

Quantities of Recycled Plastic Waste in the EU and Croatia

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Abstract

The growing use of plastics has simultaneously increased the accumulation of ubiquitous plastic waste in landfills and the environment, posing global aesthetic and ecological challenges. Consequently, various waste disposal procedures are implemented, with recycling or waste recovery occupying a prominent position in the waste management hierarchy. Plastic waste recovery includes mechanical, chemical, or energy-related processes, yielding products suitable for reuse. This method of plastic waste disposal is currently the most cost-effective solution, aiming to avoid landfill dumping and reduce waste volumes. In the past two decades, the focus of waste management has shifted increasingly from disposal methods to prevention and recycling, with European Union (EU) member states committed to implementing and harmonising current legal measures related to plastic items prescribed by EU directives. The ultimate goal is to transition toward a circular economy model, promoting the sustainable use of plastics and minimising waste generation. Despite the increasing waste production rate in the EU, the quantity of municipal waste dumped in landfills has decreased overall, partly due to the introduction of European legislation, such as the Directive 62/1994 on packaging and packaging waste. However, Croatia's plastic packaging waste recycling rate still lags behind the EU average.

Keywords

Polymeric materials, recycling of plastic waste, disposal of plastic waste

1 Introduction

The term “polymers” is a common name for both natural and synthetic, organic and inorganic polymeric substances and materials, consisting of large molecules, *i.e.*, macromolecules with repeating units. Historically, only natural polymer materials (rubber, cellulose, cotton, etc.) were used until the beginning of the 20th century, but today synthetic polymer materials dominate considerably.¹ Material, in general, refers to any technically usable substance, modified or refined through various additives and/or physical and chemical processes, existing in a solid or liquid aggregate state.²

Plastic, an indispensable material in modern life, plays an extremely important role across diverse human activities, spanning everyday use to applications in construction, medicine, electronics, transportation, and packaging. Its practicality has easily integrated it into daily life, often influenced by consumer preferences for aesthetically appealing packaging. The problem arises when these products fulfil their purpose and become surplus to end consumers. Such products need to be appropriately collected, sorted, and repurposed for new production whenever possible. The term “recovery” summarises the various possibilities available for polymer waste utilization, including reuse and recycling. The recovery of polymer products is divided into mechanical, chemical, and energy recovery, with energy

recovery representing a partial solution to the problem of waste volume and alternative energy needs. The continuous development of the polymer industry constantly broadens the scope of applications for polymer materials.³ Since the 1950s, plastics production has grown exponentially, reaching a global production volume of 367 million tons in 2020.⁴ In Europe alone, 25.8 million tons of plastic waste are generated annually, with a mere 30 % collected for recycling purposes.⁴

Due to the increase in consumption and use of long-lasting plastic products, the volume of plastic waste continues to surge. However, this proliferation of synthetic polymers results in substantial waste generation.⁵ The aim of this study was to elucidate the concept of polymers, polymer materials, and plastics, and to interpret available data on the collection and recycling of plastic waste in both Croatia and the European Union.

2 Waste disposal

The management of plastic waste encompasses an entire series of various waste disposal methods, starting from collection, sorting, transportation, and processing; import-export; storage, above or below-ground disposal, and ultimately, landfill remediation and closure. Furthermore, waste management includes conversion operations aimed at facilitating reuse, recovery, or recycling of waste, all with the central goal of reducing waste volumes, optimising the use of natural resources, reducing environmental impact, and initiating new economic activities.⁶

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2.1 Management of plastic waste in the EU

According to the European Strategy for Plastics in the Circular Economy, the European Union is in the best position to lead the transition toward the plastics of the future. The strategy lays the groundwork for a new, circular approach to plastics management (Fig. 1). It encourages the design and production of plastic products that prioritise reuse, repair, and recycling, along with the development and promotion of more sustainable materials, thus aiming to reduce plastic pollution and its adverse effects on both human well-being and the environment.⁴



Fig. 1 – Principles of circular economy (source: *European Commission, 2014*)⁷

Slika 1 – Načela kružnog gospodarstva (izvor: *Europska komisija, 2014.*)⁷

In a circular economy, products and materials undergo utilisation throughout their entire life cycle. Unlike the current linear system, where products ultimately end up in landfills, the circular model reintroduces them into the production process. Thus, the system must facilitate their utilisation within a circular economy. The European Union allocates funding for waste management infrastructure, collection, sorting, and disposal, primarily through the cohesion policy framework. While it is difficult to determine the financial resources earmarked solely for plastic waste management, such financing generally enhances overall waste management practices. Just one support measure is financed in this domain:⁸ Investment in household waste management (refers to waste minimisation, sorting, and recycling). The aim of this measure is to support waste disposal methods at a higher level in the waste hierarchy, thereby aligning with the ambitions of transitioning toward a circular economy. In Europe, energy recovery is the predominant method of plastic waste disposal, followed by recycling, although the potential of plastic waste remains largely untapped. Approximately 25 % of all produced plastic waste finds its way into landfills (Fig. 2), while half of the plastic waste designated for

recycling is exported to non-EU countries for processing. However, the situation varies from country to country, depending on the development of their respective waste management systems. Presently, more plastic waste is incinerated than recycled.

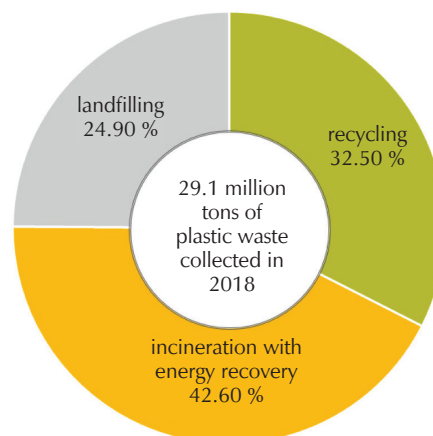


Fig. 2 – Various methods of plastic waste disposal in the EU in 2018 (source: *European Court of Auditors, 2020*)⁸

Slika 2 – Različite metode zbrinjavanja plastičnog otpada u EU-u u 2018. (izvor: *Europski revizorski sud, 2020.*)⁸

Exporting plastic waste serves as a method to address the absence of technology, proper systems for plastic waste management, but also capacity or financial resources for local waste processing. At the beginning of 2019, the EU exported approximately 150 000 tons of plastic waste per month. In 2015 and 2016, this figure was roughly twice as high, up to 300 000 tons per month, when exports were primarily directed to China. This reduction and shift in plastic waste export to other Asian countries can be attributed to import restrictions. Such a scenario represents a risk of increased incineration and disposal of plastic waste in Europe.^{9,10}

Unfortunately, Croatia and many other countries still resort to landfilling for waste disposal, particularly prevalent in Eastern and Southern Europe, where as many as ten countries dispose of half or more of their waste underground, with rates reaching 60 % in Romania, Bulgaria, and Slovakia.¹¹ The countries of the Western Balkans also rely heavily on waste disposal methods. Substantial amounts of waste find their way into illegal landfills. While there has been some progress over the years, recycling efforts in these countries remain negligible.

On the other hand, countries in Northwestern Europe such as Belgium, the Netherlands, Denmark, Sweden, Germany, Austria, and Finland demonstrate minimal reliance on underground disposal. In addition to recycling, waste incineration is also popular in these countries, with over 90 % of their plastic waste recycled. However, with the new legislation, it will not be possible to continue in the future. The European Strategy for Plastics in Circular Economy promotes successful and high-quality management of

polymer waste in some countries, while in others it is yet to be applied. This strategy includes the following elements:¹²

- Plastics and plastic-containing products are to be designed for increased durability, reuse, and high-quality recycling. All plastic packaging placed on the EU market must be reused, *i.e.*, recycled in a cost-effective manner;
- Significant expansion of plastic recycling capacity within the EU, facilitating job creation;
- Changes in manufacturing and design aimed at boosting plastic recycling rates for all key changes;
- Improved separate collection, and investment in innovation and skills seeking to reduce waste export for recovery. Increased plastic recycling would not only reduce Europe's reliance on fossil fuel imports but also reduce carbon dioxide emissions.
- Raising public awareness about waste avoidance and responsible handling of polymer waste, thereby actively engaging the public in the transition.
- The EU assumes a leading role in global dynamics, with countries engaging and cooperating to stop the flow of plastics into the oceans.
- EU reinforces its leading position in the field of sorting and recycling technology.
- Significant reduction in the release of plastics into the environment and the development of innovative solutions to prevent microplastic contamination in oceans.

Such a strategic vision can only be realised through the collective action of all participants in the plastics value chain: from producers and designers, through brands and retailers, to consumers, and recycling entities.

2.2 Plastic waste management in the Republic of Croatia

The increased use of plastic materials has led to a corresponding increase in plastic waste, intensifying the challenge of its disposal. Irresponsible disposal of plastic waste poses a long-lasting threat to the environment, emphasising the need for effective polymer waste management, primarily driven by economic incentives and environmental protection.

When discussing waste management, we are essentially discussing waste disposal processes. In Croatia, waste management is important solely for environmental protection, but it is also one of the most complex areas in terms of compliance with EU standards. Unlike EU member states where waste is regarded as a strategic resource yielding certain amounts of energy, waste management in Croatia is still insufficiently developed. Establishing an efficient system requires substantial effort, investment, and community education. Moreover, the range of challenges confronting the waste management system is extensive, encompassing spatial and financial constraints, illegal landfills, and inadequate implementation of EU legislation.¹³ However, Croatia has several positive examples in plastic waste management, such as the collection and recycling of single-use plastic packaging for beverages, and the recycling of vehicle tires, which have yielded significant environmental and economic benefits.

2.3 Waste management issues in the Republic of Croatia

2.3.1 Insufficient public awareness

Research conducted in 2018 revealed that as much as 96 % of respondents recognise the importance of waste separation and recycling, indicating a positive societal attitude. In contrast, the majority of respondents are unwilling to alter their lifestyles to accommodate proper waste sorting and disposal. Other findings from the research include:

- 40 % of respondents cited lack of habit as the reason for not separating waste,
- 37 % claimed lack of time,
- 18 % were unfamiliar with proper waste disposal procedures,
- 40 % were unaware of the locations of recycling yards,
- 53 % did not utilise designated waste facilities,
- 44 % believed they had sufficient information about waste management,
- 13 % were undecided.

Citizens of Croatia should be educated to respect the hierarchy of waste management by encouraging practices such as waste prevention, reuse, separate collection, and composting.¹³ The absence of a plastic waste management system and inadequate public education are primary contributors to the proliferation of plastic waste landfills.

2.3.2 Financial issues

Waste management is still not part of a circular economy, and as such has an impact on the entire economy and society. Intensified efforts are necessary in implementing a waste management system to reduce plastic waste volumes. The various costs associated with waste management activities are often high. The construction and maintenance of waste management infrastructure are expected to be financed through communal fees and contributions. Although each local self-government unit has prescribed communal fees and contributions to be paid regularly by its residents, many areas still lack adequately organised waste management systems due to insufficient financial resources. Furthermore, an increase in waste disposal prices is anticipated in county centres where waste disposal and recycling efforts are not adequately implemented.¹³

2.3.3 The issue of illegal landfills

In Croatia, waste is still primarily disposed of in landfills, with approximately 90 % of waste being disposed of without prior treatment, and 60–70 % of this waste is deposited in uncontrolled or illegal landfills (Fig. 3). Illegal waste disposal sites are areas where unidentified individuals dump waste, circumventing official landfills. These sites not only reflect the lack of public awareness, but also stress deficiencies in regulatory oversight, posing significant environmental hazards.



Fig. 3 – Illegal landfill (source: *Jutarnji list*, 2021)¹⁴
Slika 3 – Ilegalno odlagalište (izvor: *Jutarnji list*, 2021.)¹⁴

Large amounts of soil are irreversibly lost every year due to waste dumping in illegal landfills, exacerbating pollution of the air, groundwater, and sea. Additionally, these illegal waste disposal sites cause numerous fires and damage the natural landscape. Data from 2004, when remediation began, suggest that there are over 3,000 illegal waste disposal sites in Croatia. For this reason, funding was allocated in 2013 to co-finance 266 remediation projects, including 50 % of illegal landfills in Croatia.¹³

2.3.4 Non-compliance with European Union legislation and deadlines

Croatia faces significant challenges in harmonising and implementing European Union legislation, often failing to adhere to the set deadlines and goals. These challenges entail other problems, including the threat of substantial fines, and potential exclusion from other EU funding opportunities. The penalties depend on many factors, the most important of which are population and GDP. The penalty process is lengthy, typically beginning with warnings granting a “second chance” to fulfil obligations within extended deadlines. Upon expiration of these deadlines, fines are levied and enforced. Given the current situation, it is likely that Croatia will incur fines, and that citizens will pay a high price for waste mismanagement.¹² According to the National Environmental Protection Strategy of the Republic of Croatia from 2002,¹⁵ waste disposal remains the biggest problem in urban areas, emphasising the unsustainable waste management practices prevalent in cities. The Waste Management Act,¹⁶ places particular emphasis on the problem of non-recycled or undisposed plastic, which constitutes 20 % of total municipal waste in Croatia.

The significance of addressing plastic waste is highlighted by the European Council’s decision in 2020 to impose a tax on non-recycled plastic from the beginning of 2021, in the amount of 0.80 euros *per kilogram*. For example, in Split-Dalmatia County alone, about 20 % of total municipal waste comprises PET packaging and various hard and soft plastic materials annually. Given that one fifth of

municipal waste in Croatia consists of plastic waste, solving the problem of municipal waste simultaneously solves the problem of undisposed plastic.¹⁷

Separate collection of valuable raw materials through containers placed in public areas is one of the steps of responsible waste collection. This involves the segregation of various types of municipal waste, primarily paper, glass, plastic, metal, through doorstep collection, public area containers, green islands, recycling yards, and established national schemes for special categories of waste.¹⁸

The law on sustainable waste management prescribes a return fee, aimed at incentivising the submission of certain waste materials to the separate collection system. This measure serves to promote waste segregation, recycling, and recovery, while also contributing to waste reduction. The return fee applies to select packaging types, yielding considerable success, particularly in the case of PET beverage bottles.¹⁹

Public area containers facilitate the separate collection of plastic and metal waste, as well as paper and glass. Yellow containers are designated for the disposal of plastic waste, encompassing all widely used plastomers (PE, PP, PVC, PS and PET), excluding PET bottles subject to the return fee system.¹⁸

3 Discussion

3.1 Plastic waste quantities in the EU

In the European Union, plastic is mostly utilised for packaging purposes (*i.e.*, bottles for water, protective packaging for fruit and vegetables...), constituting 40 % of plastic production and contributing to 61 % of total plastic waste generated. Beyond packaging, significant quantities of plastic waste originate from sectors such as electrical and electronic equipment production, as well as construction, automotive, and agricultural industries (Fig. 4). Plastic

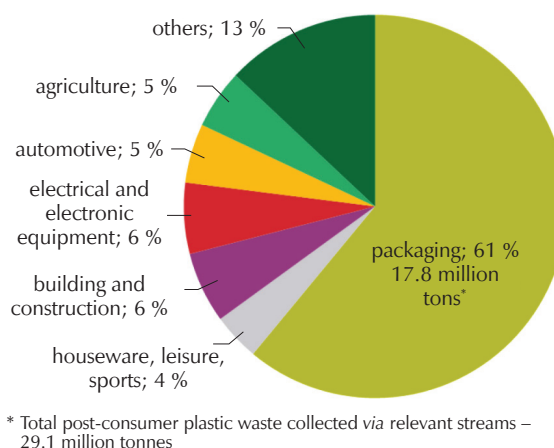


Fig. 4 – Plastic waste generation by sector in 2018 (source: *European Court of Auditors*, 2020)⁸

Slika 4 – Proizvodnja plastičnog otpada po sektorima u 2018. (izvor: *Europski revizorski sud*, 2020.)⁸

packaging has the lowest reported recycling rate in the EU (42 %) in contrast to the significantly higher recycling rates observed for metals (76 %), paper and cardboard (83 %), and glass packaging (73 %)

Thanks to the increasing restrictions on waste landfills introduced by EU member states and the ongoing efforts of the entire value chain to invest in necessary infrastructure for the recovery of plastic products at the end of their lifecycle, the volume of plastic waste sent to landfills decreased by 44 % between 2006 and 2018. According to Eurostat data, in 2019, each person living in the EU generated 34.4 kg of plastic packaging waste. Of this, 14.1 kg, or 40.99 %, was recycled (Fig. 5). Between 2009 and 2019, the quantity of plastic packaging waste produced per inhabitant increased by 24 % (+6.7 kg). The volume of recycled plastic packaging waste surged by 50 % (+4.7 kg) during the same period. Despite this progress, since 2009, the amount of non-recycled plastic packaging waste has increased by 2 kg per inhabitant due to the increase in the absolute amount of plastic packaging waste produced.²¹

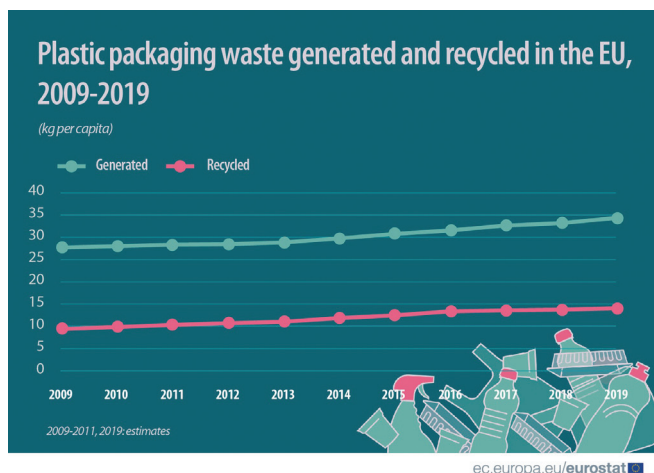


Fig. 5 – Plastic packaging waste generated and recycled in the EU, 2009–2019 (source: Eurostat, 2021)²¹

Slika 5 – Proizvodnja i recikliranje plastičnog ambalažnog otpada u EU-u, 2009. – 2019. (izvor: Eurostat, 2021.)²¹

It is estimated that 41 % of plastic packaging waste is recycled in the European Union. Nine EU member states recycle more than half of their produced plastic packaging waste: Lithuania (70 %), the Czech Republic (61 %), Bulgaria (59 %, data from 2018), the Netherlands (57 %), Sweden and Slovakia (53 %), Spain (52 %), Cyprus (51 %), and Slovenia (50 %).

In contrast, less than one third of plastic packaging waste was recycled in Malta (11 %, 2018 data), France (27 %), Ireland (28 %), Austria (31 %), Poland (32 %), and Hungary (33 %) (Fig. 6). As evident from Fig. 6, the recycling rate of plastic packaging waste in Croatia is below the EU average.



Fig. 6 – Recycling rate of plastic packaging waste, 2019 (source: Eurostat, 2021)²¹

Slika 6 – Stopa recikliranja plastičnog ambalažnog otpada, 2019. (izvor: Eurostat, 2021.)²¹

The quantities of packaging produced experienced consistent growth during the 2009–2019 period. In 2019, the volume of packaging waste reached its highest value since 2009. Over the course of these ten years, the generation of all types of packaging waste material increased, although to varying degrees. Plastic, paper and cardboard, and wooden packaging increased the most. Meanwhile, recycling and recovery rates steadily increased over the same ten-year period.

3.2 Quantities of plastic waste in the Republic of Croatia

Due to the extensive utilisation of polymer materials for packaging food and non-food items, the majority of plastic waste in Croatia, as well as globally, originates from packaging. According to data from the Waste Management Information System for the year 2020, about 85 500 tons of plastic waste were collected separately, with the majority sourced from households (32 934 tons) and the service sector (25 314 tons). Out of these quantities, about 7000 tons of separately collected plastic waste ended up in landfills, while the remainder was directed for recovery within Croatia or exported.

3.3 Share of plastic in packaging waste

To provide a comprehensive understanding of the entire packaging waste management system, we present data sourced from the Environmental Pollution Register (ROO). These data are reported by collectors through waste collection forms as well as by waste processors through waste recovery/disposal forms. The reported quantities exceed those reported by the Environmental Protection and Energy Efficiency Fund (FZOEU), due to some entities with permits for packaging waste management lacking valid contracts with FZOEU. However, the data from the ROO database lack a sufficiently detailed set to independently fulfil all needs for understanding packaging waste flows.

For official reporting purposes, here we used FZOEU data collected in compliance with the Ordinance on Packaging and Waste Packaging (Official Gazette 88/15, 78/16, 116/17, 14/20 and 144/20).²²

In 2020, within the FZOEU system in Croatia, the share of plastic waste in the total packaging waste amounted to approximately 17 %, *i.e.*, 25 292 tons (Fig. 7).

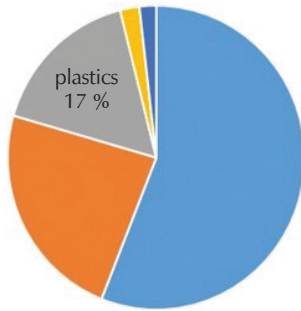


Fig. 7 – Share of plastic in collected packaging waste in 2020 (source: MINGOR, 2020a)²²

Slika 7 – Udio plastike u prikupljenom ambalažnom otpadu u 2020. (izvor: MINGOR, 2020a)²²

The total collected amounts of packaging waste categorised by materials, and the amounts collected within the FZOEU system are graphically presented in (Fig. 8) (shown in blue).

According to data reported in the Register of Environmental Pollution (ROO), out of the total packaging waste collect-

ed, 68 742 tons of plastic packaging were collected. The presentation of collected quantities for the 2015–2021 period is also presented in Fig. 8 (shown in orange).²³

According to data from the Cross-border Waste Transport database, a total of 44 757 tons of packaging waste were exported in 2020. Among the exported packaging waste, plastic packaging waste accounted for 28 %, ranking second (Fig. 9).

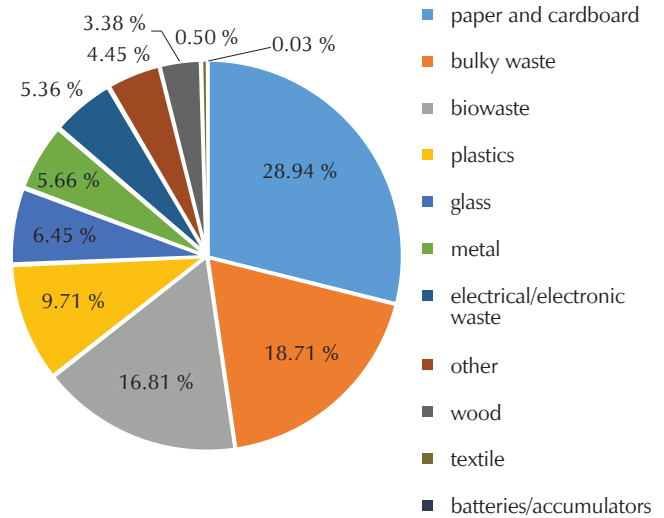


Fig. 9 – Export of packaging waste categorised by materials for the 2015–2020 period, in tons (source: MINGOR, 2020a)²²

Slika 9 – Izvoz ambalažnog otpada prema materijalima za razdoblje 2015. – 2020., u tonama (izvor: MINGOR, 2020a)²²

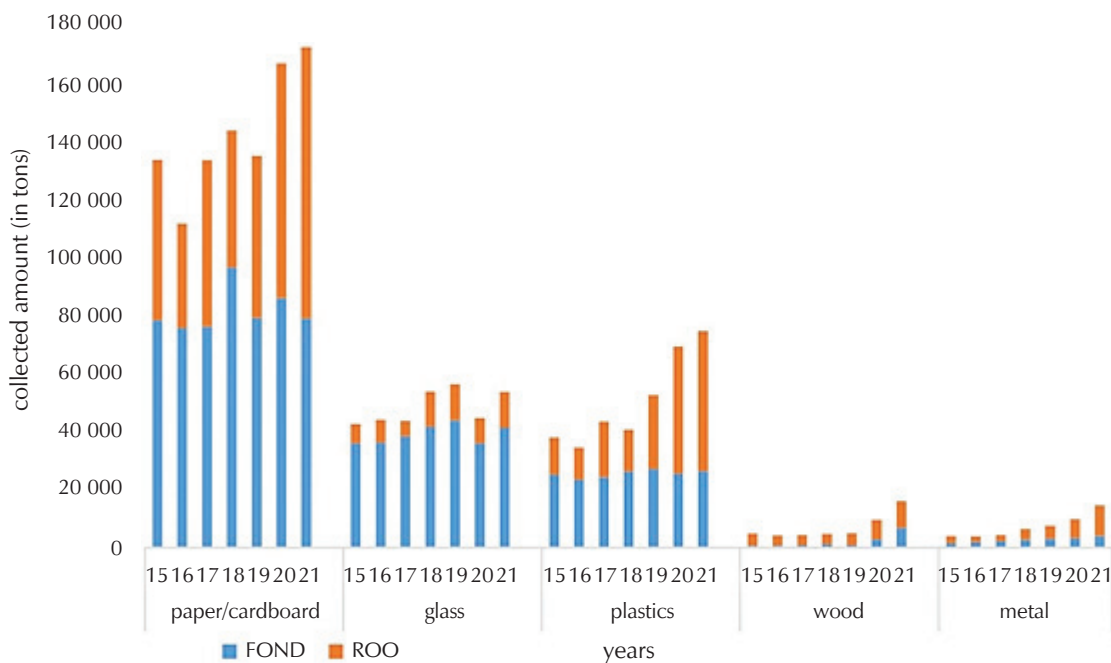


Fig. 8 – Total quantities of packaging waste collected categorised by materials, and the share of packaging collected for the 2015–2021 period (source: MINGOR, 2021)²³

Slika 8 – Ukupne količine prikupljenog ambalažnog otpada kategorizirane po materijalima te udio prikupljene ambalaže za razdoblje 2015. – 2021. (izvor: MINGOR, 2021.)²³

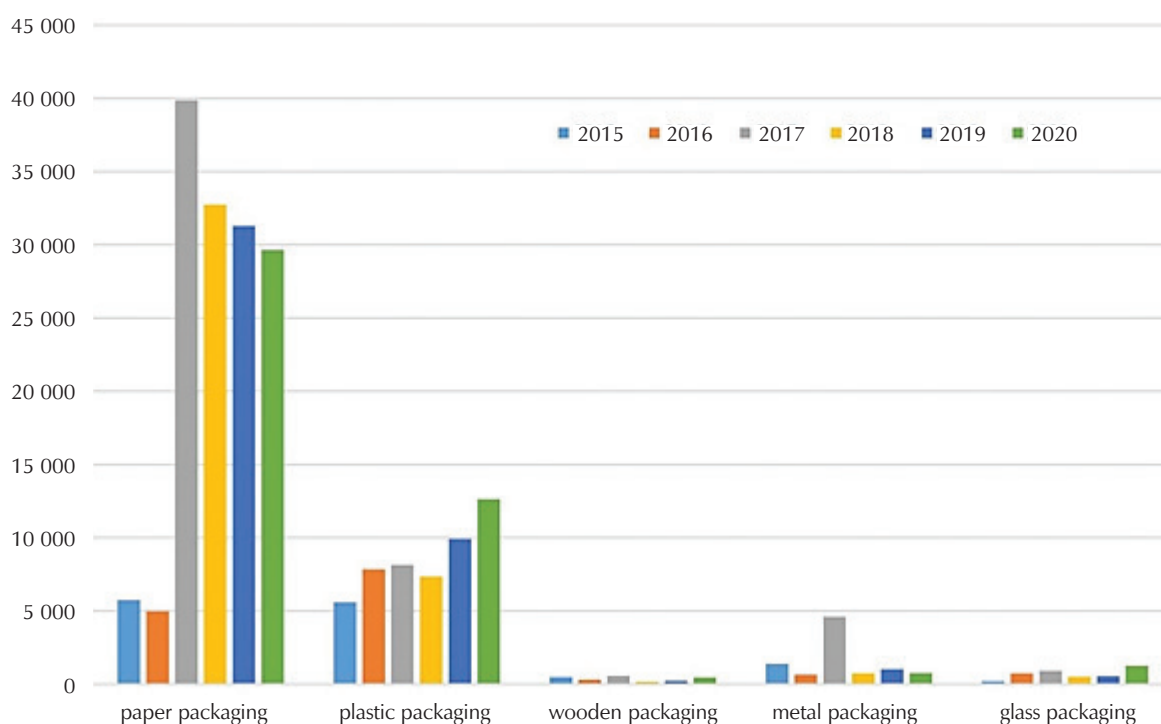


Fig. 10 – Share of plastic in separately collected municipal waste in 2020 (source: MINGOR, 2020b)²⁴

Slika 10 – Udio plastike u odvojeno prikupljenom komunalnom otpadu u 2020. (izvor: MINGOR, 2020b)²⁴

In 2015, the export of plastic packaging waste amounted to 5599 tons, while in 2020, it amounted to 12 636 tons, marking a substantial increase of 226 % compared to 2015.²² In 2020, the majority of plastic waste was exported to neighbouring Slovenia (6783 tons).²²

3.4 Share of plastic in municipal waste

Using data on the composition of municipal waste obtained from tests conducted in individual local self-government units, and data on separately collected amounts of various types of municipal waste from the 2020 Municipal Waste Report,²⁴ the share of plastic in municipal waste in Croatia was determined. In 2020, the proportion of plastic in the total amount of separately collected municipal waste was 9.71 % (Fig. 10).

In 2020, separate collection of various types of waste from municipal waste, organised by local self-government units, was carried out in 514 local self-government units.

Out of a total of 24 845 tons of plastic waste collected, the highest amounts of plastic waste in separately collected municipal waste for 2020 were recorded in the City of Zagreb (11 924 tons), Zagreb County (4516 tons), and Osijek-Baranja County (2299 tons), while the lowest amounts were recorded in the counties of Požega-Slavonia (228 tons), Brod-Posavina (206 tons), and Lika-Senj (110 tons).²⁴

4 Conclusion

The use of plastic is intricately tied to the modern way of life and dominates in various market sectors. The constant demand for plastic and plastic products leads to continual increases in plastic production, resulting in plastic waste generation and subsequent environmental pollution. Through the Green Plan and waste management policies, the European Union aims to bolster circular management by extracting quality resources from waste. Achieving these objectives necessitates finding climate-friendly and circular methods for managing plastic waste, promoting innovation in recycling, and reducing landfill waste.

While the European Union is experiencing a rise in waste generation, the total amount of municipal waste in landfills has decreased, partly due to the implementation of EU legislation, such as Directive 62/1994 on packaging and packaging waste.

The Republic of Croatia is faced with issues of poor waste management, but there are positive examples of plastic waste management, such as the collection and recycling of single-use plastic packaging for beverages and the recycling of vehicle tires. Insufficient enforcement of EU laws and financial constraints pose significant obstacles. It is also important to mention spatial issues, with concerns often voiced regarding the location of landfills and waste management centres. The large number of illegal landfills exacerbates the problem and stems from the citizens' lack of

education and awareness. While progress has been made in almost all segments of waste management, it remains too slow to achieve the set national and EU goals. Therefore, additional efforts are needed to primarily reduce waste volumes and enhance public awareness of the importance of waste separation. Improving existing infrastructure and constructing new facilities for municipal waste management are also crucial steps toward a more efficient waste management system.

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SAŽETAK

Količine recikliranog plastičnog otpada u EU-u i Hrvatskoj

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Rastući trend uporabe plastike povećava nakupljanje plastičnog otpada na odlagalištima i u okolišu, što predstavlja globalni estetski, ali i ekološki problem. Zbog toga se provode različiti postupci zbrinjavanja otpada. U hijerarhiji različitih postupaka zbrinjavanja otpada postoji recikliranje ili uporaba otpada. Oporaba plastičnog otpada može biti mehanička, kemijska i energetska, a dobiveni proizvodi mogu se ponovno upotrebljavati u korisne svrhe. Takav način zbrinjavanja otpadne plastike trenutno je najisplativije rješenje, a njime se nastoji izbjeći odlaganje otpada na odlagališta, odnosno smanjiti količinu otpada. Tijekom posljednja dva desetljeća problem otpada sve se više pomicao s metoda zbrinjavanja na prevenciju i recikliranje. Države članice Europske unije predane su implementaciji i usklađivanju aktualnih zakonskih mjera vezanih uz plastične artikle koje su propisane europskim direktivama, a krajnji cilj je model kružnog gospodarstva koji će upotrebljavati plastiku na održiviji način i smanjiti stvaranje otpada na minimum. Unatoč činjenici da se u zemljama Europske unije stvara sve više otpada, ipak se smanjuje količina komunalnog otpada koji se odlaze na odlagališta. Tome je djelomično pridonijelo i uvođenje europskih zakona poput Direktive 62/1994 o ambalaži i ambalažnom otpadu, no unatoč svemu tome stopa recikliranja plastične ambalaže u Hrvatskoj još uvijek je niža od prosjeka EU-a.

Ključne riječi

Polimerni materijali, recikliranje plastičnog otpada, odlaganje plastičnog otpada

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