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Metodologies for reducing the mass of paper and cardboard packaging: Environmental and economic benefits

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Abstract – **This paper examines methods and the importance of reducing paper and cardboard packaging mass. It analyzes packaging waste by material, focusing on paper and cardboard's role. The significance of packaging mass is explored, and strategies for its reduction are developed. Lowering paper and cardboard packaging mass yields essential economic and environmental benefits.**

Keywords – **packaging, paper, cardboard, waste, mass, nanocellulose.**

I. Introduction

Environmental protection is a broad concept that encompasses the air, water, and soil that make up the environment. In the context of packaging, it is important to minimize the impact on the environment by reducing waste and pollution resulting from packaging materials. This paper focuses on the methods and importance of reducing the mass of paper and cardboard packaging, as a significant part of the total packaging waste, and examines the environmental and economic benefits of such strategies.

II. Analysis of Packaging Waste

To understand the importance of reducing the mass of paper and cardboard packaging, it is first necessary to analyze packaging waste as a whole. This analysis includes comparing the representation of each material individually, in order to determine the percentage representation of different packaging materials and their contribution to total waste. By identifying the dominant materials, efforts can be directed towards those with the greatest potential for waste reduction. Particular attention is paid to paper and cardboard packaging to highlight its specific representation and significance in the overall picture of packaging waste.

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According to Eurostat, packaging waste in the European Union in 2022 is shown in Table I and Fig.1. The Eurostat report indicates that paper and cardboard packaging constitutes the largest share of packaging waste, accounting for 41% of the total.

TABLE I
PACKAGING WASTE GENERATED IN THE EU IN 2022

Material type	Percentage
Glass	18.8%
Plastic	19.4%
Paper and cardboard	40.8%
Metal	4.9%
Wood	16.0%
Other	0.2%

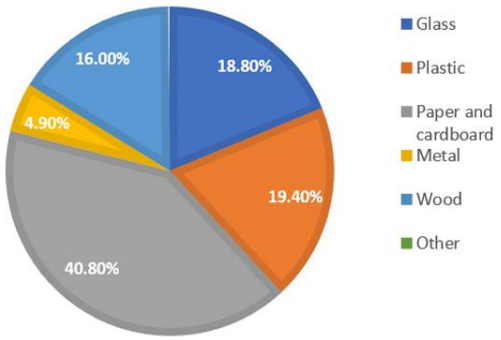

Fig. 1. Visual presentation of packaging waste generated in the EU in 2022

According to the 2023 annual report on the Quality of the Environment in the Republic of North Macedonia, published by the Macedonian Information and Environmental Centre within the Ministry of Environment and Physical Planning of the Republic of North Macedonia, cardboard and paper packaging also represents the largest percentage in our country, amounting to 35% of the total packaging placed on the market, as it can be seen in Table II and Fig. 2.

Based on the annual reports submitted to the Ministry of Environment and Physical Planning by collective handlers for 2023, the total quantity of packaging waste placed on the market amounts to 76,172.57 tons, while the total quantity of packaging waste collected in 2023 is 46,665.59 tons.

TABLE II
QUANTITY OF PACKAGING PLACED ON THE MARKET BY TYPE OF MATERIAL IN THE R.N. MACEDONIA IN 2023

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Material type	Percentage
Glass	18%
Plastic	28%
Paper and cardboard	35%
Metal	5%
Wood	10%
Composite materials	4%

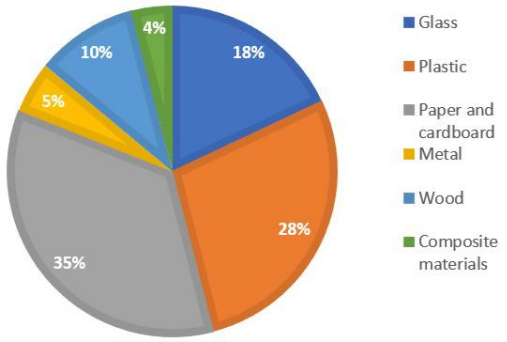

Fig. 2. Visual presentation of quantity of packaging placed on the market by type of material in the R.N. Macedonia in 2023

III. The Economic Aspect of the Mass of Packaging Material

The mass of packaging materials is a key factor that influences the environmental and economic aspects of packaging. Reducing mass directly contributes to reducing the total amount of waste, which is vital for environmental protection. In addition, reducing mass can result in lower costs for transportation, storage, and waste management, which has positive economic implications.

To protect the environment and manage waste, numerous laws and regulations exist. In the Republic of North Macedonia, the first law on the environment was adopted in 2005, and since then, several amendments have been made and additional regulations have been enacted to address this issue. Managing packaging waste is one of the measures for environmental protection. Anyone who places packaging materials on the market is obliged to ensure that they do not end up in open landfills and do not pollute the environment. This means that the materials should be recycled, used for energy recovery, or processed to ensure they are not harmful to the environment. Waste management is carried out by other legal entities, which charge for their services, and the price is calculated based on the mass of the packaging material.

The fees that manufacturers and traders pay for waste management are calculated based on the weight of the material. Table III shows the fees for packaging waste management for 2025, according to the Pakomak price list.

Table III
Fees for Packaging Waste Management

Material type	Fee per ton excluding VAT of 5%
Glass	2,935.50 ден.
Plastic	2,562.70 ден.
Paper and cardboard	2,101.20 ден.
Aluminum	2,935.50 ден.
Other metal	2,552.00 ден.
Wood	2,070.30 ден.
Composite materials	2,564.70 ден.

Below in the Table IV you can see an abbreviated version of the Specification for calculating the mass of packaging materials for a single product. In this example, the method for calculating the mass of packaging materials for 1.5 liters of water is given.

Table IV
Specification for Calculating Packaging Materials Mass

Name of packaged product: Water 1.5 l	Type of packaging material by weight for one bottle (kilograms)		
Packaging elements	Plastic	Paper and cardboard	Wooden materials
Bottle	0.048		
Cap	0.005		
Label	0.003		
Plastic foil wrapper for 6 bottles	0.005		
Cardboard between the lines		0.009	
Irreversible wooden pellet			0.04
TOTAL	0.061	0.009	0.04

The above analysis has indicated that paper and cardboard packaging, and the generated waste, constitute the largest percentage both within the European Union and, comparatively, in the R.N. Macedonia. Consequently, the reduction of their mass warrants significant attention, primarily due to the associated environmental and economic benefits.

IV. Metodologies for Reducing the Mass of Paper and Cardboard Packaging

Several methodologies exist to reduce the weight of paper and cardboard packaging. The further analysis will focus on the physical reduction of the packaging's surface area and modifications to the material composition of the paper and cardboard.

Regarding the reduction of the surface area of packaging, several factors merit consideration. Prior to package design, a detailed analysis of the dimensions of the products intended for packaging is essential. This encompasses the measurement of length, width, height, as well as the form and specific attributes of the products. Furthermore, packaging should be engineered to minimize internal void space. Superfluous empty space necessitates additional packaging materials, such as cardboard

inserts, thereby increasing transportation expenditures. To this end, the utilization of packaging design software can facilitate the optimization of package dimensions and the minimization of empty volume.

The design process should also integrate logistical considerations, specifically the dimensions of transport containers and pallets. Optimizing package dimensions to maximize spatial efficiency during transit is crucial. For instance, in the context of palletized transport, designing packaging compliant with standard pallet dimensions (e.g., 1200 x 800 mm or 1200 x 1000 mm) can mitigate wasted space and associated transportation costs.

Moreover, reducing the surface area of the packaging can be achieved by considering the dimensions of the closure flaps (tabs). Decreasing the flap surface area necessitates a careful evaluation of the cardboard joining method and the potential requirement for alternative fastening mechanisms or equipment.

When designing a package, the efficient use of the material should be considered. This means considering reducing the area that is wasted after die cutting the packaging forms. In order to reduce the amount of wasted material, the die cutting form should contain the maximum number of packages on one sheet that can be achieved by their optimal arrangement. Here, the use of sheets with optimally calculated and appropriate dimensions should also be taken into account.

When considering reducing the area of the packaging material, the following questions should be asked: Is packaging still necessary for the product or is just a sticker sufficient? Is it okay to pack multiple products in one group package? What is the lightest material that will meet the packaging needs?

The weight of paper and cardboard is directly correlated with their material composition. The production of paper and cardboard from primary cellulose fibers yields a high-quality product characterized by lower weight and enhanced tear resistance. However, contemporary environmental imperatives in the paper and cardboard manufacturing sector increasingly involve the recycling of raw materials.

The recycling process leads to a reduction in the length of cellulose fibers, consequently diminishing the material's mechanical properties. The strength of the paper depends mostly on the strength of the fibers themselves, the strength of the bond between the fibers and the degree and characteristics of the entanglement of the fibers in the matrix.

To compensate for the degradation of cellulose fibers and achieve improved material quality, manufacturers often increase thickness and incorporate additives, which directly impact the final mass of the product.

In both scenarios – the production of paper and cardboard from primary and secondary cellulose fibers – the incorporation of nanocellulose during the manufacturing process presents a viable strategy for mass reduction.

Nanocellulose exhibits unique characteristics, including a high surface area, mechanical strength, and stiffness, enabling the production of thinner materials with maintained or enhanced mechanical properties. Its facile production and biodegradability render nanocellulose an environmentally sound and economically attractive alternative to conventional additives in paper and cardboard production.

The most economically sustainable sources for nanocellulose extraction include annual plants and waste streams from industrial processing of cereals, as well as other cellulose-rich industrial byproducts.

For a better understanding of the impact of nanocellulose on paper and cardboard, the principles of functioning of nanocellulose in these materials will be briefly explained. The addition of nanocellulose increases the strength of the paper by increasing the bonding strength of the fibers. Of particular importance in this process is the formation of hydrogen bonds between cellulose fibers. The diameter of cellulose nanofibrils is very thin, and the length-to-diameter ratio is large. Therefore, the specific surface area is large, which leads to a high potential for hydrogen bonding. The hydroxyl groups of cellulose nanofibrils can generate stronger hydrogen bonds with the hydroxyl groups of the fiber, so nanocellulose is considered an excellent paper reinforcement to improve the mechanical strength of paper. As a promising bio-based material, nanocellulose has unique nano-characteristics. A large number of hydroxyl groups on the surface can form hydrogen bonds with pulp fibers, cross-linking to fill the voids in the paper and improve the strength of the paper.

Nanocellulose is a material that adds value to paper and cardboard, but it is not used exclusively in the production of paper and cardboard. Its exceptional characteristics make it applicable in many areas of material production. Table V summarizes the properties and specific performances of the nanocellulose as well as its applications.

TABLE V
PROPERTIES OF NANOCELLULOSE

Properties	Specific performance	Application
Mechanical properties	Young's modulus: 150 GPa; excellent network hydrogen bonding between celluloses	Reinforcement in polymer matrix
Rheology	Strong hydrogen bond and the ability to form a uniform layer on a hydrophilic substrate; suspension viscosity decreasing with increasing shear rate	Green adhesive; paint; paper coating; rheology modifier for food, coatings, cosmetics, and pharmaceutical products

Optical properties	Translucent, highly consistent gel	Transparent material; nano-paper
Thermal performance	Up to 350°C degradation temperature	Insulation material
Biodegradability	Hydrophilic surface; rapid degradation at ambient temperature	Films/membranes, beads/microspheres, hydrogels/aerogels, bioplastics
Oxygen barrier	Tight configuration between the fibers leads to reduced porosity	Liquid and gas material barrier

V. CONCLUSION

Reducing the weight of paper and cardboard packaging is of great importance in several respects. From an environmental point of view, reducing the weight of this packaging material reduces packaging waste, thereby reducing environmental pollution.

Greater attention to packaging design can significantly reduce the amount of material needed for packaging. The use of innovative materials such as nanocellulose from annual plants and cellulose waste offers a dual benefit: reducing the weight of packaging and reducing waste during production, as it requires fewer treatments.

Economic benefits are reflected in reduced waste management costs, savings in transportation and potential reduction in production costs. This paper shows that methods for reducing the weight of paper and cardboard packaging are key to achieving sustainability in the packaging industry.

ACKNOWLEDGEMENT

Due to the fact that not all packaging producers comply with the legal obligation to submit annual reports to the Ministry of Environment and Physical Planning in R.N. Macedonia, or only a portion of producers participate in the collective handling system, the actual quantity of packaging placed on the market may be even greater.

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