DOI: 10.47743/ECO4ALL.2025.1.3

PACKAGING WASTE GENERATION AND RECYCLING IN THE EU: TRENDS, TARGETS, AND INSIGHTS FOR A CIRCULAR ECONOMY

JULIJANA ANGELOVSKA
University of Skopje
Skopje, North Macedonia
julijana.angelovska@yahoo.com

NINA ANGELOVSKA STANKOV
University of Skopje
Skopje, North Macedonia
nina.angelovska@gmail.com

Abstract
The increasing generation of packaging waste in the European Union, driven by sustained economic growth and intensifying consumerism, has raised significant environmental concerns. Despite the expanding volume of packaging waste, recycling rates have not kept pace with this growth, posing a serious challenge to the EU's sustainability ambitions. In response, the EU has transitioned from the long-standing Packaging and Packaging Waste Directive (94/62/EC) to the more rigorous Packaging and Packaging Waste Regulation (PPWR). It establishes binding recycling targets of 65% by 2025 and 70% by 2030, aiming to significantly enhance recycling performance and resource efficiency. This research aims to map the trends between packaging waste generation and recycling rates in the EU-27, identify disparities across Member States, and evaluate their alignment with the PPWR targets. A quantitative analysis was conducted combining trend analysis, correlation analysis, and cluster analysis, using Eurostat data: Packaging waste by waste management operations and Recycling rates of packaging waste for monitoring compliance with policy targets, by type of packaging in the period 2011-2022. The results show that packaging waste generation in the EU-27 reached 83.4 million tonnes in 2022, with growth of 18.7%, while the recycling rate improved by only 1.9 percentage points compared to 2011. At the EU level, the recycling rate targets for 2025 and 2030 have already been achieved; however, the goal of reducing overall packaging waste remains unmet. The findings underscore persistent disparities in recycling performance across EU members and highlight the need for intensified efforts and policy interventions, especially in lagging countries. This study contributes to a clearer understanding of the trajectory of EU Member States toward circular economy goals and the challenges that remain in achieving uniform compliance with EU-wide environmental standards.

Keywords: *Recycling rates, PPWR compliance, circular economy, waste prevention, cluster analysis*
JEL Classification: Q53, C38

1. INTRODUCTION

The growth of the EU's packaging waste is largely driven by economic progress, changing consumer lifestyles, and the rapid increase in online shopping, creating a pressing environmental concern. Packaging is a multidisciplinary field that spans multiple business areas and processes. Beyond its material components, it serves crucial logistical functions, including product protection, transportation efficiency, storage convenience, information dissemination, and sales facilitation. Its role extends across the entire product lifecycle, highlighting its importance in modern consumption and distribution systems. Packaging is not only functional but also strategic. It plays a pivotal role in the marketing mix by serving as a tool for communication and brand differentiation. As Mason (1958) observed, packaging is more than a container; it is a strategic element influencing consumer perceptions and behaviors. Effective packaging balances functionality with aesthetics, enhancing product utility while appealing to consumer preferences. This dual role underscores the necessity of aligning packaging design with marketing objectives to maximize impact in competitive markets. Packaging is ubiquitous, with households accumulating waste from nearly every purchase. While commonly associated with product wrapping, packaging encompasses much more. According to its definition, the packaging includes "the totality of operations whose basic purpose is to protect the product, make it suitable for transport or storage, or contain it (Vuk *et al*., 2023). However, the increasing volume of packaging waste presents significant sustainability challenges. The growing demand for packaging, driven by consumption patterns and e-commerce expansion, strains natural resources and contributes to environmental degradation. Consequently, there is an urgent need for a circular approach that minimizes waste, maximizes resource efficiency, and promotes sustainable consumption.

The European Union has long recognized the environmental impact of packaging waste and has responded with regulatory measures aimed at sustainability. The EU Packaging Directive was introduced as part of a comprehensive European strategy to improve waste management and reduce environmental impacts. Initially established through Directive 94/62/EC, it aimed to harmonize national regulations, setting baseline recycling and recovery requirements to encourage waste minimization and recycling improvements (European Union, 1994). Over time, the directive evolved to address emerging challenges, drawing on earlier national initiatives such as Netherlands' Dutch Packaging Covenant of 1993 and Denmark's 1996 report on transport packaging waste (Ingram, 1999). Subsequent amendments, including Directive 2004/12/EC, enhanced its effectiveness in promoting recycling and reducing landfill dependency (European Union, 2004). In 2018, Directive 2018/852 introduced ambitious recycling and recovery targets, aligning packaging practices with sustainability goals (European Commission, 2018). Directive 2019/904 further emphasized reducing plastic pollution and marine litter by targeting single-use plastics (Ragonnaud, 2023). The European Commission's 2022 proposal represents the latest regulatory advancement, focusing on enhancing circularity, packaging design, and recycling rates. Building on these developments, the proposed Packaging and Packaging Waste Regulation (PPWR) seeks to replace the current directive framework with directly applicable rules, further harmonizing EU efforts and setting binding targets to reduce packaging waste and boost reuse and recyclability (European Commission, 2022a).

The study goals are:

- To map the trends in packaging waste generation and its material-specific composition in the EU-27 from 2011 to 2022.
- To analyze recycling rates of packaging waste by material category (paper, plastic, wood, metal, and glass) over the same period and examine the correlation between the packaging waste generation and recycling performance.
- To assess disparities in packaging waste management performance among EU member states through a cluster analysis based on 2022 data, and their alignment with the PPWR targets.

Despite the growing body of research on packaging waste and recycling, there remains a notable gap in comprehensive, multi-dimensional analyses that track both packaging waste generation and recycling performance over time across all 27 EU Member States. Existing studies often concentrate on specific materials, particularly plastics and focus on a limited number of countries, or assess the effects of individual policy measures. However, few provide a holistic overview that captures long-term trends, highlights cross-national disparities, and evaluates collective progress toward the binding targets established by the Packaging and Packaging Waste Regulation. This study addresses that gap by offering an integrated assessment that combines temporal, spatial, and policy-oriented dimensions.

The findings provide valuable insights into the effectiveness of current policies and highlight areas for improvement to achieve sustainability goals. By exploring the dynamics of packaging waste and recycling within the EU, this paper contributes to the ongoing discourse on circular economy practices and sustainable development.

The structure of the paper is as follows: after the introduction, Section 2 reviews relevant literature on circular economy and packaging waste, recycling and regulation. Section 3 outlines the methodology, including data sources and analytical methods. Section 4 presents the results, while Section 5 discusses the findings in the context of EU policy targets. Finally, Section 6 concludes with implications for policy and future research directions.

2. BACKGROUND

2.1. Circular economy

Economic development and environmental sustainability are inherently linked. Historically, rapid economic growth has often been associated with increased environmental degradation. As industries expanded and consumption surged, natural resources were exploited at unprecedented rates, leading to pollution, habitat destruction, and climate change. This pattern of economic progress, primarily driven by the linear "take-make-dispose" model, proved unsustainable as it disregarded the environmental costs of waste and resource depletion (Van Buren *et al.*, 2016; Galvão *et al.*, 2018; Masi *et al.*, 2018). The concept of a circular economy (CE) emerged as a transformative solution to these environmental challenges. Unlike the traditional linear economy, the circular model focuses on minimizing waste, extending product life cycles, and regenerating natural systems.

The origins of circular economy thinking can be traced back to the late 20th century, but it gained formal recognition and widespread attention in the 1970s and 1980s (Geissdoerfer *et al*., 2017). One of the earliest conceptual frameworks was developed by Kenneth Boulding (1966), who envisioned the economy as a "closed loop" system similar to natural ecosystems. The concept gained traction in the 1970s with the Club of Rome's 1972 report "The Limits to Growth", highlighting the dangers of continued economic growth without considering environmental limits (Park *et al*., 2023). The term itself became more established in the 1990s and early 2000s as sustainability and resource efficiency became global priorities (Ghisellini *et al*., 2016).

The modern interpretation of the circular economy, however, was shaped significantly by the Ellen MacArthur Foundation, founded in 2010 (MacArthur, 2013), which popularized the concept and advocated for system-level change. CE frameworks emphasize:

- **Resource efficiency**: Designing products for reuse, remanufacturing, and recycling.
- **Waste minimization**: Transforming waste into valuable inputs for new products.
- **Systemic innovation**: Integrating sustainable practices throughout the supply chain.
- **Economic resilience**: Reducing dependency on finite resources by closing material loops.

Today, the circular economy is considered a pivotal strategy to decouple economic growth from environmental degradation. It addresses the root causes of waste and pollution while fostering innovation and sustainable business practices. Governments, industries, and environmental organizations increasingly recognize the circular economy as essential for achieving long-term sustainability and combating climate change (Sarangi, 2023).

By promoting circular principles, economies aim to transition from wasteful linear systems to resilient and regenerative models, fostering both environmental protection and sustainable economic development (Kandpal *et al*. 2024).

2.2. Packaging waste, recycling and regulation

At the end of the 20th century, the concept of environmental packaging design emerged as a response to growing concerns about the ecological impacts of packaging waste and resource consumption (Brydson, 1999; Soroka, 1999). This approach views packaging as an essential intermediary between the product and the environment, aiming to minimize their interaction. Packaging serves to shield the product from environmental influences while simultaneously protecting the environment from the potential harmful effects of the product (Lydekaityte and Tambo, 2020). However, this beneficial effect only persists while the product remains within the packaging (Rundh, 2016). The environmental burden arises from both the production of packaging materials and their transformation into waste after use. The primary goal of environmental packaging design is to ensure that packaging materials fulfill their protective role while minimizing environmental impacts throughout their entire life cycle (Keoleian and Menerey, 1994; Svanes *et al.*, 2010; Boz, Korhonen and Koelsch Sand, 2020).

The emphasis on sustainable practices in packaging logistics has significantly progressed over the years. Initial work by Gray and Guthrie, (1990) addressed ethical issues surrounding eco-friendly packaging. This was expanded by later research, such as Murphy, Poist and Braunschweig (1994), who examined environmental management in logistics, and Szymankiewicz (1993), who discussed the difficulties of adopting green practices. Recovery involves the process of reclaiming materials, components, or energy from packaging waste, either partially or fully, and reintegrating them into the production process (Kutz, 2007). This can be achieved through material recovery, incineration for energy production, or biodegradation under aerobic or anaerobic conditions (Demirbas, 2011; Hermann *et al.*, 2011). Recyclable packaging materials encompass a wide range of items, including glass (of all colours), paper, aluminium foil, take-away containers, aluminium cans, tin and steel cans, PET, and HDPE (Marshall, 2007; Coles and Kirwan, 2011).

Environmental packaging regulations establish general requirements based on principles aimed at reducing environmental impacts, including prevention, reuse, and recycling (Marshall 2007). Key prevention elements include reducing the weight of packaging, minimizing the use of multiple packaging layers, implementing refill systems, optimizing both the quantity and characteristics of packaged products, avoiding the use of hazardous or harmful substances, and researching alternative packaging materials (Yam, 2010).

On September 28, 1976, the Organisation for Economic Co-operation and Development (OECD) issued its first recommendation for establishing a comprehensive waste management policy among European Union Member States. This marked the first coordinated effort to address waste management at the EU level (Vuk, Szűcs and Bauerné Gáthy, 2023). Subsequently, in 1991, Germany introduced the first specific legislation targeting packaging waste, guided by principles aimed at minimizing future waste generation, ensuring the use of environmentally friendly materials, and reducing packaging weight and volume (Brisson, 1993).

A significant milestone came with the adoption of Directive 94/62/EC on December 20, 1994, which took effect in EU Member States by June 30, 1996. This directive set forth rules for managing packaging and packaging waste, aiming to harmonize national measures while enhancing environmental quality by preventing and reducing the impact of packaging waste (Malinauskaite, Jouhara and Spencer, 2017). The directive's core objective was to promote prevention, reuse, and recycling while minimizing environmental harm (European Union, 1994). Implementation of the EU Packaging Waste Directive has highlighted the tension between harmonization and flexibility across Member States, with national differences, such as those between the UK and Germany, reflecting varied applications of economic instruments in environmental policy (Bailey, 1999). Central to the Packaging Directive are the recycling quotas that each Member State must achieve within a specified time frame (Avogadro and Ragaini, 1994). Directive 75/442/EEC outlined the fundamental aspects of waste management and treatment for all waste types, emphasizing the prevention of waste generation and its hazardousness, as well as prioritizing waste recovery. By June 30, 2001, Member States were required to recover at least 50% and up to 65% by weight of packaging waste. Additionally, 25% to 45% of all packaging material had to be recycled, with a minimum of 15% per material type (European Parliament and Council, 1995).

Following June 30, 2001, recycling quotas were increased, mandating that by 2006, at least 60% to 75% of packaging waste by weight must be recovered, and 55% to 70% of all packaging materials recycled. When the EU expanded in 2004, the new Member States were required to comply with the amended directive. Belgium, Germany, Luxembourg, Austria, and the Czech Republic successfully met the increased 60% minimum target. However, Cyprus and Malta struggled with both packaging recycling and environmental management (García-Álvarez and Moreno, 2018).

The next amendment, Directive (EU) 2018/852, introduced updated measures to further reduce packaging waste and encourage reuse, recycling, and other recovery methods (European Commission, 2018). It emphasized preventing packaging waste generation and promoting circular economy practices rather than relying on final disposal. This directive applies to all types of packaging placed on the EU market, regardless of material or the sector involved, including industrial, commercial, household, and service packaging (Ragonnaud, 2023).

The rules, originally established in the Packaging and Packaging Waste Directive (Directive 94/62/EC), are now governed by a new regulation proposed by the European Commission under document COM/2022/677 on 30 November 2022, as part of the European Green Deal and the Circular Economy Action Plan (European Comission, 2022). Building on these early contributions, the Packaging and Packaging Waste Regulation (PPWR) aims to move the EU closer to a more circular and sustainable packaging system (Matlhare, Monnapule, 2024). The proposal underwent legislative review and was formally adopted by the European Parliament and the Council on 19 December 2024 as Regulation (EU) 2025/40 (European Parliament and Council, 2024). It was published in the Official Journal on 22 January 2025 and entered into force on 11 February 2025, with general application beginning 18 months later, on 11 August 2026. Packaging and Packaging Waste Regulation (PPWR), sets out requirements for packaging placed on the EU market, along with measures for packaging waste prevention and management.

Article 43, Prevention of packaging waste states:

1. Each Member State shall reduce the packaging waste generated per capita, as compared to the packaging waste generated per capita in 2018 as reported to the Commission in accordance with Decision 2005/270/EC, by at least:

(a) 5 % by 2030;

(b) 10 % by 2035;

(c) 15 % by 2040.

PPWR further in Article 52, Recycling targets and promotion of recycling, established long-term targets for packaging recycling rates.

1. Member States shall take the necessary measures to achieve the following recycling targets covering the whole of their territory:

2025	2030
65 % by weight of all packaging waste	70 % by weight of all packaging waste
50 % of plastic	55 % of plastic
25 % of wood	30 % of wood
70 % of ferrous metals	80 % of ferrous metals
50 % of aluminium	60 % of aluminium
70 % of glass	75 % of glass
75 % of paper and cardboard	85 % of paper and cardboard

3. DATA AND METHODOLOGY

The data used in this study are obtained from the Eurostat database, which provides comprehensive information on packaging waste generation, and recycling rates as reported by EU countries, in accordance with Commission Decision 2005/270/EC. The reported data typically becomes available approximately 20 months after the end of the reference year. Packaging is defined as any material used to contain, protect, handle, deliver, or present goods. It encompasses a wide range of items such as glass bottles, plastic containers, aluminium cans, food wrappers, timber pallets, and drums. Packaging waste can arise from diverse sources, including supermarkets, retail outlets, manufacturing industries, households, hotels, hospitals, restaurants, and transport companies (*Statistics | Eurostat*, 2024). The recycling rates are calculated as the total quantity of recycled materials divided by the total quantity of generated packaging waste, with certain exceptions. The dataset titled "Recycling rates of packaging waste for monitoring compliance with policy targets, by type of packaging (env_waspacr)" includes "Adjusted recycling rates" for specific materials, such as plastic and wood. These adjusted rates are defined in line with Article 6 of Directive 94/62/EC and Article 6b(1) of Decision 2005/270 (*Statistics | Eurostat*, 2024).

For the purpose of this research, Eurostat indicators for packaging waste generation per capita and recycling rates of packaging waste by categories are used. The analysis covers the period from 2011 to 2022 for all EU member states. The chosen indicators and time period enable a comprehensive assessment of trends in packaging waste generation and recycling, reflecting the progress made toward meeting EU policy targets. The selected indicators are presented in Table 1:

Table 1. Eurostat indicators for packaging waste generation per capita and recycling rates of packaging waste by categories

Packaging waste by waste management operations [env_waspac]:	Recycling rates of packaging waste for monitoring compliance with policy targets, by type of packaging [env_waspacr]
Generation of packaging waste (kg per capita)	Recycling rates for packaging waste (%)
Paper and cardboard packaging generated (kg per capita)	Recycling rates for packaging waste - Paper and cardboard packaging (%)
Plastic packaging generated (kg per capita)	Recycling rates for packaging waste – plastic packaging (%).
Wooden packaging generated (kg per capita)	Recycling rates for packaging waste – wooden packaging (%)
Metal packaging generated (kg per capita)	Recycling rates for packaging waste – glass packaging (%)
Glass packaging generated (kg per capita)	Recycling rates for packaging waste – metal packaging (%).

To achieve the research objectives, this study applies a set of quantitative methods. Trend analysis is used to examine developments in packaging waste generation and recycling rates across EU-27 Member States from 2011 to 2022, highlighting general patterns and growth tendencies. Growth rates are calculated to assess increases in waste generation across five main material categories: paper and cardboard, plastic, wood, metal, and glass. Comparative analysis between countries complements the trend evaluation, identifying variations in national performance.

Correlation analysis is used to evaluate the strength and direction of the linear relationship between the two variables: packaging waste generation per capita and recycling rate of packaging waste in the period 2011-2022 in EU (27). Its primary purpose is to determine whether, and to what extent, changes in one variable are associated with changes in another. This technique enables the identification of underlying patterns and associations that may indicate whether increased waste generation aligns with improved recycling performance or highlights inefficiencies in waste management systems.

Cluster analysis is an exploratory, interdependence-based statistical technique used to classify a set of observations, such as countries, into distinct groups, or clusters, based on shared characteristics. A key strength of this method lies in its unsupervised nature: unlike methods such as discriminant analysis, cluster analysis does not require pre-defined groups. Instead, it uncovers natural groupings within the data based solely on patterns of similarity. The main objective of cluster analysis is to segment a dataset into a small number of mutually exclusive and internally homogeneous groups (Hair *et al.*, 2010). That is, entities within a cluster are highly similar to one another, while entities across clusters differ significantly. In the context of packaging waste generation and recycling rates, cluster analysis offers a robust way to detect patterns across EU member states. By reducing the complexity of a dataset, such as 27 EU countries, into a few well-defined clusters, we can simplify interpretation, highlight commonalities, and draw more focused conclusions. A hierarchical cluster analysis using Ward's method was conducted to classify EU member states into five distinct groups based on two key indicators for 2022: packaging waste generation per capita and the recycling rate of packaging waste. To determine the optimal number of clusters, an Analysis of Variance (ANOVA) test was conducted to evaluate whether the means of the key clustering variables significantly differed across clusters. This configuration provides a robust and meaningful classification of EU member states, enabling a nuanced assessment of their progress toward packaging waste reduction and recycling goals in line with EU sustainability directives. Countries grouped into the same cluster exhibit similar behaviors or performance levels related to the circular economy, making it easier to identify common challenges, best practices, or policy needs. This type of analysis has been widely adopted in previous studies on environmental and sustainability metrics, including those by (Mathrani *et al.*, 2023; Claudio, Quiroga and Poza, 2024), who have used clustering to inform policy decisions and circular economy performance. Mathrani *et al.* (2023) demonstrated its usefulness in examining Sustainable Development Goal (SDG) indicators by identifying groups of countries with similar sustainability characteristics. Similarly, Claudio, Quiroga and Poza (2024) employed clustering techniques to assess circular economy performance, highlighting its potential to inform evidence-based policy decisions through the identification of shared challenges and opportunities among countries.

4. RESULTS

The results of this study are presented in three main sections. The first, Trends and Correlations between Packaging Waste Generation and Recycling in the EU-27, analyzes the evolution of packaging waste and recycling rates from 2011 to 2022 and explores the relationship between these indicators. The second, Disparities in packaging waste management across EU members in 2022: Cluster Analysis and PPWR Alignment, identifies groups of countries based on packaging waste and recycling rate indicators, revealing substantial disparities in meeting the targets set by the PPWR. The third section shifts focus to a critical reflection on compliance with PPWR targets, questioning whether achieving the 2025 and 2030 recycling rates is sufficient. It highlights that even countries meeting the targets may still generate larger volumes of non-recycled packaging waste compared to others that have not yet reached the recycling thresholds.

4.1. Trends and Correlations between Packaging Waste Generation and Recycling in the EU-27

In 2022, the total packaging waste generated across the European Union (EU-27) reached approximately 83.4 million tonnes, underscoring the significant environmental footprint of packaging materials in modern economies. Paper and cardboard remained the most prevalent waste category, contributing 34.0 million tonnes or 40.8% of the total. This dominance reflects the continued preference for paper-based solutions, particularly in sectors emphasizing recyclability and environmental sustainability. Plastic packaging was the second largest contributor, generating 16.1 million tonnes or 19.4% of the total. Despite increasing regulatory and consumer pressure to reduce plastic use, its considerable share reveals the ongoing dependency on plastics, especially in food and consumer goods packaging. Glass followed with 15.7 million tonnes, representing 18.8%, due to its extensive use in the beverage and preserved food industries. Wooden packaging accounted for 13.3 million tonnes or 16.0%, primarily associated with transport and storage systems. In contrast, metal packaging made up just 4.1 million tonnes, representing 4.9% of the total waste, reflecting its limited use and higher recyclability rates. All other packaging materials combined amounted to a marginal 0.2%, indicating their relatively minor role in the EU packaging landscape. Overall, the data illustrate a clear hierarchy in material usage, with paper and cardboard leading due to their perceived environmental benefits, and metal and other materials contributing the least. These trends not only shows consumption patterns but also point to key areas where circular economy initiatives must be intensified to mitigate the growing volume of packaging waste.

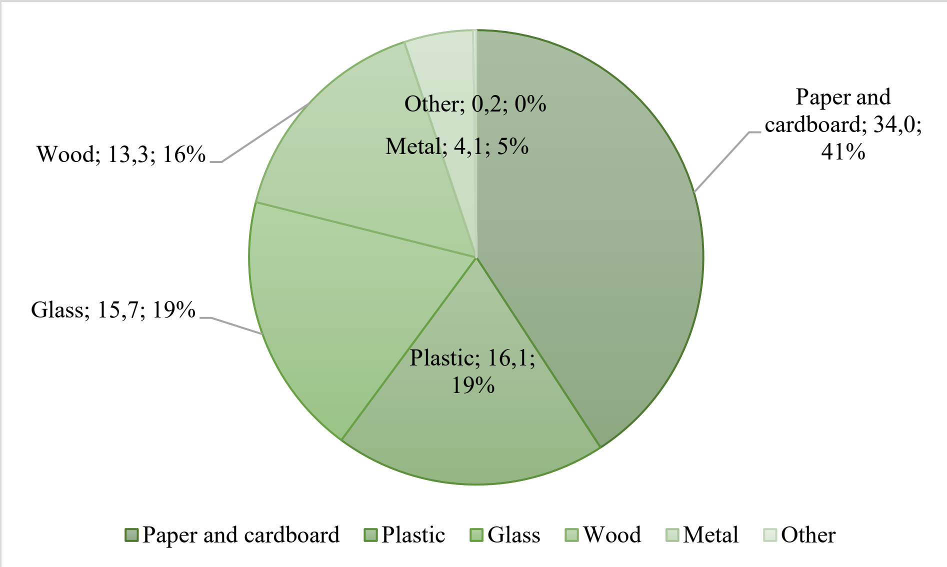

Figure 1. Packaging waste generated by a packaging material mill. tones, EU (27), 2022
Source: Eurostat (online data code: env_waspac)

Between 2011 and 2022, the generation of packaging waste per capita exhibited a consistent upward trend, marking an overall increase of 18.67% from 157.2 to 186.5 kg per capita. This growth of packaging waste generation in the EU reflects evolving consumer behaviors and an intensified demand for packaging, particularly driven by economic growth. Among the various packaging categories, plastic packaging showed the most significant growth, increasing by 27.30% from 28.4 to 36.1 kg per capita, highlighting its continued dominance despite global initiatives aimed at reducing plastic waste. Paper and cardboard packaging followed with a growth of 19.41%, rising from 63.7 to 76.0 kg per capita, indicating an increased focus on sustainable packaging solutions. Wood packaging recorded an increase of 17.98%, from 25.3 to 29.8 kg per capita, although some fluctuations were observed, particularly between 2017 and 2018. Glass packaging waste displayed moderate growth of 16.58%, increasing from 30.0 to 35.0 kg per capita, reflecting stable but gradual expansion. Meanwhile, metal packaging remained the smallest category in terms of waste generation, with a modest increase of 5.54%, from 8.7 to 9.1 kg per capita, suggesting a preference for lighter and more flexible alternatives over time (fig.2).

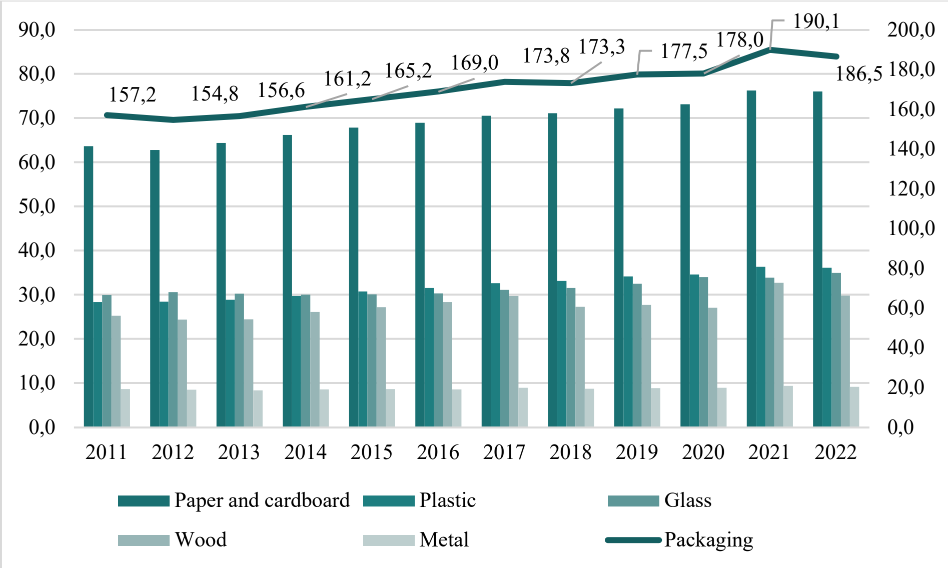

Figure 2. Packaging waste generated per capita, by packaging material, EU (27), 2011–2022
Source: Eurostat (online data code: env_waspac)

The overall recycling rate of packaging waste has remained relatively stable, fluctuating between 64.2% in 2011 and 65.4% in 2022. The plastic packaging waste recorded the most significant increase in recycling rates, growing from 35.6% in 2011 to 40.7% in 2022, marking an increase of 5.1 percentage points. Although this growth is notable, it still falls short of the EU target of 50% by 2025, indicating a significant gap that needs to be addressed to meet policy goals. Wooden packaging experienced a moderate decrease in recycling rates, falling from 36.6% in 2011 to 34.2% in 2022. The 2025 target of 25% and the 2030 target of 30% have already been met. However, maintaining and further improving this performance will be crucial for long-term compliance. Metallic packaging (including ferrous metals and aluminum) showed a slight increase from 75.7% in 2011 to 76.9% in 2022. Despite the small growth, the recycling rate for metallic packaging already meets the 2025 targets of 70% for ferrous metals and 50% for aluminum, indicating strong performance in this category. However, the 2030 target of 80% for ferrous metals and 60% for aluminum will require additional efforts to ensure continued progress. Glass packaging maintained a stable recycling rate throughout the period, with a minor fluctuation from 72.3% in 2011 to 75.6% in 2022. The 2025 target of 70% and 2030 of 75% has already been achieved. Paper and cardboard packaging, which represents the largest share of packaging waste, maintained consistently high recycling rates, ranging from 82.7% in 2011 to 83.2% in 2022. These rates comfortably meet the 2025 target of

75% and are approaching the 2030 target of 85%, highlighting the effectiveness of paper recycling systems compared to other materials. In conclusion, while some categories like metals, glass, and paper have either met or are close to meeting the 2025 targets, plastic packaging remains a critical challenge. Reaching the 2030 targets will require significant improvements, particularly in recycling plastic and maintaining the momentum in other categories (Fig.3).

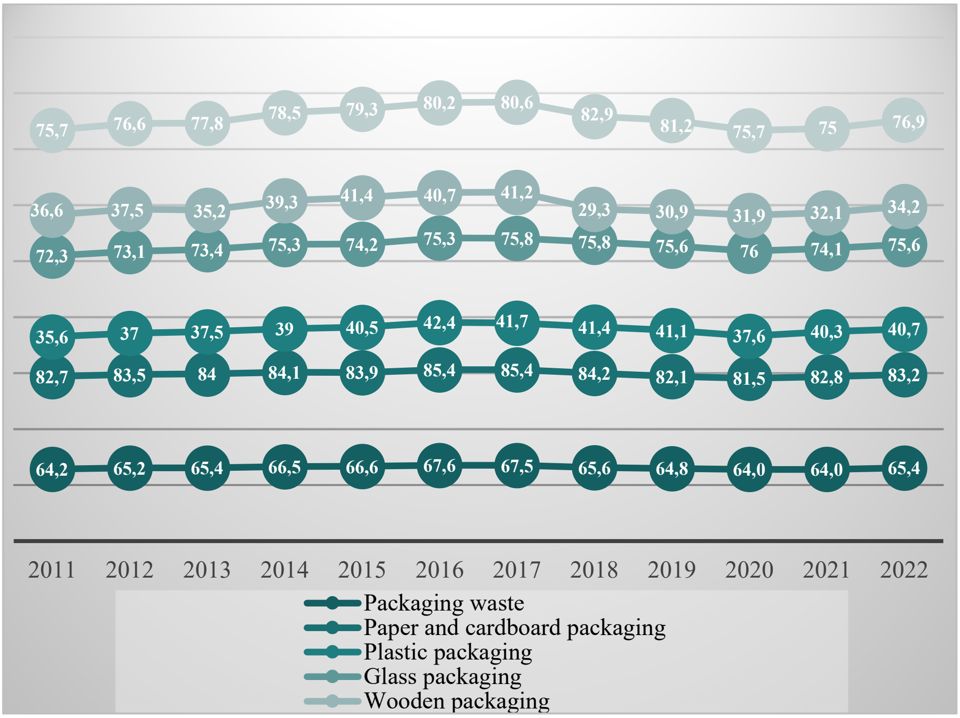

Figure 3. Recycling rates of packaging waste in %, by packaging material, EU (27), 2022

Source: Eurostat (online data code: env_waspacr)

To assess the evolving dynamics of packaging waste in the EU, we analyzed the growth in packaging waste generation alongside changes in recycling rates by material type between 2011 and 2022. During this period, packaging waste increased across all material categories, reflecting rising consumption and expanding logistics demands. Overall, total packaging waste in the EU rose by 18.7% over the decade, whereas the overall recycling rate increased by just 1.9 percentage points. The most pronounced growth was observed in plastic packaging waste, which surged by 27.3%, followed by paper and cardboard (+19.4%), wood (+18.0%), and glass (+16.6%). In contrast, metal packaging waste exhibited the most modest increase, rising by only 5.5%. However, the progress in recycling rates did not keep pace with the growth in waste generation. While plastic recycling rates improved notably by 14.3 percentage points, indicating efforts to address plastic pollution, the recycling rates for paper and cardboard (+0.6%) and metal (+1.6%) showed only marginal improvement. Alarmingly, wood recycling experienced a significant decline of 6.6 percentage points, suggesting setbacks in material recovery systems. Glass recycling saw a modest improvement of 4.6 percentage points, despite a considerable rise in waste volume. This growing disparity signals that while waste generation continues to climb, recycling systems are not advancing at a comparable pace. The findings underscore the urgency for enhanced material-specific strategies and investment in recycling infrastructure to bridge this gap and meet the EU's circular economy goals (Fig.4).

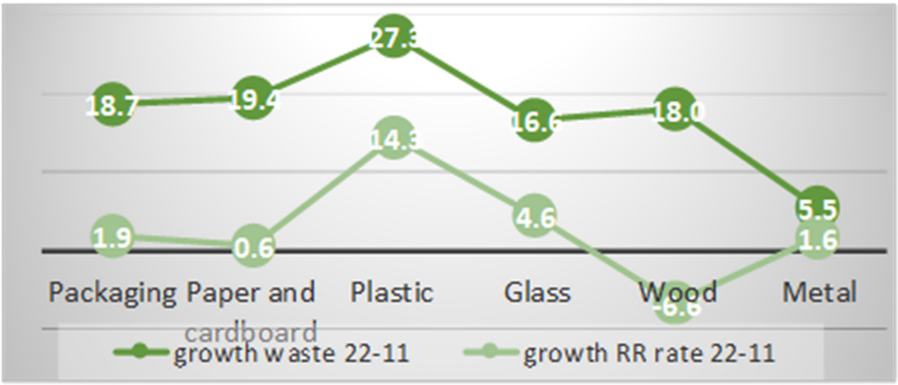

Figure 4. Growth of packaging waste generation and recycling rates of packaging waste in %, EU (27), 2011-2022
Source: Eurostat (online data code: env_waspacr)

The correlation matrix offers insights into the relationship between packaging waste generation and recycling rates across material categories in the EU (Table 2). The data shows that total packaging waste generation is highly and positively correlated with waste generation from individual materials such as paper and cardboard, plastic, and metal. These strong correlations (e.g., 0.9938 between total packaging and paper and cardboard, and 0.9921 between total packaging and plastic) suggest that as overall packaging waste increases, waste from each material type tends to increase in tandem. This is expected, given the dominant share of these materials in the total packaging composition. However, a different pattern emerges when analyzing the relationship between packaging waste generation and recycling rates. The overall correlation between packaging waste and its corresponding recycling rate is negative and insignificant (-0.2164), indicating that higher packaging waste generation is not associated with better recycling performance. In fact, in most cases, there appears to be a weak or even inverse and insignificant relationship between generation and recycling, particularly for paper and cardboard (-0.2730), metal (-0.24826), and wood (-0.14316). This suggests that increased material use does not necessarily lead to improved recycling outcomes, and in some cases, may strain the recycling infrastructure. Positive but insignificant is correlation between glass generation and recycling (0.46336). One exception is the positive and significant correlation between plastic packaging waste and its recycling rate (0.56), indicating that higher plastic waste generation might be somewhat aligned with improved recycling performance, potentially due to policy interventions or technological investments targeting plastic recycling. Additionally, RRPlastic shows moderate to strong positive correlations with other recycling indicators, such as RRGlass (0.7056) and RRMetal (0.6830), implying that recycling capacities may be integrated or supported by common systems or frameworks across materials in certain member states. In contrast, recycling rates for wooden packaging exhibit negative and insignificant correlations with most variables, including a strong negative correlation with glass (-0.6246) and plastic (-0.5314) waste generation. This reflects the unique challenges or limited prioritization associated with wood recycling in the EU context. Furthermore, RRMetallic packaging appears to be largely uncorrelated with overall packaging waste (correlation of -0.0230), suggesting its recycling is driven by factors independent of total waste volumes, perhaps due to its specialized collection systems or economic value.

The data show that higher generation levels are not accompanied by higher recycling rates, and in several instances, the relationship is either weak or negative. The only moderate exception is observed in the case of plastic, where a positive and statistically significant correlation indicates a partial alignment between generation and recycling capacity.

Table 2. Correlation analysis between the growth in packaging waste generation and the growth in recycling rates by category at the EU level (2011–2022)

	Packaging	RRPackag	Paper and	RRPaper a	Plastic	RRPlastic p	Glass	RRGlass pa	Wood	RRWoode	Metal	RRMetallic
Packaging	1											
RRPackagi	-0.21637	1										
Paper and	0.993832	-0.1926	1									
RRPaper a	-0.27304	0.904848	-0.27145	1								
Plastic	0.992135	-0.2353	0.995989	-0.31289	1							
RRPlastic p	0.569431	0.588878	0.583727	0.486449	0.560007	1						
Glass	0.879134	-0.498	0.88126	-0.55346	0.902938	0.20314	1					
RRGlass pa	0.60571	0.323706	0.663775	0.104974	0.656721	0.705564	0.463364	1				
Wood	0.895547	0.036614	0.861559	0.040646	0.840029	0.661108	0.631575	0.453527	1			
RRWoode	-0.47737	0.742075	-0.48876	0.648899	-0.53137	0.059837	-0.62462	-0.19826	-0.14316	1		
Metal	0.928091	-0.36914	0.892088	-0.36904	0.895608	0.342947	0.851816	0.362348	0.877998	-0.42966	1	
RRMetallic	-0.02301	0.612477	0.018158	0.529349	0.011283	0.682946	-0.30231	0.521805	-0.01099	0.032433	-0.24826	1

Source: Author calculation

4.2. Disparities in packaging waste management across EU members in 2022: Cluster Analysis and PPWR Alignment

Figure 5 shows packaging waste generation per capita across EU countries for 2011, 2018, and 2022, illustrating the trends over the observed period and highlighting disparities among Member States. The graph demonstrates substantial differences in packaging waste generation across countries, reflecting diverse consumption patterns and waste management practices. In 2022, Ireland generated the highest packaging waste per capita at 233.84 kg, followed by Italy (232.36 kg) and Germany (226.94 kg). On the opposite end, Bulgaria generated the least packaging waste at 78.75 kg per capita, with Romania (127.21 kg) and Greece (104.95 kg) also among the lowest. Compared to 2011, when Germany and Italy already recorded high levels of packaging waste at 205.37 kg and 195.99 kg per capita, respectively, Ireland continued to increase generation of packaging waste, reflecting a consistent upward trend. Conversely, countries like Bulgaria and Romania remained low throughout the period, emphasizing a persistent disparity between Western and Eastern European countries. When comparing 2022 data to the 2018 baseline, the most significant growth was observed in Romania (58.1%), Greece (38.3%), and Slovenia (23.8%), while some countries managed to reduce their packaging waste per capita. The most notable reductions were recorded in Estonia (-9.4%), Luxembourg (-6.8%), France (-3.6%), and Sweden (-2.1%), while Germany showed a slight decrease of -0.2%. According to the PPWR, Member States should reduce packaging waste generation per capita by at least 5% by 2030 compared to 2018 levels. Based on current trends, only Estonia, Luxembourg, and France have achieved reductions compared to 2018. Sweden and Germany have also decreased from 2018, while most other countries are still increasing their packaging waste generation. The overall increase in packaging waste generation in most Member States, driven by intensified consumption and e-commerce growth, indicates that significant efforts are required to reverse this trend and comply with waste prevention objectives.

A hierarchical cluster analysis using Ward's method was conducted to classify EU member states into five distinct groups based on two key indicators for 2022: packaging waste generation per capita and the recycling rate of packaging waste. The aim was to identify performance patterns and categorize countries according to their alignment with the PPWR objectives. To determine the optimal number of clusters, an Analysis of Variance (ANOVA) test was conducted to evaluate whether the means of the key clustering variables significantly differed across clusters. The results confirmed that the five-cluster solution produced statistically significant differences in mean values of both packaging waste per capita ($p < 0.01$) and recycling rates across clusters ($p < 0.05$). The resulting clusters show substantial disparities among member states and offer insight into targeted policy interventions.

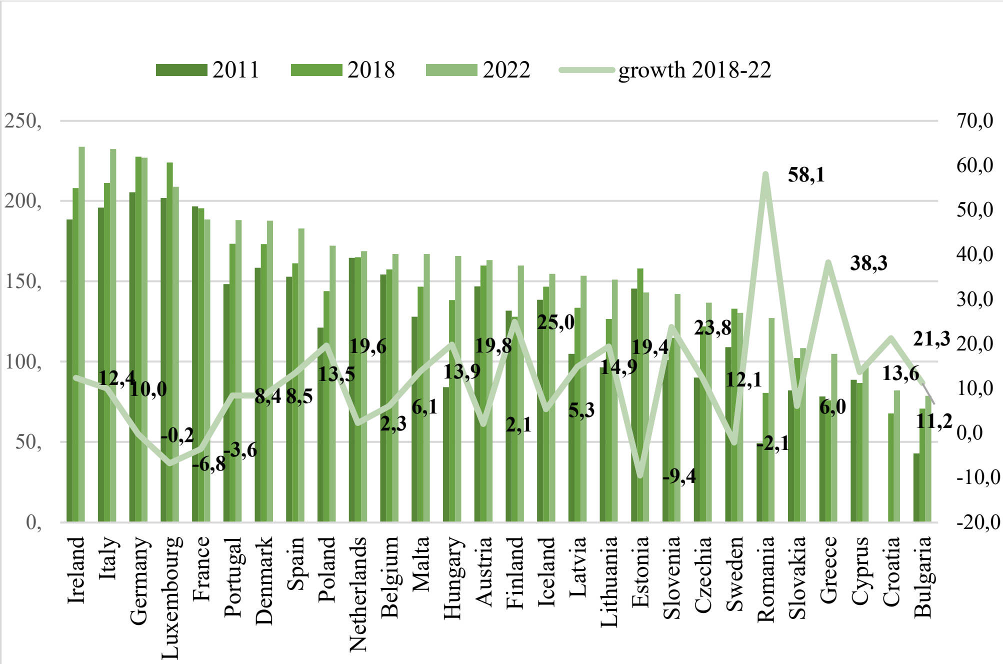

Figure 5. Packaging waste generated per capita, EU countries, 2011, 2018, 2022, and growth 2022-2018
Source: Eurostat (online data code: env_waspac)
Note: Data for Poland are from 2019 and Czechia and Romania 2021

Cluster 1 High Performers includes: Belgium, Denmark, Spain, France, the Netherlands, Austria, Portugal, and Finland. These countries show relatively high recycling rates (average: 69.7%, range: 61.1%–80.4%) and moderate levels of packaging waste per capita (average: 175.8 kg, range: 159.9–188.5 kg). Most members of this group have already met 2030 PPWR recycling target of 70%: Belgium (80.4%), Netherlands (75.2%), and Finland (73.5%), while Spain (69.4%), France (67.2%), Austria (66.2%) and Denmark (64.9%) meet the 2025 target of 65%. In this group, only Portugal (61.1%) does not meet the PPWR targets.

Cluster 2 Transitional Countries with Low Waste consists of: Bulgaria, Greece, Croatia, Cyprus, Romania, and Slovakia. This group is characterized by low packaging waste per capita (average: 100.0 kg, range: 78.8–127.2 kg) but lower average recycling rates (average: 55.7%, range: 38.3%–72.2%). Only Slovakia (72.2%) and Cyprus (69.5%) meet the 70% target, while countries like Romania and Greece fall significantly short.

Cluster 3 Balanced Performers comprises: Czechia, Estonia, Latvia, Lithuania, Slovenia, and Sweden. These are middle performers, with moderate levels of waste (average: 142.8 kg, range: 130.3–153.4 kg) and recycling rates (average: 65.1%, range: 58.3%–73.0%). Some members of this cluster meet or closely approach the PPWR 2030 target: Estonia (73%), Czechia (69.1%), and Sweden (66.9%).

Cluster 4 High Waste, Good Recycling includes: Germany, Ireland, Italy, and Luxembourg. This group is characterized by the highest levels of packaging waste per capita (average: 225.5 kg, range: 208.9–233.8 kg) alongside good recycling performance (average: 66.5%, range: 61.7%–71.9%). Italy (71.9%) and Germany (68.5%) meet the PPWR 2025 and 2030 targets, but their high waste generation suggests room for improvement in prevention measures.

Cluster 5 Lagging Behind includes: Hungary, Malta, and Poland. These countries are characterized by moderate packaging waste per capita (average: 168.3 kg, range: 165.8–172.2 kg) and low recycling rates (average: 44.0%, range: 31.8%–55.5%), indicating serious challenges in aligning with the PPWR targets and a pressing need for systemic improvements.

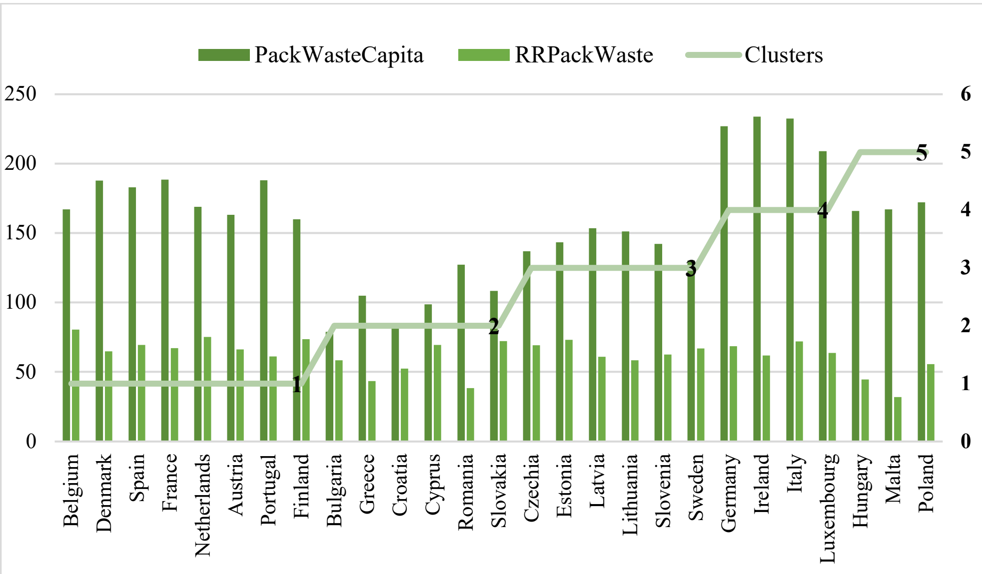

Figure 6. Hierarchical cluster analysis, 2022.
Source: Author calculation

4.3. Discussion: Beyond Recycling Rates – The Significance of Non-Recycled Packaging Waste

The analysis of packaging waste generation and recycling trends in the EU-27 from 2011 to 2022 reveals a widening gap in their growth. Packaging waste has grown at a significantly faster rate than recycling rates, with no clear correlation between the two. This raises critical questions about the adequacy of current policy targets, such as those set in the Packaging and Packaging Waste Regulation, specifically, the goal of reducing packaging waste by 5% compared to 2018 levels, and achieving recycling rates of 65% by 2025 and 70% by 2030.

The cluster analysis identified five distinct country groups based on packaging waste generation and recycling performance. Of particular interest is Cluster 4, which consists of countries with high levels of packaging waste generation and relatively high recycling rates. Despite meeting or exceeding EU targets for recycling rates, these countries still produce substantial volumes of non-recycled packaging waste in absolute terms. This stands in contrast to Cluster 2, which is composed of countries with lower packaging waste generation and moderate to low recycling rates, which ultimately generate less non-recycled packaging waste per capita.

This underscores a key limitation in using recycling rates alone as performance indicators. While recycling rates are often presented as the key metric for evaluating progress toward a circular economy, they can present an incomplete picture when assessed in isolation. A country may meet or exceed recycling targets, yet still contribute disproportionately to environmental degradation if its overall packaging waste generation is high. The analysis of non-recycled packaging waste per capita, derived by subtracting the recycled share from total packaging waste generation, offers a more nuanced and accurate reflection of circularity performance. This approach reveals important disparities. For example, Germany and Ireland report relatively strong recycling rates of 68.5% and 61.7%, respectively. However, due to very high levels of packaging waste per capita (226.94 kg and 233.84 kg), these countries still generate 71.5 kg and 89.6 kg of non-recycled packaging waste per capita, among the highest in the EU. In contrast, countries such as Bulgaria (58.3% recycling rate, 78.75 kg total packaging waste per capita) and Croatia (52.4% recycling, 82.17 kg total) have significantly lower non-recycled waste outputs of just 32.8 kg and 39.1 kg per capita, respectively. This suggests that higher recycling rates alone do not necessarily translate into lower environmental pressure from packaging waste.

In conclusion, evaluating non-recycled packaging waste per capita offers a more nuanced and accurate measure of a country's environmental performance regarding packaging waste. It highlights the need for comprehensive strategies that address both waste reduction and recycling efficiency to achieve sustainable waste management goals.

This insight supports a shift in analytical and policy focus, from relative improvements in recycling to absolute reductions in non-recycled waste. The PPWR targets, while important, may need to be complemented by stricter waste prevention measures, such as caps on per capita packaging waste or incentives for reusable and refillable systems. Without this pivot, high-performing recyclers that generate even higher amounts of packaging waste may inadvertently undermine the EU's broader circular economy goals.

Therefore, shifting the focus from "how much is recycled" to "how much is not" may offer a more actionable and policy-relevant insight into the circularity of EU economies. It supports the argument that prevention and waste reduction must take precedence in the waste hierarchy, aligned with the core principles of the circular economy. Achieving the 2025 and 2030 PPWR targets will not only require improving recycling infrastructure but also reducing the absolute volumes of packaging placed on the market, especially in high-income, high-consumption member states.

5. CONCLUSIONS

The goal of this research was to map the trends between packaging waste generation and recycling rates in the EU-27, identify disparities across Member States, and evaluate their alignment with the Packaging and Packaging Waste Regulation (PPWR) targets. At the EU-27 level, packaging waste generation reached 83.4 million tonnes in 2022, with paper and cardboard (40%) leading, followed by plastic (19%), glass (18%), wood (17%), and metal (6%). The trend shows a consistent 18.7% increase in packaging waste generation over the 2011–2022 period, while recycling rates improved by only 1.9 percentage points.

According to the PPWR, Member States should reduce packaging waste generation per capita by at least 5% by 2030 compared to 2018 levels. Based on current trends, only Estonia, Luxembourg, and France have achieved reductions compared to 2018. Sweden and Germany have also decreased from 2018, while most other countries are still increasing their packaging waste generation.

The cluster analysis confirms significant disparities in packaging waste generation and recycling performance across EU member states and highlights distinct country groupings that reflect varying levels of progress toward the PPWR targets. High-performing countries such as Belgium, the Netherlands, Finland, and Spain have already met or are very close to meeting both the 2025 and 2030 recycling targets, combining efficient recycling systems with relatively moderate packaging waste levels. In contrast, despite low per capita waste, transitional countries like Bulgaria, Romania, and Greece exhibit insufficient recycling rates, revealing structural challenges. Balanced performers such as Czechia, Estonia, and Sweden display encouraging signs of progress, with several members approaching or achieving the 70% recycling rate threshold. Meanwhile, countries like Germany and Italy in the high-waste but good-recycling cluster demonstrate strong recycling systems but require targeted waste prevention strategies to address excessive waste generation. Finally, Hungary, Malta, and Poland, identified as laggards, face critical challenges, with high packaging waste and poor recycling rates, underscoring the need for comprehensive policy and infrastructure reforms.

This disparity raises critical questions about the effectiveness of the existing EU policy framework, particularly whether the PPWR targets reducing packaging waste by 5% compared to 2018 levels and achieving recycling rates of 65% by 2025 and 70% by 2030, are sufficient indicators for addressing the core challenges of packaging waste management. Notably, while some countries have achieved recycling targets, they still produce large volumes of non-recycled waste. High-performing recyclers like Germany and Ireland continue to generate higher absolute quantities of non-recycled packaging waste compared to low-waste countries such as Bulgaria and Croatia, underscoring the need for a shift in focus from recycling rates to absolute waste reduction.

Overall, while the EU has made progress in meeting recycling targets, packaging waste prevention remains a critical gap. To achieve a truly circular economy, future efforts must prioritize both recycling improvements and significant reductions in packaging waste generation at both the EU and national levels.

References

1) Avogadro, A. and Ragaini, R.C. (eds) (1994). *Technologies for Environmental Cleanup: Toxic and Hazardous Waste Management*. Dordrecht: Springer Netherlands. Available at: https://doi.org/10.1007/978-94-017-3213-0.
2) Bailey, I. (1999). Flexibility, Harmonization and the Single Market in EU Environmental Policy: The Packaging Waste Directive, *JCMS: Journal of Common Market Studies*, 37(4), pp. 549–571. Available at: https://doi.org/10.1111/1468-5965.00196.
3) Boulding, K. (1966). *The Economics of the Coming Spaceship Earth (historical) - Encyclopedia of Earth*.
4) Boz, Z., Korhonen, V. and Koelsch Sand, C. (2020). Consumer Considerations for the Implementation of Sustainable Packaging: A Review, *Sustainability*, 12(6), p. 2192. Available at: https://doi.org/10.3390/su12062192.
5) Brisson, I. (1993). Packaging waste and the environment: economics and policy, *Resources, Conservation and Recycling*, 8(3), pp. 183–292. Available at: https://doi.org/10.1016/0921-3449(93)90026-C.
6) Brydson, J.A. (1999). *Plastics materials*. Elsevier. Available at: https://books.google.com/books?hl=en&lr=&id=OlgSAEZYmmoC&oi=fnd&pg=PP1&dq=Brydson,+1999&ots=CJH_9dZ_Np&sig=col-AsfvwL5Dqt9eSeSyTUziEts (Accessed: 17 March 2025).
7) Claudio-Quiroga, G. and Poza, C. (2024). Measuring the circular economy in Europe: Big differences among countries, great opportunities to converge, *Sustainable Development*, 32(5), pp. 4707–4725. Available at: https://doi.org/10.1002/sd.2925.
8) Coles, R. and Kirwan, M.J. (2011). *Food and beverage packaging technology*. John Wiley & Sons. Available at: https://books.google.com/books?hl=en&lr=&id=kf8CEQAAQBAJ&oi=fnd&pg=PR13&dq=Recyclable+packaging+materials+encompass+a+wide+range+of+items,+including+glass+(of+all+colours),+paper,+aluminium+foil,+take-away+containers,+aluminium+cans,+tin+and+steel+cans,+PET,+and+HDPE+&ots=m-5gtKhWAL&sig=raoow1-jEZT7dI68-x1NQ2EB3gA (Accessed: 17 March 2025).

9) Demirbas, A. (2011). Waste management, waste resource facilities and waste conversion processes, *Energy Conversion and Management*, 52(2), pp. 1280–1287.
10) European Comission (2022). Proposal for a Regulation of the European Parliament and of the Council on packaging and packaging waste. COM(2022) 677 final, 2022/0396 (COD).
11) European Commission (2018). *Proposal for a Regulation of the European Parliament and of the Council on Packaging and Packaging Waste.*
12) European Commission (2022a). *Revision of the Packaging and Packaging Waste Directive*.
13) European Parlament and Council (2024). REGULATION (EU) 2025/40 on packaging and packaging waste, amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and repealing Directive 94/62/EC. Official Journal of the European Union.
14) European Parliament and Council (1995. Directive 94/62/EC, *Journal of Environmental Law*, 7(2), pp. 323–337. Available at: https://doi.org/10.1093/jel/7.2.323.
15) European Union (1994). *Council Directive 94/62/EC, on Packaging and Packaging Waste*, pp. 10–23.
16) European Union (2004). *Directive 2004/12/ec of the European parliament and of the council of 11february 2004*.
17) Galvão, G.D.A. *et al.* (2018). Circular economy: Overview of barriers, *Procedia Cirp*, 73, pp. 79–85.
18) García-Álvarez, M.T. and Moreno, B. (2018). Environmental performance assessment in the EU: A challenge for the sustainability, *Journal of Cleaner Production*, 205, pp. 266–280.
19) Geissdoerfer, M. *et al.* (2017). The Circular Economy–A new sustainability paradigm? *Journal of cleaner production*, 143, pp. 757–768.
20) Ghisellini, P., Cialani, C. and Ulgiati, S. (2016). A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems, *Journal of Cleaner Production*, 114, pp. 11–32. Available at: https://doi.org/10.1016/j.jclepro.2015.09.007.
21) Gray, V. and Guthrie, J. (1990). Ethical issues of environmentally friendly packaging, *International Journal of Physical Distribution & Logistics Management*, 20(8), pp. 31–36.
22) Hair, J.F. *et al.* (2010). Multivariate data analysis: A global perspective (Vol. 7). Upper Saddle River, NJ: Pearson.
23) Hermann, B.G. *et al.* (2011). To compost or not to compost: Carbon and energy footprints of biodegradable materials' waste treatment, *Polymer degradation and stability*, 96(6), pp. 1159–1171.
24) Ingram, V. (1999). *Joint Environmental Policy Making in the EU The Packaging Waste Case*.
25) Kandpal, V. *et al.* (2024). Circular Economy Principles: Shifting Towards Sustainable Prosperity, in Kandpal, V. *et al*., *Sustainable Energy Transition*. Cham: Springer Nature Switzerland (Circular Economy and Sustainability), pp. 125–165. Available at: https://doi.org/10.1007/978-3-031-52943-6_4.

26) Keoleian, G.A. and Menerey, D. (1994). Sustainable Development by Design: Review of Life Cycle Design and Related Approaches, *Air & Waste*, 44(5), pp. 645–668. Available at: https://doi.org/10.1080/1073161X.1994.10467269.
27) Kutz, M. (ed.) (2007). *Environmentally Conscious Materials and Chemicals Processing*. 1st edn. Wiley. Available at: https://doi.org/10.1002/9780470168219.
28) Lydekaityte, J. and Tambo, T. (2020). Smart packaging: definitions, models and packaging as an intermediator between digital and physical product management, *The International Review of Retail, Distribution and Consumer Research*, 30(4), pp. 377–410. Available at: https://doi.org/10.1080/09593969.2020.1724555.
29) MacArthur, E. (2013). Towards the circular economy, *Journal of industrial ecology*, 2(1), pp. 23–44.
30) Malinauskaite, J., Jouhara, H. and Spencer, N. (2017). Waste prevention and technologies in the context of the EU Waste Framework Directive: lost in translation?, *European Energy and Environmental Law Review*, 26(3). Available at: https://kluwerlawonline.com/journalarticle/European+Energy+and+Environmental+Law+Review/26.3/EELR2017009 (Accessed: 17 March 2025).
31) Marshall, J. (2007). Packaging unwrapped, *New Scientist*, 194(2598), pp. 37–41.
32) Masi, D. *et al.* (2018). Towards a more circular economy: exploring the awareness, practices, and barriers from a focal firm perspective, *Production Planning & Control*, 29(6), pp. 539–550. Available at: https://doi.org/10.1080/09537287.2018.1449246.
33) Mason, W.R. (1958). A theory of packaging in the marketing mix, *Business Horizons*, 1(3), pp. 91–95. Available at: https://doi.org/10.1016/0007-6813(58)90082-X.
34) Mathrani, A. *et al.* (2023). Clustering analysis on sustainable development goal indicators for forty-five asian countries, *Sci*, 5(2), p. 14.
35) Matlhare, Monnapule (2024). *EU Packaging and Packaging Waste Regulation - A New Dawn or A Fading Twilight?.*
36) Murphy, P.R., Poist, R.F. and Braunschweig, C.D. (1994). Management of environmental issues in logistics: current status and future potential, *Transportation journal*, pp. 48–56.
37) Park, J., Cuervo-Cazurra, A. and Montiel, I. (2023). Chapter 2: The evolution of sustainability concerns over business activities: from local to cross-national to global, in. Available at: https://www.elgaronline.com/edcollchap/book/9781802207040/book-part-9781802207040-7.xml (Accessed: 16 March 2025).
38) Ragonnaud, G. (2023). Revision of the Packaging and Packaging Waste Directive, *European Parliamentary Research Service* [Preprint]. Available at: https://bioplasticsnews.com/wp-content/uploads/2023/10/PPWD-Revision.pdf (Accessed: 17 March 2025).
39) Rundh, B. (2016). The role of packaging within marketing and value creation, *British Food Journal*, 118(10), pp. 2491–2511.
40) Sarangi, U. (2023). CIRCULAR ECONOMY AND ITS IMPLICATIONS IN ACHIEVING THE UNITED NATIONS SUSTAINABLE DEVELOPMENT GOALS AND 2030 AGENDA, *International Journal of Legal Studies (IJOLS)*, 14(2), pp. 481–497.
41) Soroka, W. (1999). Paper and paperboard, *Embelm and H. Embelm (Eds.)*, pp. 95–112.

42) *Eurostat* (2024). Available at: https://ec.europa.eu/eurostat/ databrowser/ view/cei_pc050/default/table?lang=en&category=cei.cei_pc (Accessed: 17 March 2025).
43) Svanes, E. *et al.* (2010). Sustainable packaging design: a holistic methodology for packaging design, *Packaging Technology and Science*, 23(3), pp. 161–175. Available at: https://doi.org/10.1002/pts.887.
44) Szymankiewicz, J. (1993). Going green: The logistics dilemma, *Logistics Information Management*, 6(3), pp. 36–43.
45) Van Buren, N. *et al.* (2016. Towards a circular economy: The role of Dutch logistics industries and governments, *Sustainability*, 8(7), p. 647.
46) Vuk, A., Szűcs, I. and Bauerné Gáthy, A. (2023). Packaging waste and recycle in EU, *International Review of Applied Sciences and Engineering*, 14(3), pp. 402–412. Available at: https://doi.org/10.1556/1848.2023.00615.
47) Yam, K.L. (2010). *The Wiley Encyclopedia of Packaging Technology*. John Wiley & Sons.