Pt is assigned to the human health category, which is related to the higher energy consumption of the process in the first variant.

Table 3
Values of impacts on three categories of impacts resources, human health, ecosystems expressed in Pt

impact category	unit	variant	collecting the raw material	wrapping a group of products with foil	shrinking the foil	cooling shrink wrap	additional drives	all
resources	Pt	variant 1	7.360	7.320	7.960	7.310	7.310	37.260
		variant 2	7.370	7.320	7.820	7.310	7.380	37.200
human health	Pt	variant 1	4.100	4.034	6.232	4.009	4.021	22.396
		variant 2	4.120	4.038	4.887	4.012	4.134	21.191
ecosystems	Pt	variant 1	0.264	0.258	0.310	0.259	0.259	1.350
		variant 2	0.265	0.260	0.311	0.258	0.266	1.360

CONCLUSION

The analysis shows that the use of gas as a power source for the heating furnace in the mass packaging process reduces the harmfulness to ecosystems. Because changing the power source increased the energy consumption of machines, the harmfulness affecting human health and resources also increases. In the process of mass packaging of bottles in heat-shrinkable foil, the stage with the greatest impact on the environment is shrinking of the foil in both analyzed cases. This fact is related to the high energy consumption of this stage. Carrying out LCA made it possible to achieve the objectives of the article, which was to indicate the most onerous stage of the process and to verify the impact of two variants of the process by changing the source of energy used for shrinking the film.

The analysis conducted reveals that utilizing gas as a power source for the heating furnace in the mass packaging process results in reduced ecological harm. However, this change in power source leads to an increase in energy consumption by the machines, consequently raising the potential negative impact on human health and resources. Within the context of the mass packaging of bottles using heat-shrinkable foil, it is evident that the foil shrinking stage has the most substantial environmental footprint in both examined scenarios. This finding is attributed to the high energy requirements of this particular stage.

By employing Life Cycle Assessment (LCA), the objectives of the article were successfully achieved. These objectives included identifying the most burdensome stage of the packaging process and assessing the impact of two process variants by altering the energy source used for film shrinking. The LCA approach provided valuable insights into the environmental consequences associated with the analyzed process, enabling a comprehensive evaluation of its sustainability.

Furthermore, the study highlights the intricate relationship between energy sources, machine energy consumption, and their subsequent effects on environmental and human factors. While the use of gas as a power source may mitigate the ecological harm caused by the packaging process, it is essential to consider the trade-offs and potential repercussions, such as increased energy consumption and its implications for human health and resource depletion.

In conclusion, this scientific analysis emphasizes the significance of considering multiple factors when evaluating the environmental impact of industrial processes. The study's findings underscore the importance of identifying critical stages and evaluating the effects of alternative approaches, such as altering energy sources. By comprehensively assessing the environmental burdens associated with various process variants, decision-makers can make informed choices to minimize harm to ecosystems and promote sustainability in the mass packaging industry.

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