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TOWARDS A CIRCULAR ECONOMY: A COMPREHENSIVE POLICY FRAMEWORK FOR PACKAGING WASTE MANAGEMENT IN THE EUROPEAN UNION

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ABSTRACT

Directive 94/62/EC on packaging and packaging waste (PPWD) aimed at harmonizing regulations and coherence of the European Union (EU) internal market and preserving the environment and natural resources. Despite its economic importance, packaging production poses significant environmental challenges, including the generation of solid waste and the depletion of natural resources. This paper addresses the current policy framework that the EU intends to implement to minimize the growing generation of packaging waste, promote circularity, and integrate recycled materials in the EU. The proposed regulatory measures, including the transition from a directive to a Regulation, the establishment of mandatory targets for the reduction of solid waste and recycled content, and the strengthening of reuse systems, aim to promote a resilient value chain, mitigate environmental degradation, and stimulate economic growth. By adopting a circular economy approach, the EU strives to champion sustainable development in the internal market and improve social well-being in various sectors.

1. INTRODUCTION

Packaging is essential in today's commercial activity to protect goods during transport, storage, and consumption. However, the rapid expansion of packaging production and use poses significant environmental challenges, which require a paradigm shift in regulations to ensure sustainability and mitigate adverse environmental impacts. Directive 94/62/EC, which regulates packaging and packaging waste (PPWD), constitutes one of the fundamental pieces of the European Union's (EU) commitment to harmonizing and regulating the sector, preserving the environment, and promoting coherence in the international market.

Recognizing the complexity between economic relevance and environmental sustainability, the EU seeks to reconcile these two divergent aspects. Only the EU plastics value chain generated a turnover of more than €400 billion in 2021 (Plastics Europe, 2023), most of that in the packaging sector. This symbolizes the economic vitality of the market while representing a significant environmental challenge. From resource depletion to ecosystem contamination and greenhouse gas emissions, the environmental effects of the proliferation of packaging are very substantial (Zhuo et al., 2023).

The EU legislative approach to packaging waste management incorporates a holistic vision that aims to reconcile economic issues with the interests of safeguarding environmental values, for example, the Circular Economy Action Plan (Resolution P9_TA(2021)0040). The essential requirements stipulated by Directive 94/62/EC entailed strict standards for packaging manufacturing and sustainability criteria, underlining the EU's commitment to promoting a circular economy. However, despite these regulatory efforts, the truth is that packaging waste generation continues to increase, waste circularity is negligible, and the integration of recycled materials requires further improvements (Tallentire and Steubin, 2020; Ncube, 2021). Using recycled materials in packaging is an essential strategy, but additional improvements are needed in the collection, sorting, and recycling processes (Eygen et al., 2018; Balwada et al., 2021). The transition to a circular economy, particularly in the plastic packaging industry, is crucial and requires a holistic approach involving all stakeholders (Billiet and Trenor, 2020).

The current EU initiative to transition from a Directive to a Regulation comes from regulatory gaps, market inefficiencies, and uneven applications across member states, which have consequently worsened the packaging waste problem with far-reaching environmental consequences.

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Therefore, there is an urgent imperative for comprehensive regulatory action beyond mere application, requiring fundamental legislative reforms so that economic expectations can best be met without neglecting environmental aspects and ecological sustainability.

On the other hand, we seek to align the new Regulations on packaging and packaging waste with the objectives of the European Ecological Pact and the Circular Economy Action Plan to make the EU legislative framework compatible and modernized (Foschi and Bonoli, 2019; Stankevičius et al., 2020). The EU thus seeks to facilitate the transition to a circular economy in the packaging sector by harmonizing regulations, defending sustainable practices, and promoting stakeholder engagement. This article describes the challenges, policy objectives, and regulatory measures proposed to mitigate packaging waste, promote circularity, and promote sustainable development in the EU.

2. CHALLENGES IN PACKAGING AND PACKAGING WASTE MANAGEMENT

2.1 Packaging waste generation

Effective packaging waste management presents several challenges to the EU, especially with the exponential increase in packaging consumption and production (Foggia and Beccarello, 2022). These challenges include a very significant increase in the generation of packaging waste, circularity hampered by the characteristics of some types of packaging, inadequate integration of recycled materials, and regulatory and market inefficiencies (Vogt et al., 2021).

From 1990-2015, there was an average 26% reduction in unit weight. However, variations exist within material groups, often due to marketing reasons. E-commerce exacerbates over-packaging, with excess outer packaging and space. While light-weighting reduces weight, there is a shift to materials with worse environmental footprints, from metal/glass to plastic/paper. Reuse of packaging, mainly primary and tertiary, has decreased over the past decades, with exceptions in specific beverage sectors. One-way packaging, significantly single-use plastic, is rising due to evolving retail practices. This trend will likely continue despite recent signals of a slowing decline in reusable packaging (Coelho et al., 2020; Diprose et al., 2023). Some EU member states are promoting reuse through targets, green procurement, and Extended Producer Responsibility schemes, but challenges to internal market integrity and proportionality exist.

The EU faces a significant challenge in managing the unstoppable production of packaging waste, particularly in materials such as plastic and paper. Factors contributing to this increase include the widespread adoption of disposable packaging, driven by social trends and the proliferation of e-commerce activities. The onset of the COVID-19 pandemic further boosted this trend, as the increased demand for packaged products led to an unprecedented increase in the production of packaging waste (Jacobs et al., 2022). Consequently, the EU faces a growing waste crisis with environmental and socio-economic implications. According to Eurostat statistical data, the evolution of per capita production of packaging waste in EU countries went from 154 kg in 2010 to 188.7 kg in 2021, and the quantity of recycled material from 98.5 to 120.7 kg in the same period (Figure 1).

This quantity varied between 73.8 kg per inhabitant in Croatia and 246.1 kg per inhabitant in Ireland. By packaging material, for 2021, the distribution of the most common materials in the EU are paper and cardboard (40.3%), plastic (19.0%), glass (18.5%), wood (17.1%), and metal (4.9%). Other materials represented only 0.1% of the total volume of packaging waste generated in 2021 (Figure 2). In 2021, the EU generated an estimated total volume of 84.3 million tons of packaging waste – an increase of 6.0% (or 4.8 million tons) compared with 2020. The growth in 2021 was mainly due to the rise in waste from packaging made of wood by 2.3 million tonnes (+19.0%). There was also a notable increase in paper and cardboard packaging waste compared with 2020, up 1.3 million tonnes (+3.9%). The increases in waste material were smaller for packaging made of plastic (up 598 thousand tones; 3.9%), glass (up 467 thousand tones; 3.1%), and metal (up 181 thousand tones; 4.5%). Over the 11 years from 2010 to 2021, paper and cardboard were the primary packaging waste material, contributing 34.0 million tonnes to the total packaging waste generated in 2021; since 2010, this waste stream has grown by 23.5%. Plastic packaging reached a total of 16.1 million tones as the second most crucial packaging

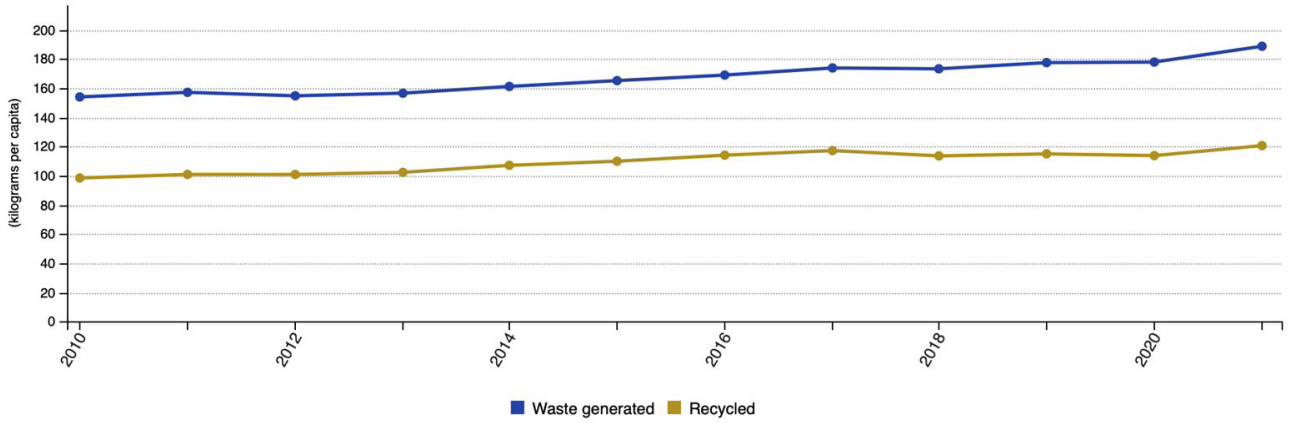

FIGURE 1: Evolution of packaging waste production and recycling in EU (2010-2021). Source: Eurostat (online data code: env_waspac).

material (+29.9% compared with 2010). Glass packaging waste had a volume of 15.6 million tones (+18.1%), wood 14.4 million tones (+32.7%) and metal packaging 4.2 million tones in 2021 (+10.6%).

In conclusion, the EU faces various challenges in effectively managing packaging waste, ranging from increasing waste production to hampered circularity and inadequate integration of recycled materials. Regulatory and market inefficiencies further aggravate these challenges, requiring comprehensive and decisive action to achieve a good relationship between the economic development of the packaging sector and environmental sustainability. By identifying and addressing these challenges, the EU can pave the way for a more sustainable and resilient future supported by circularity, efficient use of resources, and environmental management and protection.

2.2 Packaging and packaging waste problems

The escalation in non-recyclable packaging from 2012 to 2020 has posed significant challenges to recycling efforts. Despite the technical recyclability of many packaging types, collection, sorting, and demand issues in end markets have led to incineration, landfilling, or exportation as standard disposal methods. The prevalence of lightweight materials like multi-layer flexible packaging further complicates matters, as re-processors often reject them due to inadequate incentives, exacerbating environmental litter.

Notably, plastic packaging presents a formidable challenge, with 44% encountering design issues affecting recyclability. Although the EU reports a 40.6% recycling rate for plastic packaging, a mere 14% is effectively recycled when the waste exported outside the EU was not considered (25% when assuming that all the waste exported was also reprocessed), highlighting significant environmental repercussions such as increased greenhouse gas emissions, resource depletion, and biodiversity pressure (Antonopoulos et al., 2021).

Efforts to promote circularity in the packaging sector encounter barriers such as material types and design complexities, hindering efficient recycling and reuse. Design features impeding recyclability, cross-contamination of recycling streams, and hazardous substances in packaging pose considerable challenges to achieving circularity objectives. Recycling rates have stagnated, with many Member States at risk of failing to meet recycling targets set by current legislation, perpetuating the linear "take-make-dispose" model (Vogt et al., 2021; Hondroyiannis et al., 2024). The inadequate integration of recycled materials into the packaging value chain perpetuates reliance on virgin resources, exacerbating pressure on natural resources. Market dynamics, regulatory inconsistencies, and logistical challenges impede the widespread adoption of recycled materials in packaging production, hindering the EU's sustainability objectives (Antonopoulos et al., 2021).

Regulatory and market inefficiencies exacerbate challenges associated with packaging waste management in the EU, leading to legislative fragmentation and suboptimal waste management practices. Additionally, the demand for bio-based and compostable plastics has surged, leading to confusion regarding end-of-life management due to inconsistent labeling practices across the EU. Hazardous substances in packaging materials pose risks to human health and the environment, undermining confidence in recycled materials (Geueke et al., 2023). Waste sorters and recyclers express dissatisfaction with packaging producers' choices, complicating waste treatment processes and limiting potential economies of scale. For example, packaging producers often design products focusing on aesthetics, durability, or cost-efficiency without fully considering how easily the materials can be sorted and recycled. This also

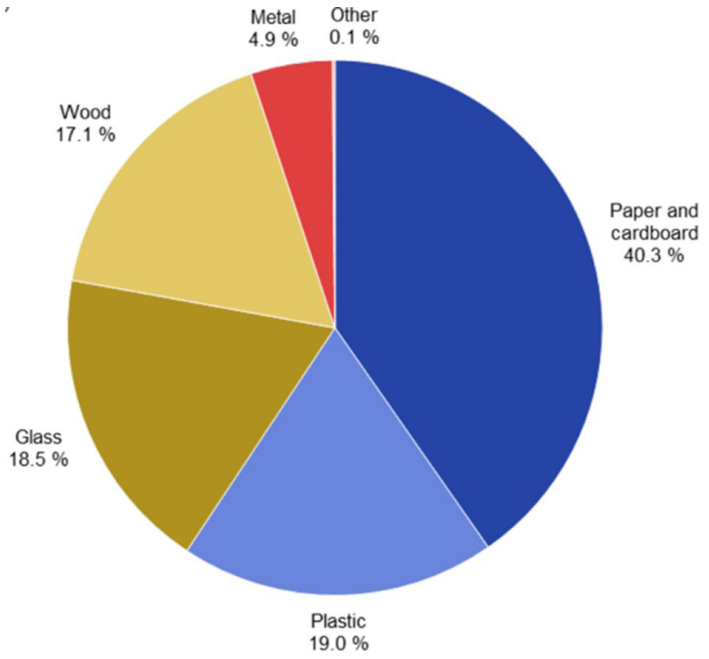

FIGURE 2: Waste generation by packaging material in 2021 in the EU.

might include using non-recyclable plastics, multi-layer packaging, or materials that are difficult to separate. When packaging is not designed with recyclability, the sorting process is more complex, time-consuming, and less efficient. Waste treatment processes become harder when packaging materials are diverse and not standardized. Economies of scale in recycling occur when there is a large quantity of uniform materials to process, making recycling more cost-effective. However, when there is too much variation in packaging materials, recyclers cannot efficiently process large batches of the same material. As a result, recyclers may miss opportunities to save on costs or achieve higher profitability through large-scale processing (Bassi et al., 2020; Rutkowski, 2020; Colelli et al., 2022).

A clear legal framework incentivizing circularity risks is needed to deter investment in recycling technologies. Moreover, confusion persists among consumers regarding waste sorting due to diverse labeling practices, hindering correct waste separation and recycling efficiency. The current predominance of downcycling in waste recycling and varying uptake rates of recycled material in packaging underscores the need for comprehensive strategies to promote circularity and mitigate environmental impacts. These challenges jeopardize the EU internal market, impede the transition to a circular economy, and generate adverse environmental consequences. Addressing these issues requires harmonizing regulations, enhancing circularity in packaging design and production (ecodesign regulations), and implementing sustainable waste management practices. Firstly, these problems negatively affect the functioning of the internal market by posing challenges to the free circulation of packaged goods. Divergent legislations across Member States lead to additional costs for producers to adapt, hinder economies of scale, and impede investment in reprocessing capacity and innovation.

Fragmentation in the market also results in efficiency losses in the supply chain due to reduced demand and additional stock holding. Secondly, the demand for packaging, coupled with low reuse, recyclability, and recycled content, hinders progress towards a circular economy. Ambiguities in the definition of recyclable packaging and other barriers impede Member States' ability to meet recycling targets, increase the use of recycled materials, and create jobs in recycling sectors. Thirdly, the manufacture of packaging has significant adverse environmental impacts, including carbon emissions and litter pollution (Ncube et al., 2020; Pilli et al., 2021).

Littered plastics, especially in marine environments, pose risks to ecosystems and human health as they degrade into micro and nano plastics and enter the food chain (Mofijur et al., 2021; Gündoğdu et al., 2024). Greenhouse gas emissions from packaging are projected to increase unless measures are taken to reduce them, undermining the EU's goal of carbon neutrality by 2050 (Beghetto et al., 2023). Additionally, packaging waste contributes to soil and land pollution and marine littering, exacerbating environmental degradation. In summary, addressing these issues requires comprehensive strategies that promote harmonization of regulations, enhance circularity in packaging design and production, and mitigate environmental impacts through sustainable practices and waste management.

2.3 Packaging waste impacts

The multifaceted impacts of packaging and packaging waste on society, consumers, brands, manufacturers, and waste management companies include environmental pollution, resource depletion, emissions, economic loss, and public health risks. Consumers need more transparent and harmonized information about packaging options, hindering their ability to make informed decisions and manage packaging waste effectively. Brands must balance packaging functions with increasing consumer demand for environmentally conscious solutions amidst regulatory uncertainties. Packaging manufacturers must meet brand demands and regulatory requirements while maintaining competitiveness through innovation and cost-efficiency. Waste management companies and recycling industries need more profitability due to fragmented markets and regulatory gaps, calling for a harmonized economic framework and legal clarity to improve coordination and efficiency in waste management.

Environmental degradation is at the forefront of the consequences of insufficient packaging waste management. The proliferation of packaging materials, often derived from non-renewable resources, exacerbates resource depletion and contributes to ecosystem contamination. Improper packaging waste disposal, including landfilling, leads to visual pollution and habitat destruction, disrupting delicate ecological balances. Plastic packaging poses a significant threat to marine environments, where it fragments into nano-microplastics (Boone et al., 2023), infiltrating marine food chains and causing harm to aquatic life. Additionally, packaging waste incineration releases greenhouse gases and pollutants into the atmosphere, exacerbating climate change and air pollution (Zhuo et al., 2023).

The economic consequences of inadequate packaging waste management are multiple, including significant costs for municipalities, companies, and taxpayers, as resources are diverted to waste collection, transport, and disposal (Deniz et al., 2023). Furthermore, the reliance on virgin materials for packaging production perpetuates a linear economic model characterized by resource extraction, production, consumption, and disposal, leading to missed resource efficiency and cost savings opportunities (Zhu et al., 2022). Moreover, the environmental externalities associated with packaging waste, such as pollution clean-up and health impacts, impose additional financial burdens on society, undermining the economic resilience and competitiveness of the EU (Dechezleprêtre and Sato, 2017).

The health consequences of inadequate packaging waste management extend beyond environmental degradation to encompass direct risks to public health. Improperly disposed packaging waste, particularly plastics, can leach harmful chemicals and additives into soil and water, contaminating food and water supplies and posing risks to human health. Moreover, the accumulation of packaging litter in urban and natural environments creates breeding grounds for pests and disease vectors, increasing the

prevalence of vector-borne diseases and compromising public health and sanitation standards (Wright and Kelly, 2017; Krystosik et al., 2020). In addition to environmental, health, and economic consequences, inadequate packaging waste management engenders social disparities and inequities. Vulnerable communities, including marginalized populations and low-income households, bear a disproportionate burden of the negative externalities associated with packaging waste, such as exposure to environmental pollution and health hazards.

In summary, the consequences of inadequate packaging waste management within the EU are far-reaching and profound, encompassing environmental degradation, economic losses, public health risks, and social disparities. Addressing these consequences necessitates concerted efforts to transition towards sustainable packaging practices, promote circular economy principles, and enhance waste management infrastructure and governance mechanisms. By mitigating the adverse impacts of packaging waste, the EU can foster environmental sustainability in the internal market, promote economic prosperity, and safeguard public health and well-being for present and future generations.

3. POLICY OPTIONS DESCRIPTION

3.1 General description

A new regulatory approach to address shortcomings in current legislation governing packaging and packaging waste management is necessary. Despite existing controls, environmental sustainability objectives have yet to be achieved. Regulatory failures, such as delayed transposition and uneven application, reveal the necessity for harmonization through Regulation rather than revising the current directive. A comprehensive set of regulatory solutions is proposed to promote a transition to a low-carbon and circular economy. Placing obligations on economic operators ensures consistent implementation across Member States, addressing the challenge of uneven national regulatory frameworks. A Regulation would provide legal certainty, reduce competition distortion, and send clear signals to non-EU market actors. Implementing measures can be swiftly developed to flesh out the Regulation further. This approach aligns with industry calls for harmonization and political commitments outlined in the European Green Deal and the Circular Economy Action Plan to ensure all packaging is reusable or recyclable by 2030. The EU faces complex challenges in managing packaging waste while also seeking to promote a circular economy. In the legislative change process in the EU, several policy options were proposed to face these challenges, each offering different approaches to promote the reduction of packaging waste production, its circularity, and the integration of recycled materials in the packaging sector (Farmer, 2020). Extensive analysis, stakeholder consultations, and applicability and effectiveness considerations inform these policy options. The first set of options focuses on standardizing and clarifying the essential requirements for packaging, establishing the basis for subsequent measures. The Essential Requirements would be revised and expanded to include clear definitions and performance criteria to minimize excess packaging and promote recyclability. By providing regulatory clarity and consistency, this option seeks to increase the effectiveness of packaging minimization requirements and facilitate compliance across Member States. Although this option may involve minimal administrative and economic costs, its main objective is establishing a robust regulatory framework that promotes waste reduction and circularity as, for example:

- Minimization of space in packaging: Sets maximum void space limit to reduce packaging waste in various sectors.
- Update of Essential Requirements: Defines over-packaging and specifies packaging performance criteria to minimize excessive packaging.
- Revision of CEN standard for reusable packaging: Updates standards for defining and improving reusable packaging.
- Clarity on the definition of reuse activity: This section clarifies when reusable packaging becomes waste to facilitate reuse systems.
- Packaging to be reusable or recyclable by 2030: Establishes enforceable requirements prioritizing reusable packaging to be recyclable by 2030: Requires recyclability for reusable packaging.
- Qualitative definition of recyclable packaging: Defines recyclable packaging to improve recycling rates.
- Updates of Essential Requirements and EN 13432 - Biodegradable Packaging Certification: Clarifies biodegradability and compostability concepts in packaging.
- Allowing compostable and conventional plastics for selected packaging types: This policy permits compostable materials for specific packaging.
- Definition of Recycled Content and Measurement Method: Establishes methodology for calculating and verifying recycled content levels in packaging.
- Update of current material-based labeling: This update removes alphanumeric codes for waste sorters and introduces more competent sorting labeling requirements.
- Update of 'hazardousness' definition: Reviews packaging legislation objectives and updates hazardous substance requirements.
- Expanding information on hazardous substances: Identifies and prioritizes relevant dangerous substances in packaging for potential limitations or restrictions.

The second set of options introduces mandatory targets for waste reduction, reuse, and minimum recycled content in plastic packaging, along with requirements for full recyclability by 2030 and harmonized product rules. These goals encourage economic operators to adopt sustainable packaging practices, minimize packaging waste, and integrate recycled materials into their production processes. These measures seek to drive systemic changes in packaging design, production, and consumption, establishing clear objectives and deadlines and promoting a transition to a circular economy. While these options may entail implementation challenges and economic adjust-

ments for the packaging sector, their ambitious goals reflect a commitment to advancing sustainability objectives and promoting resource efficiency. These measures seek to accelerate progress toward circularity by imposing more stringent targets and requirements on economic operators, such as:

- Definition of Recyclable Packaging: This measure establishes criteria for packaging design and recyclability assessment procedures. It aims to increase recycling rates and improve recycled material quality.
- Harmonization of Extended Producer Responsibility (EPR) Fee Modulation Criteria: This involves harmonizing EPR fee modulation criteria to incentivize improved packaging design and recycling. It aims to make recycling targets more efficient and cost-effective.
- Mandatory Compostability for Certain Plastic Packaging Types: Lightweight plastic carrier bags, tea bags, and labels on fruits and vegetables must be made from compostable plastic polymers. This measure aims to reduce waste contamination and increase the usage of compostable plastic.
- Broad Targets for Plastic Packaging Recycling: Mandatory targets for postconsumer recycled content in plastic packaging for 2030 and 2040 are set to increase the use of recycled content and reduce environmental impacts.
- Mandatory Deposit Refund Systems (DRS) and Minimum Requirements: DRS systems for plastic bottles and metal cans are made compulsory, with voluntary systems for other beverage containers. This measure aims to increase waste collection and purity rates.
- Harmonized Labelling of Products and Waste Receptacles: Uniform labeling systems are introduced to facilitate waste sorting and harmonize collection systems across the EU.
- Restrictions on Confusing Labels: This measure restricts how information on packaging is communicated to reduce consumer confusion.
- Labelling Criteria for Recycled Content: Standardized labeling requirements for recycled content in packaging are introduced to prevent misleading claims.
- Harmonized Labelling for Reusable Packaging: A mandatory symbol for reusable packaging is introduced to promote reuse and prevent fragmentation of labeling schemes.
- Notifying Substances of Concern in Packaging: Legal obligations have been introduced to inform substances of concern in packaging to enhance safety and transparency.
- Mandatory Minimum Green Public Procurement Criteria for Packaging: Mandatory minimum criteria for environmentally friendly packaging in public procurement are established to promote sustainability.
- Harmonization of EPR Reporting System for Packaging Producers: Reporting requirements for Extended Producer Responsibility systems are harmonized to streamline data processing and reporting.
- Reporting Obligation on Plastic Carrier Bags: To ensure comprehensive data collection, reporting requirements for plastic carrier bags are extended to include bags of different thicknesses.

Finally, a third set of options represents a more ambitious approach, covering higher mandatory targets for waste reduction, reuse and recycled content, and additional product requirements. These measures can produce more significant environmental benefits and resource savings. However, they can also imply implementation burdens and higher economic costs for industries in the sector. However, the potential long-term benefits of these measures, in terms of reduced environmental impacts and greater resource efficiency, justify their consideration as a policy option. The key measures are:

- Mandatory high-level targets to increase packaging reuse and refill by 2030/2040 in selected sectors. The targets aim to reduce packaging waste and increase reusable packaging, with estimated economic impacts and environmental benefits.
- Banning the heaviest packaging for selected items by 2030 based on existing lighter alternatives. This measure initially targets plastic and glass bottles and aims to reduce overall waste generation.
- Establishing a mandatory target of a 23% reduction in packaging waste per capita by 2030 compared to the baseline. This measure aims to reduce waste and has significant economic and environmental impacts.
- Quantitatively defining recyclable packaging based on actual recycling rates. This measure aims to increase recycling rates, but its implementation needs to be improved due to technological limitations.
- Mandating compostability for selected plastic packaging types. While this measure eliminates consumer confusion, it poses challenges for the packaging industry and faces opposition from waste management sectors and Member States.
- Introducing higher ambition and broad targets for recycled content in plastic packaging by 2030 and 2040.

This measure aims to increase recycling rates but may need help due to tighter market conditions. Including prioritized use of recycled packaging from Deposit Refund Systems (DRS), waste collection schemes alternative to DRS, notification of all substances in packaging, restrictions of substances under the reviewed PPWD, mandatory minimum Green Public Procurement (GPP) criteria for packaging, and compulsory reporting requirement for recycled content for all packaging. These measures aim to support recycling, reduce environmental impact, and ensure packaging sustainability.

3.2 Sustainable Packaging Regulation

The proposal for a Regulation of the European Parliament and of the Council is made up of twelve chapters and 64 articles that can generally be described as follows:

- Chapter I (Articles 1 to 4) outlines the general provisions and defines the regulation's scope, including requirements for the entire packaging lifecycle, environmental sustainability, labeling, extended producer

responsibility, and packaging waste management. The regulation aims to facilitate the placement of packaging on the market while addressing environmental concerns and promoting the transition to a circular economy. Specifies that the regulation applies to all packaging and packaging waste types, irrespective of the material used. Provides definitions necessary for understanding the regulation, including terms adopted from existing legislation and new definitions related to recyclable packaging, recycled content in plastic packaging, reusable packaging, and packaging waste prevention. Establishes the principle of free movement within the single market for packaging that meets the sustainability and labeling requirements outlined in the regulation.

- Chapter II (Articles 5 to 10) addresses the regulation details sustainability requirements for packaging and imposes restrictions on the concentration levels of certain substances in packaging, such as lead, cadmium, mercury, and hexavalent chromium. The Commission can adjust these restrictions and grant exemptions through delegated acts. Mandates that packaging must be recyclable, with specific criteria to be met in two stages. By January 1, 2030, packaging must comply with design criteria for recycling, and by January 1, 2035, it must also meet requirements for effective collection, sorting, and recycling ("recycled at scale"). The Commission will establish criteria and methodologies for assessing recyclability and recycling scale through delegated acts. Financial contributions by producers for extended producer responsibility will be based on recyclability performance grades, which will include thresholds for recyclability at scale from 2035 onwards. Innovative packaging and specific medical device packaging are granted exemptions until 2034. Stipulates that plastic packaging must contain a minimum amount of recycled content from postconsumer plastic waste by January 1, 2030, with increasing amounts required by January 1, 2040. The Commission will establish a methodology for calculating and verifying recycled content percentages and may adjust the minimum percentage through delegated acts. Defines conditions for compostable packaging and specifies certain items, such as filter coffee pods and sticky labels on fruits and vegetables, that must be compostable within 24 months of the regulation's entry into force. Other packaging, except for lightweight plastic carrier bags, must be eligible for material recycling. The Commission can amend the list of compostable packaging through delegated acts. Mandates minimizing packaging weight and volume while ensuring safety and functionality, with compliance demonstrated through technical documentation. Outlines requirements for reusable packaging, including being designed for multiple uses and part of a reuse system meeting specified conditions outlined in Annex VI of the regulation.
- Chapter III (Articles 11 to 13) of the regulation focuses on labeling, marking, and information requirements for packaging. Article 11 mandates that packaging contain a label containing information about its material composition to aid consumer sorting. Similar labels should be placed on waste receptacles to assist consumers in identifying appropriate disposal routes. Harmonized labels may also include information about recycled content in plastic packaging, and reusable packaging should feature a QR code or other data carrier facilitating reuse. The Commission has the authority to establish harmonized labeling requirements and formats, including digital marking technologies.
- Chapter IV (Articles 14 to 28) outlines obligations for economic operators, including provisions regarding information exchange between suppliers and manufacturers, maximum space in packaging, and restrictions on specific packaging formats and purposes. Economic operators must ensure systems for reuse are in place for reusable packaging and comply with refill requirements for products offered for purchase through refill stations.
- Chapter V (Article 29) limits the annual consumption of lightweight plastic carrier bags and provides exemptions for certain types of bags.
- Chapter VI (Articles 30 to 34) addresses conformity assessment procedures for packaging.
- Chapter VII (Articles 35 to 51) focuses on managing packaging and packaging waste, including requirements for Member States to designate competent authorities, establish waste management plans, and progressively reduce packaging waste generation. It also mandates the establishment of producer registers, extended producer responsibility, and deposit and return systems for specific single-use packaging.
- Chapter VIII (Articles 52 to 56) covers safeguard procedures.
- Chapter IX (Article 57) allows for the adoption of delegated acts to establish green public procurement requirements.
- Chapter X (Articles 58 and 59) includes delegated and implementing acts provisions.
- Chapter XI (Articles 60 and 61) contains amendments to existing regulations.
- Chapter XII (Articles 62 to 64) contains final provisions, including penalties, an evaluation of the regulation after eight years, and transitional provisions.

4. RESULTS AND DISCUSSION

Considering the application of the proposed Regulation of the European Parliament and the Council, environmental impacts result mainly in reducing greenhouse gas (GHG) emissions and water use. Thus, by 2030, there could be a reduction of 1.1 million tons of CO_2e emissions and a decrease in water use by 31,000 m^3. Considering the perspective that all packaging must be reusable or recyclable, such a change could be responsible for significant savings, which could result in a reduction of around 812,000 tons of CO_2e emissions and a reduction of 29,000 m^3 in water use due to the decrease in the amount of packaging waste sent for incineration. On the other hand, diverting packaging waste from incineration and landfills for recycling could save 550,000 tonnes of CO_2e emissions and

reduce water use by 18,000 m^3. Given its current absence, the Commission's definition of recyclable packaging is crucial. Although the impact of introducing only a qualitative definition on recycling rates is not globally significant, certain types of packaging could see an increase in recycling rates of 3 to 5%. This change could generate savings of 1.2 million tons of CO_2e emissions and a reduction of 44,000 m^3 in water use. However, while recycling can reduce greenhouse gas emissions and resource depletion, mechanical recycling may increase microplastic emissions (Gabisa et al., 2023). MNPs can enter the food web, affecting marine organisms and potentially human health through cytotoxicity and immune responses (Mofijur et al., 2021; Yee et al., 2021). Advanced imaging techniques have shown direct evidence of nanoplastic release from recycled plastics (Zhang et al., 2020). MNPs can interact with other contaminants, increasing toxicity and potentially biomagnifying in the environment (Singh et al., 2021). Current research gaps include developing quantification techniques, understanding degradation mechanisms, and creating sensors for environmental detection (Singh et al., 2021).

Table 1 describes the sectors and types of packaging and products with the most significant economic and environmental impacts with the targets for 2030 and 2040 on the new Regulation. The adoption of reusable packaging is expected to result in reductions in GHG emissions of 1.25 million tons of CO_2e in 2030 (5.54 million tons of CO_2e in 2040) and a decrease in water consumption of 69,000 m^3 in 2030 (212,000 m^3 in 2040). The progressive elimination of avoidable or unnecessary packaging suggests a reduction of 2.18 million tons of CO_2e emissions and 91,000 m^3 of water use. Measures such as reducing space, phasing out unnecessary packaging, and reuse targets contribute to almost 60% of waste reduction. EU member states are tasked with lowering absolute packaging waste per inhabitant, targeting a 19% reduction compared to the 2030 baseline, equivalent to a 5% reduction compared to 2018 values. In terms of reduction of GHG emissions in 2030 compared to the base scenario, they are estimated at 11.8 million tons of CO_2e. The definition of recyclable packaging is based on design criteria for recycling, complemented by a recyclability assessment procedure and a negative list of non-recyclable packaging characteristics. This measure is expected to result in environmental benefits, with savings equivalent to 4.2 million tons of CO_2e emissions and a reduction of 150,000 m^3 in water use. Mandatory compostability is required for certain types of selected plastic packaging, while compostable or conventional plastics are permitted for others. This measure includes lightweight plastic bags, tea bags (and similar items such as capsules or coffee bags), and fruit and vegetable stick-on labels, all of which must be produced from compostable plastic polymers. The estimated model predicts savings of 1.1 million tons of CO_2e emissions. However, we cannot fail to mention that bioplastics, introduced as envi-

TABLE 1: Reuse/refill targets for particular packaging for 2030 and 20490 in the EU.

Sector	Packaging type	Packaging groups and products	Target 2030 / 2040	Target 2030 / 2040
Food and beverage (HORECA)	Primary	Beverage (cold and hot) served into a container at the point of sale for take-away, to be sold in packaging within a system for re-use or refill	20% / 80%	30% / 95%
	Primary	Food for take-away, to be sold in packaging within a system for re-use or refill	10% / 40%	20% / 80%
Food and beverage (Retail)	Primary	Alcoholic beverages (wine and spirits not included) and products based on wine, spirits, or other fermented beverages mixed with non-alcoholic beverages, to be sold in packaging in a reuse or refill system	10% / 25%	20% / 80%
	Primary	Wine, sparkling wine, spirits, and other spirituous beverages are to be sold in packaging within a system for reuse or refill	5% / 15%	20% / 80%
	Primary	Non-alcoholic beverages are to be sold in packaging within a system for re-use or refill	10% / 25%	20% / 80%
	Tertiary	Large household appliances, e.g., washing machines or fridges, to be sold in reusable packaging	90% / 90%	20% / 80%
Commercial and Industrial	Tertiary	Goods sold using pallets, crates, foldable boxes, pails, and drums for the conveyance or packaging of the goods, to be sold in reusable packaging	30% / 90%	20% / 80%
	Tertiary	Non-food goods sold via e-commerce using packaging for transport and delivery, to be sold in reusable packaging	10% / 50%	20% / 80%
	Tertiary	Pallet wrappings and straps for stabilization and protection of goods during transport, to be sold in reusable packaging	10% / 30%	20% / 80%
	Tertiary	Grouped packaging boxes used for wholesale (excluding cardboard) to group a certain number of goods to create a stock-keeping packaging unit are classified as reusable packaging within a system for re-use.	8% / 25%	20% / 80%
	Secondary	Grouped packaging boxes use outside sales packaging to group a certain number of goods to create a stock-keeping packaging unit, which is classified as reusable packaging within a system for re-use.	8% / 25%	20% / 80%

ronmentally friendly alternatives to conventional plastics, are defined as biodegradable if they can be decomposed by microorganisms into carbon dioxide, methane, inorganic compounds, and biomass (Lavagnolo et al., 2024). However, the biodegradability of bioplastics is influenced by their physical and chemical structure, environmental conditions, and microbial populations (Folino et al., 2020). Standard methods for assessing biodegradability often fail to provide clear targets and may not accurately represent real-world conditions (Folino et al., 2023; Lavagnolo et al., 2024). Research has shown significant variability in biodegradation rates across different environments, including compost, soil, and aquatic habitats (Kliem et al., 2020). The comparison of results from different studies is challenging due to variations in methodologies and experimental conditions (Lavagnolo et al., 2024). Future research should focus on long-term field experiments and standardized testing methods to better understand the environmental fate of bioplastics (Polman et al., 2021; Afshar et al., 2024).

Regarding measures regarding the recycled content of plastic packaging, recycling efforts and incorporating recycled content in the EU alleviate uncertainty associated with oil supplies related to geopolitical issues. The 2030 medium ambition target is expected to reduce the EU's fossil fuel needs by 3.1 million tons annually. Increasing the recycled content of plastics is estimated to save 6.5 billion tons of CO_2e emissions compared to the 2030 baseline.

Mandatory high-level targets are set to increase packaging reuse and replenishment by 2030/2040 in selected sectors. These targets are expected to reduce packaging waste by 7.8% in 2030 (26.4% in 2040). Furthermore, this measure aims to increase the percentage of reusable packaging from 2.4% in the 2030 baseline to 8.6% (19.2% in 2040). The predicted increase in reusable packaging for 2030 is expected to result in a decrease in GHG emissions of 2.67 million tons of CO_2e (15.76 million tons of CO_2e in 2040) and water consumption of 118,000 m^3 (451,000 m^3 in 2040). By 2030, heavier packaging for selected items is expected to be banned in favor of existing lighter alternatives. This measure estimates a reduction of 766 thousand tons of CO_2e emissions and 39,000 m^3 of water in 2030. A mandatory target of a 23% reduction in packaging waste per capita by 2030 compared to the baseline is set, equivalent to a 10% reduction compared to waste generated in 2018. The environmental impact of this measure includes a decrease estimated in 2030 relative to the baseline of 14.6 million tons of CO_2e emissions.

Regarding measures on recyclability and compostability in the policy option, a quantitative definition of recyclable packaging is implemented, with estimated savings of 8.3 million tons of CO_2e emissions and 287,000 m^3 in 2040. Mandatory compostability for all selected types of plastic packaging is applied, with an estimated saving of 2.1 million tons of CO_2e emissions. With greater ambition and broad targets for recycled content in plastic packaging, reducing the EU's fossil fuel needs would amount to 4.5 million tons per year. The model predicts savings of 12 million tons of CO_2e emissions and a reduction of 930,000 m^3 of water use.

5. CONCLUSIONS

The proposed Regulation of the European Parliament and the Council on packaging and packaging waste management presents a comprehensive approach to addressing packaging materials' environmental and economic challenges. The EU aims to promote sustainability, circularity, and resource efficiency in the packaging sector through policy options and regulatory measures. Key measures include increasing the reuse and recyclability of packaging, eliminating unnecessary packaging, and boosting the recycled content in plastics. By 2030, these initiatives are expected to significantly reduce more than 1 million tons of CO_2e emissions and decrease water consumption, with even more significant reductions projected by 2040.

The transition to reusable packaging and the gradual elimination of superfluous packaging are central strategies for achieving these environmental goals. By reducing the amount of waste sent for incineration and landfills, alongside higher recycling rates, the proposed measures will lead to substantial savings in CO_2e emissions and water usage. However, the successful implementation of these measures will depend on clear and comprehensive definitions of recyclable packaging to maximize their effectiveness.

While recycling offers many environmental benefits, the text also highlights potential risks, such as the increased release of microplastics during mechanical recycling, which can threaten ecosystems and human health. These microparticles may interact with other contaminants, amplifying toxicity and spreading through the food chain. Additionally, the biodegradability of bioplastics, which are promoted as a sustainable alternative to conventional plastics, varies significantly depending on environmental conditions and material structures. There is substantial variability in biodegradation rates across different environments, such as composting, soil, and aquatic ecosystems, and a lack of standardized methodologies makes it challenging to compare results between studies. As a result, ongoing and more extensive research is needed, particularly in long-term field experiments and the development of standardized testing methods, to better understand the environmental fate of bioplastics and the impacts of plastic recycling.

The ambitious targets for increasing recycled content in plastic packaging and reducing per capita packaging waste underscore a commitment to reducing the EU's reliance on fossil fuels while promoting a more sustainable circular economy. By increasing recycled content, Europe is projected to save millions of tons of CO_2e emissions and large volumes of water. Therefore, these measures are crucial for the European Union to meet its broader environmental objectives, advancing the transition to a future with lower environmental impact and greater resource efficiency.

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