NOVA SCHOOL OF SCIENCE & TECHNOLOGY

DEPARTMENT OF MATERIALS SCIENCE

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BSc in Industrial Engineering

ANALYSIS OF PLASTIC PACKAGING EXTENDED PRODUCER RESPONSIBILITY SCHEMES IN THE EUROPEAN UNION

IMPACT ON RECYCLING VALUE CHAIN AND SECTORIAL PERCEPTION

MASTER IN Advanced Materials Innovative Recycling

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ABSTRACT

The recycling of plastic packaging is a significant challenge in the EU's transition to a circular economy. This waste stream is produced in large volumes, and its characteristics complicate the recycling process and pose environmental risks if mismanaged. Extended Producer Responsibility (EPR) schemes are crucial in developing the sector, as they connect all stakeholders, however they vary greatly among Member States. This study examines the EU's plastic packaging recycling value chain to understand the main differences in these schemes, how these differences impact the systems, and how professionals perceive them. The results could lay the groundwork for future research on specific operational aspects of recycling.

Three core differences that characterize EPR schemes were identified: the market structure (monopoly or open competition for producer responsibility organizations), the allocation of financial and operational responsibility, and the adoption of the eco-modulation of fees. The systems in the EU27 were presented based on these differences, and the systems of Italy and Germany were analyzed in detail. For the sectorial perception, an exploratory survey was carried out, using a questionnaire that was sent to 3,124 actors of the European plastic packaging recycling value chain and collected 74 responses. From the survey emerged that the most effective measures to improve recycling efficiency are the eco-modulation of EPR fees, an increase in transparency across the value chain, and recycling targets given also for the material quality, and not only according to the quantity. The market structure of the system had minor influence on respondents' opinions. While the first two measures are part of the future EU strategy, the focus on material quality is less considered by legislators.

Future research could explore the implementation of fee eco-modulation in competitive systems and methods to incentivize the conservation material quality in the recycling process.

Keywords: Plastic packaging, Extended producer responsibility, Recycling, European Union

RESUMO

A reciclagem das embalagens de plástico constitui um desafio significativo na transição da UE para uma economia circular. Este fluxo de resíduos é produzido em grandes volumes e as suas características complicam o processo de reciclagem e representam riscos ambientais se mal geridos. Os esquemas de responsabilidade alargada do produtor (RAP) são cruciais para o desenvolvimento do sector, pois ligam todas as partes interessadas, embora variem muito entre os Estados-Membros. Este estudo examina a cadeia de valor da reciclagem de embalagens de plástico na UE para compreender as principais diferenças entre estes esquemas, o impacto dessas diferenças nos sistemas e a perceção que os profissionais têm delas. Os resultados poderão lançar as bases para investigação futura sobre aspectos operacionais específicos da reciclagem.

Foram identificadas três diferenças fundamentais que caracterizam os esquemas de RAP: a estrutura do mercado (monopólio ou concorrência aberta para as organizações de responsabilidade do produtor), a atribuição da responsabilidade financeira e operacional e a adoção da eco-modulação dos ecovalores. Os sistemas da UE27 foram apresentados com base nestas diferenças, e os sistemas da Itália e da Alemanha foram analisados em detalhe. Para a perceção setorial, foi realizado um inquérito exploratório, com um questionário enviado a 3,124 intervenientes do sector, tendo sido recolhidas 74 respostas. Do inquérito resultou que as medidas mais eficazes para melhorar a eficiência da reciclagem são a eco-modulação dos ecovalores, um aumento da transparência em toda a cadeia de valor e objectivos de reciclagem atribuídos também à qualidade do material, e não apenas à quantidade. A estrutura de mercado do sistema teve pouca influência nas opiniões dos inquiridos. Embora as duas primeiras medidas façam parte da futura estratégia da UE, a atenção à qualidade dos materiais é menos considerada pelos legisladores.

A investigação futura poderia explorar a implementação da eco-modulação dos ecovalores em sistemas competitivos e métodos para incentivar a conservação da qualidade na reciclagem.

Palavras chave: Embalagens de plástico, Responsabilidade alargada do produtor, Reciclagem, União Europeia

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List of Acronyms

CE	Circular Economy
DRS	Deposit-and-Refund System
GDP	Gross Domestic Product
HDPE	High-Density Polyethylene
MRF	Material Recovery Facilities
NIR	Near-Infrared
PAYT	Pay-As-You-Throw
PE	Polyethylene
PET	Polyethylene Terephthalate
PLA	Polylactic Acid
PP	Polypropylene
PPW	Plastic Packaging Waste
PRO	Producer Responsibility Organization
PVC	Polyvinyl Chloride

1

INTRODUCTION

1.1 Circular Economy

With the world's population and its per capita consumption steadily increasing, the environmental pressure intensifies, in the forms of resource depletion and waste generation. Globally, the amount of resources extracted went from 7 Gt to 89 Gt between 1900 and 2015, and the waste generated daily went from less than 0.3 Mt. in 1900 to more than 3.5 Mt. in 2010 (Aguilar-Hernandez et al., 2021; Hoornweg & Bhada-Tata, 2012). Looking at the future, governments of both developing and developed regions will continue prioritizing economic development, typically measured by GDP advancement. Considering the effects of population growth and GDP expansion together, studies predict that natural resource consumption will reach about 180% of the 1990s levels (Ayres, 2008). The trends manifest a precise reality: with the growing numbers of today, the "take, make, and dispose" model born with the Industrial Revolution will not be sustainable for long (Esposito et al., 2018). Without changing the path, obtaining the necessary resources will be extremely complicated for future generations, wherever dealing with polluted areas will be the normality. A shift in the paradigm is needed, and this shift could be the circular economy model.

While the circular economy (CE) concept is a crucial step in the direction of sustainable development, there is no universally valid definition of it (Ghisellini et al., 2016; Lieder & Rashid, 2016). CE is discussed by a large variety of stakeholders, from policymakers and businesses to academics, each with a different range of applications and therefore interpretations of the concept (Prieto-Sandoval et al., 2018). Kirchherr et al. (2017) explored a consistent amount of literature on the topic. They came up with the following definition: "*A circular economy describes an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes* […], *with the aim to accomplish*

sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations.".

1.2 The Waste Hierarchy Principle

A step to implement CE was made with the definition of the "waste hierarchy" principle, first introduced with the European Union's Waste Framework Directive of 1975. The waste hierarchy principle suggests an order of preference of actions to reduce or manage waste, with the objective of resource protection as well as the overall environmental, human health, economic, and social aspects. The order is the following: waste prevention, preparation for reuse, recycling, other recovery (e.g. energy), disposal (Directive 2008/98/EC, 2008).

The best practice according to the hierarchy, backed by scientific research (Brancoli & Bolton, 2019), is the reduction of the use of raw materials, which in turn prevents the creation of waste. This could be done by avoiding consumption or through the adoption of more efficient processes. If the waste production is unavoidable, reusing, recycling, and recovering value from it mitigates the environmental impact while also producing new economic opportunities (Nilsen, 2019). Trying to move from a linear to a circular production paradigm has various benefits: lower supply costs, cut waste management costs, create jobs and reduce carbon emissions are the most immediate ones (Mandych et al., 2023; Teekasap, 2018). Research shows that this switch could lead to a 48% reduction in CO_2 emissions, generate a net economic gain of EUR 1.8 trillion, and create two million additional jobs in the European Union (EU) by 2030 (Ellen MacArthur Foundation, 2015; European Commission, 2014). In general, it is accepted that CE is fundamental for the sustainable development of our society and plays an important role in many of the United Nations' Sustainable Development Goals (Berg et al., 2018).

It is easy to believe that the support for CE is widespread across businesses and legislators, but its on-the-ground implementation is still lagging behind (Ghisellini et al., 2016; Lacy & Rutqvist, 2016). The causes of this are multiple, as with any issue of such complexity. The great number of stakeholders involved automatically implies a difficulty in the alignment of their interests in one single direction and a greater difficulty in putting real measures into practice.

As mentioned, the most effective way to implement CE, and the related EU's number one priority, is waste prevention. However, in practice, to date little real improvement is being made on this topic, with

the focus of adopted measures being end-of-pipe waste management (Wilts, 2012). According to Eurostat data, between 2012 and 2018 (before the effects of the COVID-19 pandemic), the EU's domestic material consumption rose by 3.2% while the waste generated in weight rose by 4.3% (Eurostat, 2023a, 2023e). These figures show that the waste produced is growing even faster than the inputs of production, meaning the waste generated per unit of output actually rose and no tangible improvement was made in waste prevention.

Considering some of the main strategies for waste prevention this difficulty can be understood. The reduction at source strategy implies adopting principles such as eco-design, to minimize waste creation in the first place and promote efficiency in resource use (Singh & Sarkar, 2019). This is difficult to put into practice broadly since such methods are not necessarily generic and immediately applicable. They require some form of specific customization before use, which can obstacle their diffusion broadly and adoption (Knight & Jenkins, 2009). Another core strategy for waste prevention is the intensification of the product's use, which can be done through lifetime extension or product sharing among users, for example (European Commission, 2012). This measure is highly dependent on the person or company owning the goods, and their low acceptance of these practices is an almost insurmountable barrier to their diffusion (Hutner et al., 2017).

The second preferred action in the waste hierarchy is the preparation for reusing. The reuse of a no longer necessary product allows the saving of resources and avoids the management of waste with the minimum possible effort and the least complexity in operations. Besides reusing, operations like repair, refurbishing, remanufacturing, and repurposing are often considered on a similar level as different ways to retain a product in the economy for a longer time, therefore reducing waste generation (Morseletto, 2020).

Strategies to enhance repair and reuse practices are challenging to implement broadly since they are often specific to single product types and involve a multitude of actors (Cole, 2018). The rapid pace of technological advancement is a barrier to these practices. Functioning goods become obsolescent and are thrown away before their actual service life, and the throwaway mentality is indulged because of the swift decline of the value of products (Burns, 2010; Milios, 2016). From a regulator's perspective, it is difficult to promote and set targets for these strategies. The ideal objective would be to use products for their entire technical life, but already establishing a standard lifespan for a category of product is intrinsically complex (Wieser, 2016). According to Morseletto (2020), to facilitate reuse practices, the design phase is of great importance: products need to be designed with disassembly in mind, and ideally with standardized parts that can be singularly reused. As for waste prevention, to really incorporate the reuse

aspect of CE in the global value chains a profound change is needed, both from the consumer and the producer's side.

Recycling is the reprocessing of the recovered materials at the end of product life, returning them into the supply chain as secondary materials. With important changes in the design and materials of products, recycling could in theory cover the integrity of waste produced, however, it is not impact-free: it still is an energy-intensive option relying on physical, chemical, and/or mechanical processes (Cullen, 2017; Jensen et al., 2011; Worrell & Reuter, 2014). Despite being the third action in order of preference in the waste hierarchy, recycling is the strategy of CE development that is most covered by regulating agencies all over the world, usually in the form of targets for material recycling or quotas of secondary material incorporation (European Commission, 2015).

There is a reason for this. As mentioned in the previous paragraph, waste prevention and reusing measures have blurrier outlines and need more sophisticated incentives, and different types of products need profoundly different approaches. On the other hand, recycling targets are typically more straightforward and easier to track. Moreover, reduce and reuse practices can be slowed down since the application implies conflicts in economic interests among the stakeholders, while overall recycling was proven to have a positive effect on job creation and production, and to generate value (Bartl, 2014; Beccarello & Di Foggia, 2023).

From a technical standpoint, however, recycling presents certain challenges that justify favoring reduction and reuse. Recycling for its nature destroys a product's integrity and market value, and degrades the quality of materials. Some materials, like composites, are difficult or expensive to recycle, while the degradation of others limits the number of times they can be recycled, as for plastics. The numerous types and combinations of different materials in waste, and their contamination, require additional separation, selection, and washing steps that increase the resources needed for the recycling process. All these aspects are currently barriers to the idea of recycling as a way to ensure the perfect CE, with no input and output, since the material is losing its qualities along the value chain (Allwood, 2014; Haupt & Zschokke, 2017). Nevertheless, bearing this in mind, recycling is still crucial for sustainable waste management and the protection of resources. It reduces the need for landfills for a broader variety of waste and the related environmental issues, while also allowing for savings in energy consumption and reductions in greenhouse gas emissions.

Energy recovery and disposal, the last two actions in the waste hierarchy, should be avoided in a system aiming for CE. These techniques result in the loss of most of the waste's value, thereby limiting resource savings, and the byproducts of waste processing are released into the environment.

To reach optimal efficiency in recycling, profound changes in product design and waste management systems will also be needed; nevertheless, more than for waste prevention and reuse, for recycling some tangible progress was made in the last decades, and, at least in the EU, an effective roadmap of targets covering different section of waste production is being followed (European Commission, 2015). Due to the complexity of their implementation, waste prevention and reuse actions will take time to be deployed at a broad scale, and even then, there will be quantities of waste impossible to avoid. It is worth it to commit to building a functioning comprehensive recycling system: it is crucial to reduce the environmental impact of the world’s growing economy today, and it will be tomorrow to ensure an actual circular economic system.

2

LITERATURE REVIEW

2.1 Waste Generation and Management In the European Union

Excluding major mineral waste, in the EU 776.3 million tonnes of waste were generated in 2020 (Eurostat, 2023f). Major mineral waste is excluded because its management is typically less critical and its volumes can hide the trends of other sources. As can be seen in Figure 2.1, adapted from the 2023 Eurostat report, the overall quantity of waste between 2004 and 2020 has remained stable, however, there were changes in its source. Waste coming from manufacturing, energy production, and agriculture, forestry, and fishing saw major drops in this interval (respectively -31%, -47%, -67%), while waste from waste management and water treatment activities increased by 182% in the same period.

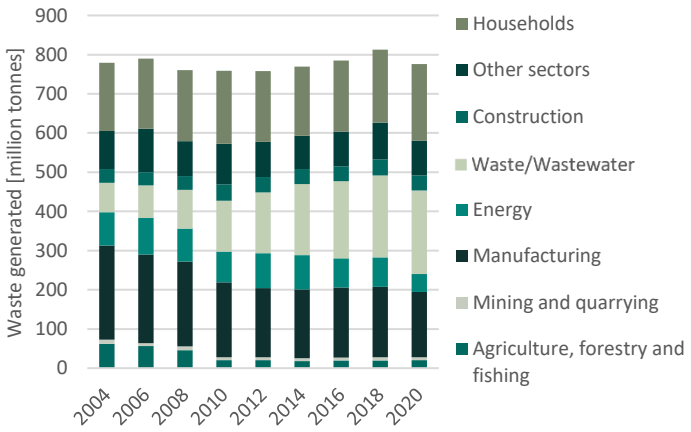

Figure 2.1: European Union's waste production data, excluding major mineral waste (Eurostat, 2023f)

Waste generation is moving from the energy and manufacturing sector to the waste treatment one, showing progress in the EU waste management: the occurrence of higher volumes of secondary waste means higher volumes go through recycling or other recovery activities. Looking at the big picture, in the 2010-2020 period, the EU's gross domestic product (GDP) per capita increased by 6% in real terms, while

waste production remained fairly stable (EEA, 2023). Economic growth is starting to show some signals of decoupling from waste generation.

To chase a CE model, greater efforts are needed for waste prevention and reuse. Some relevant progress instead was made for recycling, a crucial part of CE, as it is the most direct way of diverting waste from landfills and incineration, while creating jobs and promoting economic growth. In the 2010-2020 period, the overall recycling rate in the EU has been growing slowly but steadily, from 53% to 58% (excluding major mineral waste) (Eurostat, 2023c). EU policies like the Waste Framework Directive are having an impact on recycling, but still, a significant part of generated waste is incinerated or disposed in landfills. It must be noted that the recycling rate, as it is calculated before 2020, is an overestimation of the quantity actually recycled since it considers material sent to the recycling facilities, without accounting for material discarded from the process (Directive 94/62/EC, 1994).

The recycling rate varies significantly across EU countries and different material flows. For example, in 2020, the overall recycling rate was 37% in Romania and 87% in Belgium. For specific materials, the recycling rate in the EU was 38% for plastic packaging and 82% for cardboard and paper packaging. (Eurostat, 2023c, 2023d). Recycling is a sustainable technique of waste treatment and allows the saving of resources, it is crucial in a CE system to deal with unavoidable waste. The EU has still a way to go to reach its full recycling, especially if is considered the real recycling rate. Barriers are holding back the broader diffusion of recycling, but they are often specific to different materials or areas.

2.2 European Union's Plastic Packaging Waste Recycling

Plastic packaging waste (PPW) is a critical waste stream for a series of reasons. Firstly, the volume produced. Due to the versatility and low price of plastic materials, since the 1950s they have been taking over an increasing number of market segments. In 2020, in the EU27+3 (EU + UK, Norway, Switzerland), 53.9 Mt of plastics were processed, of which packaging was the biggest application with 39.5% of the total. The percentage even rises considering post-consumer plastic waste, of which 61% is packaging (PlasticsEurope, 2022). Plastic-based products are energy- and resource-demanding: to produce 1 kg of plastic between 62 and 108 MJ of energy are used, and plastic production worldwide is responsible for more than 4% of oil and gas consumption (Hossain et al., 2021). As for the environmental impact, plastic waste can be a severe threat if mismanaged, due to its persistence and effects. In particular, packaging usually has a short life cycle and is prone to dispersion in the environment, especially in the

oceans. The waste itself can harm wildlife, but its fragmentation in microplastics (<5 mm) allows it to enter into organisms and spread in the food chain, interacting with cells and molecules (Bucci et al., 2020). Additionally, PPW is composed of a variety of polymers often used in combination, that need careful separation for efficient recycling (Hahladakis & Iacovidou, 2018).

Because of the important volume, the criticalities in its treatment, and its impact on the environment this work focuses on the recycling of PPW.

2.2.1 Plastic Packaging Waste Recycling Data Framework

Per capita every EU citizen generated 35.92 kg of PPW in 2021, a 27% increase from 2005 (Eurostat, 2024). According to data from 2020, 46% of this was sent to recycling, 37% to energy recovery, and 17% to landfill. Figure 2.2 shows the evolution of these statistics, adapted from the 2022 PlasticsEurope report (PlasticsEurope, 2022).

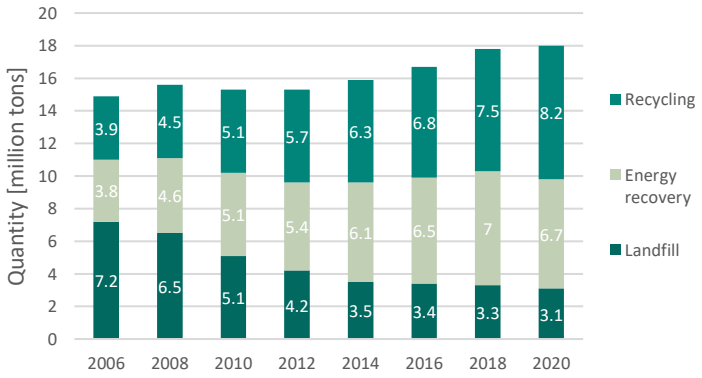

Figure 2.2: Evolution of plastic packaging waste management in the European Union (PlasticsEurope, 2022)

Since 2006, the quantity of PPW sent to recycling facilities has more than doubled, and the one sent to landfill has more than halved, but there is also a greater reliance on energy recovery, which is less efficient in the value conservation of materials. There is still a broad margin for improvement and to meet the targets of the European Commission the growth rate of recycling should almost double (Directive 2018/852, 2018).

The indicator to assess the recycling rate as mentioned above considers the material entering the recycling facilities. The material sent to recycling is not all transformed into new products. There are losses in the sorting and the recycling step, due to the presence of rejects (material not targeted by the selection) and by limited efficiency of the processes; these losses end up incinerated or landfilled. This index

therefore doesn't effectively depict the progress of the industry, since it ignores a relevant flow of rejected material, and relying exclusively on it can lead to wrong premises for decision-making (Maio & Rem, 2015). For this reason, the 2018 amendment to the Packaging and Packaging Waste Directive issues that starting from the 2020 data the recycling rate will be calculated as the ratio between outputs of recycling plants (instead of material sent to recycling) and total packaging waste generated (Directive 2018/852, 2018). With the updated calculation method, according to Eurostat the recycling rate for PPW in 2020 was 37.6% (instead of 46%), growing in 2021 to 39.7% (Eurostat, 2023b).

2.2.2 Recycling Rates and Targets In the European Union

Figure 2.3 depicts the PPW recycling rates of EU countries for 2020, according to the new calculation method of Directive 2018/852. The graph is an elaboration of Eurostat data (Eurostat, 2023b).

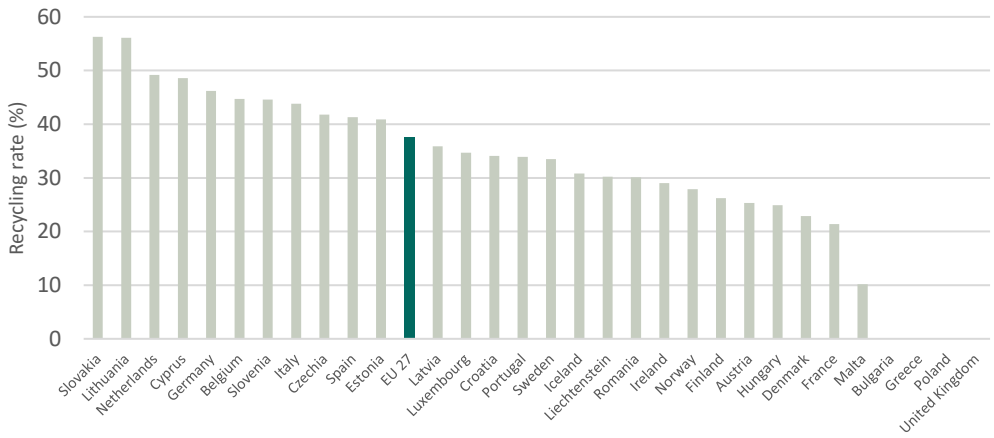

Figure 2.3: 2020 plastic packaging waste recycling rates of European Union's countries (Eurostat, 2023b)

As shown, there is an important variation among the countries, from values just above 20% for France and Denmark to values higher than 50% for Slovakia and Lithuania. There are remarkable differences also in the trends of the recycling rates: some countries, like the Baltics, have had a great improvement compared to 2012 while others have worsened their performances. Countries like Denmark, Sweden, and Czechia saw drops of around 20% in 2020 due to the change in the calculation method (Eurostat, 2023b).

In its push towards a Circular Economy, the EU addresses PPW management in different measures. The key directive is the Packaging and Packaging Waste Directive, which aims to prevent the generation of packaging waste and minimize its environmental impact (Directive 94/62/EC, 1994). In its latest amendment, Directive 2018/852, the recycling rate calculation method is updated and the following targets for

PPW are set: 50% recycling rate by the end of 2025 and 55% by the end of 2030 (Directive 2018/852, 2018).
Directive 2019/904 focuses on single-use plastics. Concerning recycling, it covers plastic bottles with volume under 3 liters. From the beginning of 2025, PET bottles must have 25% recycled content, and from 2030 every plastic bottle must have 30% recycled content. Furthermore, the collection rate of these bottles should be 77% by 2025 and 90% by 2029 (Directive 2019/904, 2019).

2.3 Factors Influencing Plastic Packaging Waste Recycling

Recycling PPW is an important objective of the EU Circular Economy and EU Green Deal, due to its impact and the criticality of its treatment. Other packaging wastes, like paper and cardboard or glass, don't present the same level of difficulties: their recycling rates in 2021 in the EU were 82.5% and 74.9% respectively (Eurostat, 2023d). The root criticality of PPW recycling is its heterogeneous composition. The waste stream is composed of various polymers in different product types and designs, often with some degree of contamination. As a result, it is complicated to recycle without downgrading the initial value and quality (Eriksen & Astrup, 2019).

The different polymers must be separated from the overall stream to maintain value in the PPW recycling process. Contamination, even at low levels, can cause severe deterioration in the material's macroscopic properties. For example, the presence of small quantities of PVC in PET is enough for the formation of acids that cause the recycled material to become brittle and change in color (Paci & La Mantia, 1999). Even products made with the same polymer can have different mechanical and chemical properties, like HDPE bottles produced from blow moulding and caps from injection moulding: the materials have different fluidity levels so that if mixed they may not be suitable for remanufacturing anymore (Wood, 1997). The failure to separate material with differences in other characteristics, like color or food grade, also involves the loss of quality and value.

Also the presence of unwanted chemicals is a source of contamination in PPW. These can be intentionally added to the material, like fillers, plasticizers, and other additives, or they can appear unintentionally, like degradation products or substances migrated from food (Bradley & Coulier, 2007). Meng et al. (2023) conducted a review of the existing literature studying chemicals present in plastic packaging and found that at least 10,259 different substances were detected, with different levels of hazardousness. The accumulation of chemicals in recycled products is affecting both their re-processability and their safety, all the more so since there is no existing publicly available source of all chemicals associated

with plastic packaging and their effect (Groh et al., 2019). At the same time, the presence of additives associated with different properties can prevent the control of the final product's characteristics, such as color or food-grade status.

Being able to correctly separate the different materials and waste types in PPW is critical to retaining its value. A homogeneous waste stream allows the replacement of virgin material even for top-grade products, saving resources while making recycling more economically viable. Nevertheless, it is important to highlight that recycling deteriorates the properties of a plastic product, hindering a closed-loop system. Degradation is mainly caused by the thermo-mechanical stress of reprocessing, the exposition to UV light in the product's lifetime, or the unavoided contaminations present in the waste (Ragaert et al., 2017). However, these problems will be more relevant when a more efficient recycling system will be in practice, allowing the same material to be recycled multiple times. In this stage, especially for short-lifetime products like packaging, separation is a critical step for environmentally sustainable waste management and higher efficiency resource use.

2.3.1 Overview of the Value Chain of Plastic Packaging Recycling

This section will focus on the difficulties the industry players are facing in putting into practice the best available techniques of PPW recycling. To do so it is necessary to briefly describe the stages of the typical value chain from the waste collection to its reprocessing.

There are three main groups of players, respectively responsible for the collection, the sorting, and the reprocessing. The first ones are organizations that arrange the pick-up of the waste, like municipal waste management companies with household waste, or organizations that receive waste from privates and companies, as a private waste management company can do. For mixed waste streams (like household “light packaging”), the waste enters one of the material recovery facilities (MRF), also referred to as sorting plants, where specific waste types are targeted, isolated from the rest, and compacted. In a MRF for example PET bottles are isolated from the material flow and baled together. This material is sent to the next player, the recycler, who from the waste produces secondary raw materials in the form of flakes, granules, or pellets (Antonopoulos et al., 2021). The feedstock produced by the recycler will ultimately be used by the plastic converter to manufacture a finished product. These players are not always so well-defined, this is a simplification of the general system. It is common to find a sorting plant producing flakes or a collector autonomously doing some degree of sorting, while there can be brokers and intermediaries that group and trade material within the steps of the value chain (Silva de Souza Lima Cano et al., 2022).

A central element of the EU's waste management policy are extended producer responsibility (EPR) schemes, defined in Article 13 of the EU Directive 2018/851 as "a set of measures taken by Member States to ensure that producers of products bear financial responsibility or financial and organizational responsibility for the management of the waste stage of a product's life cycle". Member states are required to set up systems for the collection and reuse or recycling of used packaging, this obligation is often delegated to the producers or importers through EPR schemes. In these systems, the producer or importer pays a material-specific fee for the packaging products placed on the national market, which covers all or a part of the cost of the collection and sorting of its waste (Europen, 2015). EPR schemes differ per member state, but they have a central role in the recycling value chain.

2.3.2 Plastic Packaging Design

The design of a packaging product controls to a relevant extent how it will be recycled. The variety of materials used is an important barrier to the separation of the waste, and therefore to the efficiency of the recycling process. Some applications require a combination of properties that can be achieved most easily by combining different materials, like some food packaging that needs to be physically resistant while being also safe and hygienic, but in general designing products with their recyclability in mind would have positive effects on the quantity and quality of the material recovered.

Roosen et al. investigated the composition of the most common plastic packaging products in household waste, visible in Figure 2.4 (Roosen et al., 2020). PPW is typically composed of multiple-polymer products: even when it is possible to isolate a single waste stream its composition is not homogeneous; for sorted PET bottles for example the contamination is around 20%, mainly of the PE cap and PP label. Material like the PE of the caps, although it could be recycled with a positive value, ends up in the residual fraction sent to incineration or landfill as it is often not targeted by selection. These products risk also being sorted in the wrong stream if, for example, a standard near-infrared (NIR) scanner detects the polymer of the label instead of the main one (Eriksen & Astrup, 2019).

A product design that maximizes material recovery and sorting efficiency should prioritize the use of a single polymer. If multiple polymers are necessary, they should be designed for easy separation, and public awareness campaigns should be implemented to encourage citizens to separate polymers before disposal (Eriksen & Astrup, 2019). Additionally, black packaging products should be avoided since these in most cases cannot be detected by NIR scanners and end up in the residual fraction, regardless of the polymer (Brunner et al., 2015).

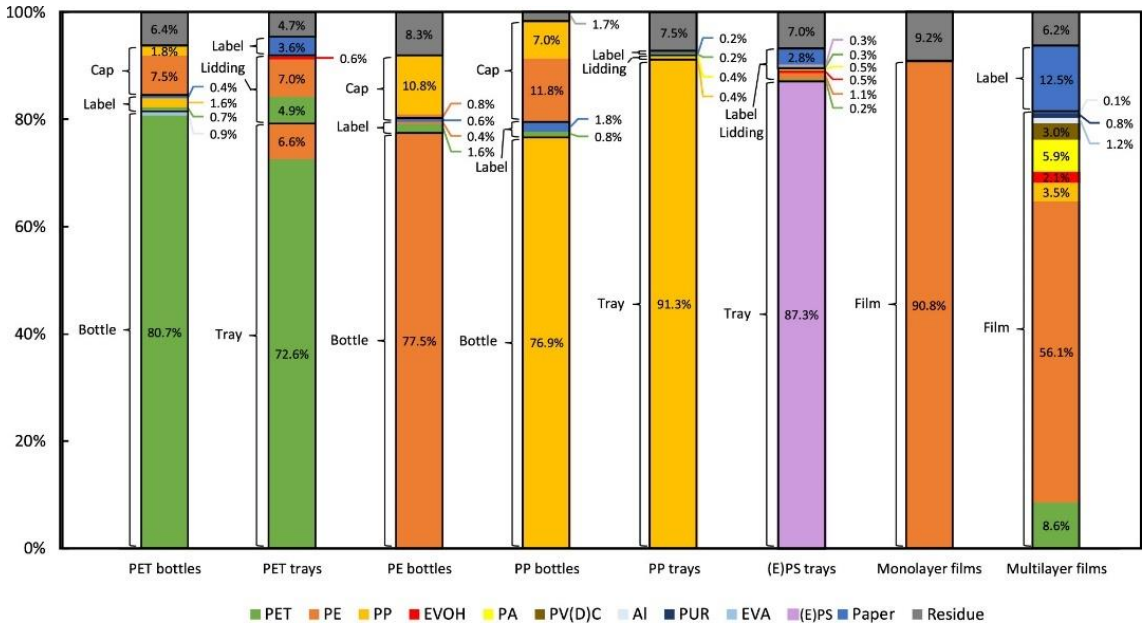

Figure 2.4: Polymer composition of different plastic packaging waste (Roosen et al., 2020)

A way to incentivize design for recyclability is the modulation of the EPR fee, meaning that producers or importers of more sustainably designed products would pay a lower contribution to put them on the market (Laubinger et al., 2021). All EPR schemes include some basic fee modulation usually dependent on the material, but a few schemes like CONAI in Italy and CITEO in France already have a more advanced eco-modulation system, by which for example non-sortable products or products with additives that disrupt recycling have a higher fee (Watkins et al., 2017).

2.3.3 Waste Collection

How PPW is collected determines how the material enters the sorting facility. For municipal waste, the main possible system differences are two: whether the waste stream is collected singularly, with other selected streams (e.g. with other lightweight packaging), or no waste stream is isolated (mixed collection), and how this is collected, the most frequent options being door-to-door (also known as curbside) collection directly at the households and in collection points, where one or more containers are available for a certain road or area (Hahladakis et al., 2018).

Given the challenge of sorting PPW in contamination-free streams, without separate collection it is difficult to recycle relevant quantities of material while retaining quality. In numerous cases, the introduction of separate collection led to a net increase in the recycling rate (Cimpan et al., 2015; Paleari et al., 2014; Zero Waste Europe). Also implementing door-to-door collection has proven beneficial for the

quality and quantity of PPW recovered, due to a greater responsibilization of the citizens, however, this option could be restricted by space constraints in cities and needs financial investments (Jenkins et al., 2003; Paleari et al., 2014; Seyring et al., 2016).

Deposit-refund systems (DRS) are an instrument to reach higher collection rates, as the 90% for plastic bottles mandated by 2029 (Directive 2019/904, 2019). When buying a product covered by a DRS the consumer would pay also a deposit, which is refunded when s/he delivers the packaging waste to the appropriate counter. DRSs are a way to incentivize the consumer to correctly separate and maintain a waste flow as clear as possible from contaminations. Due to the high volume and market value, DRS for PPW are most frequently targeting PET bottles, with the effect of a reduction in contaminations and a better grade of the recycled flake (Snell et al., 2017). At the moment 13 EU countries have a DRS in place for beverage packaging, and more are being developed (Tugran, 2023).

Another tool for incentivizing virtuous disposal behaviors of citizens is the Pay-as-you-throw (PAYT) scheme, for which households are not charged with a flat waste management tax but by a variable tax according to the waste generated (Reichenbach, 2008). PAYT is usually applied to mixed residual waste so that a careful separation process is more convenient for the user. A study on European capitals shows that cities with a PAYT scheme have a collection rate 18% higher than cities with a flat tax only (Seyring et al., 2016).

2.3.4 Sorting

The sorting step of MRFs has a crucial role in the recycling process, as it determines the quality of the material going to reprocessing and the quantity of PPW diverted from incineration or landfill. A study analyzing 84 different PPW recovery scenarios reported that MRFs efficiency is the single most important parameter for resource recovery efficiency (Eriksen et al., 2019).

Across the EU, there is a wide variation of MRF efficiencies. Antonopoulos et al. (2021) conducted a study on existing plants, based on direct surveys and selected literature. As an analysis parameter they used the sorting rate, calculated as the ratio between the plant's output of target polymer, including impurities (e.g. bales of PET bottles with caps and labels), and the total input material. They found that sorting rates in the EU varied from 45% to 97% for PET, 13-95% for HDPE, and 31-80% for PP. According to the plant operators, this is due mostly to technological limitations of the sorting line and quality of the input material. If the latter cannot be controlled by them, plant operators can invest to improve the technical yield. Adding lines with dedicated NIR detectors can increase the number of

targeted polymers, and measures like improving the speed of the bag splitter or the width of the conveyor belt can improve the final yield (Mastellone et al., 2017).

The decision to invest in equipment to improve the sorting efficiency depends essentially on the market demand and prices of recyclates. For example, regarding PET at the moment most plants recover only clear or translucent material, and even if the technology to separate colored PET exists the investment is often not justified, since the material itself is less valuable and its market is more difficult to find (Hahladakis & Iacovidou, 2018). Another aspect that makes MRF operators think twice before investing in their plants is the changing regulations. Technological progress allows sorting purity levels of virtually 99.9%, but investing in a technology to separate for example multi-layer PET trays from the PET stream, when the commercialization of these might be banned in some years, can lack financial sense. The same is true for valuable PPW that doesn't have sufficiently high volumes, like polyactic acid (PLA), whose quantities may not justify the investment to separate it (PAC Next, 2014; WMW, 2015).

Although improvements in the eco-design of packaging and waste collection can have a determinant effect on sorting efficiency, the production of some amounts of mixed plastic or non-targeted plastic cannot be avoided (Brouwer et al., 2020). To incentivize the MRFs to recover the maximum value possible from the waste stream, additional markets should develop even for these lower-value fractions. An option for these fractions could be chemical recycling. Several European petrochemical companies are establishing facilities to process sorted mixed plastics to obtain pyrolysis oil that can be refined and commercialized (OMV Group, 2018; Renasci, 2024; Shell, 2019). This route can stimulate the demand and therefore the recycling rate for these materials, however, it is still unclear if this route should be considered at the same level as mechanical recycling if the final use of the resource is not known, especially for cases where the obtained pyrolysis oil is finally used for energy production (Picuno et al., 2021).

2.3.5 Reprocessing

PPW recycling yields significant environmental benefits only when it replaces virgin plastic, meaning it avoids the need for oil and raw materials required to produce the same product, rather than being downcycled into lower-value applications (Lazarevic et al., 2010). Member states are rushing to meet EU recycling targets, mainly addressing the quantity of material recycled to the disadvantage of its quality, which instead is a crucial factor (Ragossnig & Schneider, 2017).

If MRF operators need demand for lower value fractions to justify the investment for their sorting, plastic converters, the final buyers of recycled material, complain that the quality is too low for broader use. Polymer Comply Europe (2019) surveyed 376 converters in 21 European countries and found that the main reasons preventing them from using recycled plastic material are poor quality and instability of the supply. Other reasons are that the product specifications do not allow or complicate their use (e.g. food grade approval), that the material properties vary from lot to lot, and the impossibility of fulfilling the esthetic requirements of their clients (e.g. color). When asked about possible solutions to improve the quality of recyclates, 76% of them responded "improve the collection and sorting of plastic waste" and 53% to "invest in better recycling technologies by plastic recyclers", however, 78% of the respondents stated that the price is their main incentive to use recyclates instead of virgin plastic.

As stated above, the sorters and recyclers invest in more advanced equipment only if the recovered fraction is valuable enough to justify the expense. The quantity and quality of the PPW recycled fraction therefore is strongly dependent on market factors. Measures like the compulsory incorporation of recycled material in new packaging products can increase the value of recyclates, and a broader simplification and standardization of materials and designs may introduce economy of scale dynamics for the sorters and recyclers, allowing lower costs and more homogeneity and a higher chance to compete with the cheap virgin feedstock (Milios et al., 2018).

2.4 Knowledge Gap

As member states are implementing not harmonized and occasionally conflicting strategies to reach the recycling goals, it is still not completely clear from a research perspective how these different measures contribute to the functioning of the recycling value chain, especially concerning the differences in the modes of application of the EPR principle (Ahlers et al., 2021; Beccarello & Di Foggia, 2023; Pruess, 2023). Additionally, there are very few studies assessing how recycling professionals perceive the current system and whether all relevant stakeholders are adequately involved in the decision-making. Understanding the opinions and experiences of these professionals is crucial to ensure that the recycling system addresses issues across the entire value chain, rather than just focusing on the most represented classes.

These gaps in the literature indicate a need for more comprehensive research in the EU plastic packaging recycling environment, that delves into the operational characteristics of its value chain and takes into account the actors that compose it.

3

METHODOLOGY

3.1 Research Framework

3.1.1 Research Objectives

The PPW recycling value chain comprehends numerous stakeholders each with its own interests. Reaching the recycling goals requires a strong collaboration between all of them coupled with a targeted and firm push from legislators. Today, the common ground between industry players and their channel to the regulating agencies is the EPR system. EPR schemes are a powerful tool to promote the most effective waste management solutions and a healthy and robust waste-to-resource value chain. However, these schemes differ greatly between member states, since a complete EU regulatory framework is still lacking, and stakeholders are concerned that this complexity in the EPR landscape can ultimately go against the development of recycling (Ahlers et al., 2021).

With these premises, the objective of this research is twofold: (i) to analyze the differences in plastic packaging EPR schemes in the EU and how the different characteristics impact the functioning and the improvement potential of the recycling value chain, and (ii) to perform an exploratory research on how these differences are perceived by the sector's professionals.

In this way, this work aims to shed some light on the current functioning of the plastic packaging recycling process and evaluate the approval of sector professionals regarding the system's features and the EU's development strategy. As the perception of recycling professionals is a topic underrepresented in scientific literature, it does not have prior research outcomes for reference. The exploratory nature of this study aims to identify potential patterns in the responses that could guide future targeted research. An efficient and robust recycling system requires addressing all issues across the value chain and involving all stakeholders in the process. By analyzing the current system, this research should identify specific areas for further studies in this direction, focusing on the system's characteristics and potential improvements suggested by professionals.

3.1.2 Research Structure

The results chapter is divided into two parts following the two research objectives. The first part is a qualitative analysis of the EPR schemes for plastic packaging in the EU. The core design features and possible differences in the schemes are presented, and two case studies are studied in detail to show in practice what these differences imply. The examples chosen are the EPR systems of Italy and Germany. These two systems are two of the most different in the EU, and they are representative in the sense that features of either one or the other are often present in the schemes of most of the other Member States. Additionally, these two systems are very relevant in terms of volume of waste managed and efficiency of the recycling process. The following sub-chapters will present an overview of the features of EPR schemes in the Member States and comment, in general, what are the effects and implications of these different features.

The second part of the research uses a survey to investigate the opinions of the sector professionals on the features of EPR schemes and on the measures for the future. The aim is to highlight patterns in the responses, therefore the results are analyzed both altogether and divided into groups according to the respondents' role in recycling and the structure of the EPR scheme they operate in. Finally, these opinions will be confronted with the current and discussed measures concerning EPR schemes and the EU strategies to enhance plastic packaging recycling.

3.2 Methodological Approach

3.2.1 Qualitative Analysis: Extended Producer Responsibility Schemes

A series of sources were consulted to navigate the structure of EPR schemes of the EU-27 Member States, such as documents and factsheets from the EPR organizations, reports commissioned by the EU, the related laws from single member states, and in a lower share scientific literature and personal communication with operators of the sector. The differences that characterize the most the EPR schemes are the market structure of the EPR system, the allocation of financial and operational responsibility, and the implementation of the eco-modulation of fees, as were identified in the studies of Gupt & Sahay (2015) and Preuss (2023). These are the core characteristics that most influence the overall functioning of the EPR scheme, and are the ones analyzed in this study. The sources for the information on single EPR systems, used in this research, are reported in Annex A.

3.2.2 Survey: Stakeholders' Opinion

To gather the stakeholders' opinion an online questionnaire was developed on the Microsoft Forms platform, translated into three languages (English, Italian, and Portuguese). The questionnaire is composed of five questions (see Annex B).

The first two are about the role in the recycling value chain (e.g. collection, sorting, EPR) and the country of operation. In Question 3, respondents were asked to rank five measures according to the importance they attach to the effect that these measures can have on plastic packaging recycling efficiency. The measures were intended to apply in a fairly efficient waste management system, meaning that it already puts into practice measures like door-to-door separate collection and already has a functioning EPR scheme. The options were the following, taken from good practices among EU systems: (i) recycling targets not only by quantity but also by quality (like % of material that substitutes the equivalent virgin one); (ii) more packaging products covered by compulsory inclusion of recycled material (like 25% for PET bottles); (iii) more citizenship awareness campaigns; (iv) eco-modulation of EPR fees, meaning higher contribution for less recyclable packaging such as multi-material or containing PVC, and; (v) deposit and refund schemes compulsory for a broader range of products. There was also another option, "Other", where the participants could add a measure using Question 4.

In Question 5, respondents were asked to evaluate, on a 5-point Likert scale (from very poor to very good), the effect of some features, discussed in literature or currently evaluated by legislators, on the overall recycling efficiency. The features were: (i) requirement for all actors in the supply chain to keep track of processed material, in order to have accessible data on actual overall performance; (ii) an eco-modulation system for EPR contribution that rewards packaging with higher recycling rates; (iii) allocate EPR funding for collection and sorting partly according to the quality of the material; (iv) single European market for secondary materials coming from EPR schemes, with a single platform and a single accreditation procedure, and; (v) open competition in EPR organizations, which may be for-profit.

The questionnaire, which was active from the 21st to the 31st of May 2024, was shared online through direct emails to the contacts found manually through web search (e.g. single EPR organizations, single waste management companies) and to contacts obtained from the ENF Plastic directory, in the sections "Plastic Materials Recovery Facilities" and "Plastic Recycling Plants", limited to EU countries (ENF Plastic, 2024). In total, invitations to participate in the questionnaire were sent to 3,124 contacts, but only 74 responses were received (2.4%).

To meet the proposed objective of assessing whether the existence of one or more ERP organizations influences the opinion of respondents, the sample was divided into two groups. PRO 1 group, composed of respondents operating in countries with a single EPR organization (monopoly), and PRO 2 group, for those operating in countries with more than one organization (competition). In group PRO 1 are respondents from Belgium, Cyprus, the Czech Republic, Greece, Hungary, Ireland, Italy, the Netherlands, and Spain, for a total of 57 respondents. In PRO 2 are those from Bulgaria, Estonia, France, Germany, Portugal, Romania, Slovakia, Sweden, and the United Kingdom, for a total of 16 respondents. The response from Turkey was not considered since the EPR scheme has been inactive since 2019.

Due to the large disproportionality in the size of the two groups, it was not possible to assess whether the differences between the two groups are statistically significant, therefore, only a descriptive analysis of the results was carried out, presenting and discussing the frequency distribution obtained for each response category.

4

RESULTS AND DISCUSSION

4.1 Extended Producer Responsibility Schemes in the European Union

4.1.1 Design Features of Extended Producer Responsibility Schemes

The EPR concept was developed and first introduced for packaging in the 1990s. The OECD defines it as "a policy approach that makes producers responsible for their products along the entire lifecycle, including at the post-consumer stage". The responsibility (operational and/or financial, full or partial) shifts from the public sector to the producers, and the producers should be incentivized to include environmental considerations in product design (OECD, 2024).

EPR schemes are a pillar of the EU strategy for increasing resource efficiency and circular product design. Directive 2018/851 states: "Extended producer responsibility schemes form an essential part of efficient waste management", and Directive 2018/852 requires that EPR schemes must be established for all packaging by the end of 2024 (Directive 2018/851; Directive 2018/852). It is important to note that EPR is just one of the tools available for policymakers to enhance recycling efficiency, however, it is a common ground between the industry stakeholders and gives an important opportunity of collaboration and tackling challenges in a holistic way.

Directive 2018/851 defines the general minimum requirements for EPR schemes, but, to this day, specific EU guidelines for the implementation are still lacking. Without these, member states have been implementing different national legislation resulting in profoundly different schemes, both in organization and performance. The increasing complexity of the EPR landscape, and the discrepancies between countries, can create inefficiencies in the overall EU recycling system and be a barrier to a collaborative and effective network of stakeholders. To try to harmonize the EU framework, or to assist member states

in implementing the new requirements, it is important to understand the conditions under which a certain EPR scheme can perform well.

An important player to define in EPR is the Producer Responsibility Organization (PRO). These organizations finance and/or operate the collection and sorting of waste on behalf of producers, without them having to individually implement EPR.

At the initial stage of diffusion of the EPR concept, systems were relatively simple and often transferred between countries without alteration. Over time, however, these systems began to differ due to increased complexity, shifts in market dynamics, and the necessity to tailor them to local regulations and infrastructures (Pruess, 2023). Among these distinct features, the following are the core differences that characterize the most the EPR systems:

- *monopoly/competition*: whether the producers can choose between more PROs, or there is only one player in the country market. In competitive scenarios, PROs can operate on a for-profit basis, or a combination of for-profit and non-profit models. A "clearinghouse" is instituted in some competitive markets, serving as a third-party agency responsible for regulation and oversight.
- *distribution of financial and physical/operational responsibility*: in most EPR systems the PROs take full financial responsibility for collection and sorting. The operational responsibility and the physical ownership of the waste can be divided in different ways along the value chain. In some countries, the consumer also has a share of financial responsibility through deposit-refund schemes.
- e*co-modulation of fees*: some EPR schemes are implementing eco-modulation of fees with a bonus/malus system. Others are putting in place other types of fee modulation.

The European EPR landscape is extremely diverse: not a single pair of countries has the exact same scheme. It is useful to analyze some systems as examples to clarify the nature and the implications of these differences. Two representative systems are Germany and Italy. Both countries have effective PPW recycling systems (with rates exceeding 40%) and are significant in terms of both area and population, but they implement the EPR in a profoundly different way.

4.1.2 Case Study: Italy

The Italian PRO is the national packaging consortium, called CONAI. It was born in 1997, with a legislative decree of the Italian government to implement the European Packaging and Packaging Waste Directive. CONAI is by law established as a non-profit private consortium, with the task of managing the recovery and recycling of packaging and pursuing the targets set by the EU. All packaging producers and users (meaning producers/importers of packaging and companies using it for their products) are obliged to be part of the consortium, which is divided into six branches according to the material, COREPLA being the one for plastic. A ministerial decree defines the statute of CONAI and the line of action through targets but leaves companies free to decide on the modalities of action. The decree "concerns all packaging and all economic operators", with the specific goal of implementing a unitary system able to represent the entire nation (CONAI, 2017; Decreto Legislativo 22/1997).

Packaging producers and users pay COREPLA a fee for the products they put on the market, which will be used to finance the collection, the sorting, and if necessary the recycling. The physical responsibility of collection and recovery is shared among the PRO, industry, and local authorities. The collection of household waste must be organized by the public administration, in an efficient and economic way. Every five years CONAI stipulates an agreement with ANCI, the Italian association of municipalities, dictating compensation fees, methods, and procedures. Key parameters of the agreement are the compensation fee in €/t for the quantity of PPW collected and the entity of fee variation depending on the presence of impurities. The quality of the material collected by municipalities is graded with a letter system, A-grade being the best, and the contribution is lower for material with a higher presence of impurities. The agreement is voluntary and municipalities can opt to sell directly to recyclers without contribution from CONAI. In 2023, 92% of municipalities covering 96% of the population accepted the conditions of the agreement and received the contributions of the consortium (CONAI, 2017a; COREPLA, 2024a). Since the contribution fees depend on the quantity and quality of the material collected, for some operators covering less densely populated areas, or areas with a lower participation of the population, the CONAI contribution can be insufficient to finance the operations and some public funding is necessary. In order to sell the collected waste outside the consortium there must be some recovery facility not affiliated with CONAI accepting the material at a reasonable distance, which is not always the case, and still exposes the collectors to the material price oscillations (Personal Communication, 2024).

Regarding secondary and tertiary packaging, it is typically collected by independent companies operating outside the CONAI system. However, these companies work under an agreement with the consortium and are required to report the quantities they handle. Industrial and commercial activities that want

to process their packaging waste independently can also confer it to one of the centers of the CONAI network free of charge, except for the transport (CONAI, 2017a).

The sorting step is conducted by third-party MRFs contracted by COREPLA, which for a prefixed contribution separate the material according to the consortium's standard. The material in bales is then sold to recyclers through auctions (COREPLA, 2024c).

Starting from 2018 COREPLA introduced an eco-modulation system of the producer's fees. The fees are divided into 9 classes based on the nature of the waste (industrial or household) and its sortability, recyclability, and the existence of a market for the recyclate. For example, clear PET bottles with a covering label that is punched for easy removal are in class B1.2 (233 €/t), but clear PET bottles with covering label not punched are in class B2.2 (589 €/t). Furthermore, a dedicated technical committee studies the products and adjusts the categories to the evolution of the sorting and recycling technologies available to the stakeholders. For example, in the latest update of the classes, due to improving sorting technologies PP bottles with covering labels went from class B2.2 to B2.1, so the fee went from 589 €/t to 441 €/t. The fee modulation is designed to maintain equivalence in the total level of contributions, and gradually increase the difference in fees (CONAI, 2017b; COREPLA, 2024b).

4.1.3 Case Study: Germany

The EPR scheme for packaging in Germany was established in 1991, starting as a monopolistic scheme with one single non-profit PRO. The system opened to competition in 2003, and several for-profit PROs entered the market. In 2020, there were 9 different active PROs with the market share as shown in Figure 4.1, adapted from Ahlers et al. (2021).

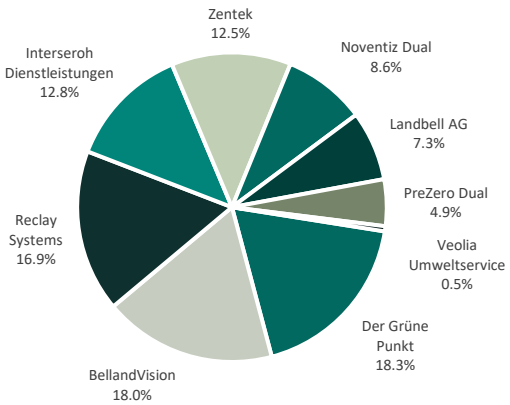

Figure 4.1: Market share of German producer responsibility organizations, by volume of products (Ahlers et al., 2021)

The German EPR system for plastic packaging covers household waste and waste from retail, as well as shipping and service packaging. Most beverage containers instead are covered by DRS. The PROs have financial and physical responsibility over the waste, they finance and organize the collection, sorting, and recycling process maintaining ownership over the material in every moment. The collection is organized jointly by the PROs, which negotiate with waste management agencies (private or municipal) that will provide the collection service in a certain area for a three-year contract. The waste volumes and the collection costs are divided between the single PROs according to the share of products on the market they cover. The following sorting and recycling is organized and operated by PROs individually. At all stages of the process, the PROs have to collect data on the quantities of PPW treated that will be reported on a dedicated platform (Ahlers et al., 2021; Bünemann & Bartnik, 2021; VerpackG, 2021). The PROs founded a joint body, the "Gemeinsame Stelle der dualen Systeme Deutschlands", that coordinates activities and assures the respect of competition in the negotiations of collection services. Furthermore, the Central Agency Packaging Register (ZSVR) was created in 2019, a public register where the PROs have to participate, to monitor and verify data on material flows. The ZSVR works also as a clearinghouse and organizes regular audits of the sorting and treatment plant, limiting the risk of improper activities by the PROs.

The shift from a monopoly to a competitive landscape of the German EPR system had a great impact on the cost of waste management. The overall cost charged by operators for collection, sorting, and recovery fell by 54% between 2003, the year of the market shift, and 2011, going from 1777 to 824 million euros (Bundeskartellamt, 2012). With more than one for-profit organization competing for the participation of producers, naturally the operating costs were optimized to maximize profit and offer more advantageous fees. However, certain measures had to be introduced to address irregularities in the reporting process.

On the other hand, the fragmented nature of the system can be a barrier to comprehensive joint action. Currently, there are no central harmonized criteria for fee modulation but the Packaging Act requires PROs to provide financial incentives individually (VerpackG, 2021). Concerning awareness campaigns, these became increasingly neglected after the market shift and the rate of waste mismanagement by citizens grew (Ahlers et al., 2021).

4.1.4 Overview of European Union's Extended Producer Responsibility Schemes

Following the European Directive 2018/852, from 2025 all EU member states must have an EPR system for plastic packaging in place. The last three countries that still didn't have one were Denmark, Hungary, and Croatia, which had only a governmental tax for producers and no compliance scheme. Hungary introduced an EPR scheme in July 2023, Denmark will do so by the beginning of 2025, and as for Croatia it was not possible to find updated information (Barsony, 2023, 2024).

The core difference among plastic packaging EPR schemes is the PRO market structure. Nine countries have a monopoly setup with a single non-profit organization, and 16 countries have a competitive market structure with only for-profit PROs (7) or both for-profit and non-profit players (9). In some countries, like Italy, the non-profit monopoly is required by law, but in others, competition would potentially be allowed. In Figure 4.2a is the map of the market structure of EU countries.

As stated above, another major difference is the allocation of financial and operational responsibility for waste management. To create separated categories, here three options are used:

- mainly financial, meaning the PROs pay for the waste management but have limited control over the operations, like in Spain, where collection and sorting are done by local authorities which then sell the separated waste to the PRO;
- financial and partially operational, like in Italy where local authorities organize and own the waste during the collection, and the PRO organizes and owns it during the sorting;
- financial and fully operational, as for Germany, where the PROs organize the whole process and maintain ownership of the waste.

With this distinction, 4 countries have a mainly financial responsibility system, 13 financial and partially operational, and 7 financial and fully operational, as in Figure 4.2b.

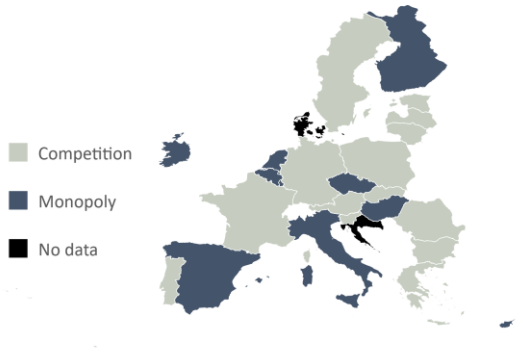

Figure 4.2a: Market structure of European Union's plastic packaging extended producer responsibility schemes

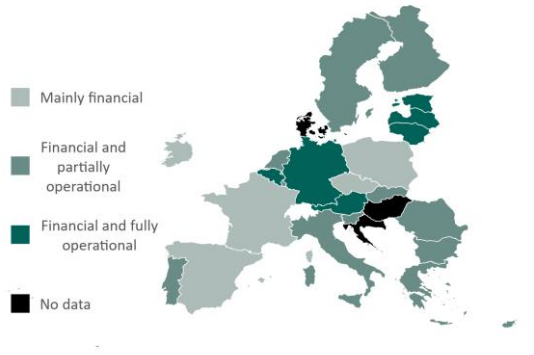

Figure 4.2b: Responsibility of plastic packaging producer responsibility organizations in the European Union

In countries where the monopoly in the PRO is not established by law, new competitors may emerge and change the market structure. This happened in Germany in 2003 but also more recently, like in 2016 in France with the creation of Léko and in Portugal with Novo Verde. As a common thread, with important exceptions, in multi-PRO systems the organizations have a higher share of operational control and vice versa.

Concerning eco-modulation of PPW fees, the first two PROs to implement such measure were CITEO in France in 2013 and CONAI in Italy in 2018. CITEO uses a bonus/malus system based on the category fee, according to the recyclability, sortability, and recycled content. For example, bottles in colored PE have a basic fee of 0.3526 €/kg, but if the product is composed of 50% recycled material there is a discount of 30%, while if the bottle is colored in black there is a 50% penalty (CITEO, 2020). These values are referred to 2021, since after that CITEO stopped publishing its fees due to competition. As mentioned in paragraph 4.1.2, the Italian eco-modulation system works with classes according to the sortability, recyclability, and existence of market for products. In general, eco-modulation is recognized as an important tool by the EU, in Directive 851/2018 it is stated that EPR fees, when possible, should be modulated "by taking into account their durability, reparability, re-usability and recyclability and the presence of hazardous substance" (Directive 2018/851, 2018). This recently pushed also other countries like Spain and Portugal to implement bonus/malus systems, while others, like Germany, approved a law for the introduction of the modulation of fees but no specifications for the implementation, which falls exclusively on the single PROs.

4.2 Impact of Extended Producer Responsibility Schemes Differences

It is not meaningful to compare two EPR schemes only based on indicators like the recycling rate or the producer fee. Every system works in a different context, with different infrastructures, different levels of citizen awareness, different geographic conditions, different market conditions, and even different methods of data collection. Instead, what will be studied in this section is the effect certain EPR scheme characteristics have on the efficiency of the recycling system and its cost, based on existing literature and reports.

The shift from monopoly to competition in EPR systems usually results in decreases in the fees for the producer to secure a broader market share, which implies cuts in operating costs. The main operating cost is the contribution for waste collection and sorting. In previous cases of shifts in PRO market

structure, the price charged by waste management operators dropped sharply, as in the abovementioned case of Germany (-54% waste management costs in 8 years), or more recently in France, with CITEO cutting the fees for PPW of 23% between 2018 and 2019 (Bundeskartellamt, 2012; Colelli et al., 2022). Generally, market dynamics are a strong driver for PROs to keep costs for waste management as close as possible to the actual cost for services provided, and to treat producers as clients, paying great attention to their satisfaction. Feeling valued and the lower fees charged by the PROs make producers typically prefer a competitive EPR system (Ahlers et al., 2021).

On the other hand, cases of strong competition can lead to the deterioration of the efficiency of the process, especially regarding collection. The for-profit nature of the organizations implies that economic considerations take precedence. Without a proper clearinghouse, it can be challenging to ensure the best available management techniques and fair access to waste for every organization. PROs with stronger bargaining power can cover collection only in more developed areas, e.g. areas with more collection points or with greater participation (the so-called "cherry-picking"), or some PROs may intentionally overfulfill their obligations to sell with a margin the excessive quantities to competitors that otherwise could not reach their collection quotas. To ensure a leveled environment for PROs a competition-neutral system for the allocation of collection areas must be put in practice, like in the German case.

The transparency of an EPR scheme is crucial to assess its performance and contrast fraudulent activities. In a competitive environment, players will be reluctant to share information, which could lead to an incomplete understanding of the system and difficulty in acting on it. A publicly available register should be kept to ensure transparency, documenting the quantities and types of products in the scheme. This register would report aggregated quantities for each product type on the market and their corresponding waste recovery operations, while maintaining confidentiality regarding the volumes managed by individual PROs. Some difficulties with this could be the low collaboration of PROs and the complexity of establishing and financing a third-party entity that overviews and manages the process. On the other hand, in a monopolistic system, there could also be a problem of lack of transparency. If the PRO is both managing the waste streams and compiling the related data, the exclusive control can be a risk for their validity and veracity (Ahlers et al., 2021).

A fragmented competitive PRO landscape can also be a barrier to innovation and awareness campaigns. First of all, if there is only a single PRO operating there is no need for coordination between more players. On the economic side, if a PRO invests alone in awareness campaigns or innovation this will lead to the loss of competitive advantage on its side. Joint action of the organizations should be promoted or imposed to guarantee a sufficient development of the system, but this will lead again to more

complexity and costs for the overarching collaboration structure. A particular case is the introduction of eco-modulation of fees, which could be beneficial according to literature and stakeholders, but poses some challenges in a competitive environment. If the amount of the basic fees differs between organizations, establishing a country-wise harmonized system for their modulation is a challenge in itself. Also, because the products on the market registered with a PRO don't correspond to the waste collected by it, there may be cases where PROs covering sustainable, easy to sort and to recycle products may gain less from contributions than PROs covering products with penalties, making the latter more advantageous. These reasons can justify why the most advanced eco-modulation systems in the EU, Italy, France, and Spain, are in countries with a monopoly EPR structure (or, as for France, that just recently shifted to an open market).

As for the responsibility allocation, a study from Cahill et al. (2011) on existing EPR schemes found that where local authorities have been engaged in the design and implementation of waste management systems, used existing infrastructure and established roles for producers and local authorities, results have been significantly more positive than in the cases where local authorities have had limited engagement. It seems that sharing the operational responsibility between local authorities and PROs leads to higher recycling rates (Colelli et al., 2022).

4.3 Results of the Survey of Recycling Professionals

4.3.1 Survey Sample Profile

Of the sample of 74 respondents, more than half operate in Italy (43), while the rest (31) are fairly distributed in the rest of the EU (Figure 4.3). Even though Italy has a developed and fragmented recycling sector, the country is overrepresented. The survey was received by 518 Italian companies (17% of the total) but their response rate was much higher than for the rest of Europe, a reason could be that the survey was translated to Italian.

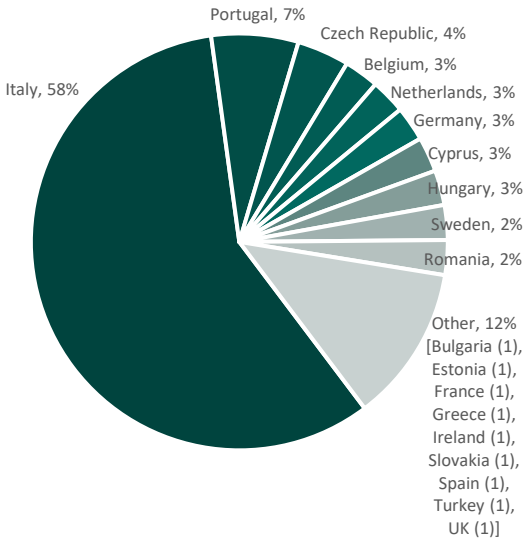

Figure 4.3: Country of operation of respondents

As can be seen in the Figure 4.4, respondents work mainly in the areas of waste collection (47.9%), waste sorting (46.6%), and recycling (41.1%). Most of the respondents have simultaneously multiple roles in recycling. Compared to group PRO 1 (respondents operating in a monopoly), group PRO 2 (competition) shows a higher percentage of respondents working in waste collection (68.8% vs 52.6%), waste sorting (81.3% vs 45.6%), and EPR organizations (62.5% vs 8.8%).

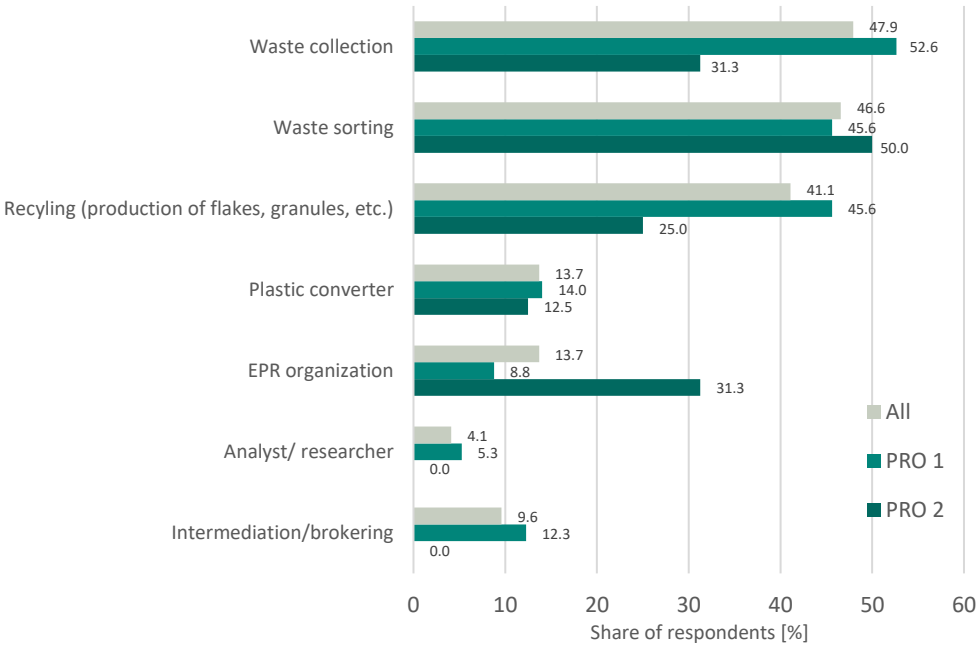

Figure 4.4: Distribution of respondents by their role in the recycling value chain

4.3.2 Opinions of Recycling Professionals

To assess respondents' opinions on the most efficient measures to promote plastic packaging recycling in the EU, the following two questions were asked: 1) "In your personal opinion, order the following measures according to the impact they would have on the efficiency of plastic packaging recycling in the EU. Efficiency is defined as the ability to substitute virgin raw materials in terms of quality and quantity.", and; 2) "How do you rate the effect of the following measures on the overall efficiency of the recycling value chain?"

In overall terms, the results obtained for the first question are shown in Figure 4.5. Across all categories, the two most highly regarded options (1st and 2nd options selected) was the eco-modulation of EPR fees (60.2%) and the setting of recycling targets considering also the material quality (58.9%). The least chosen option (4th and 5th options selected) was deposit-and-refund schemes compulsory for a broader range of products (76.8%).

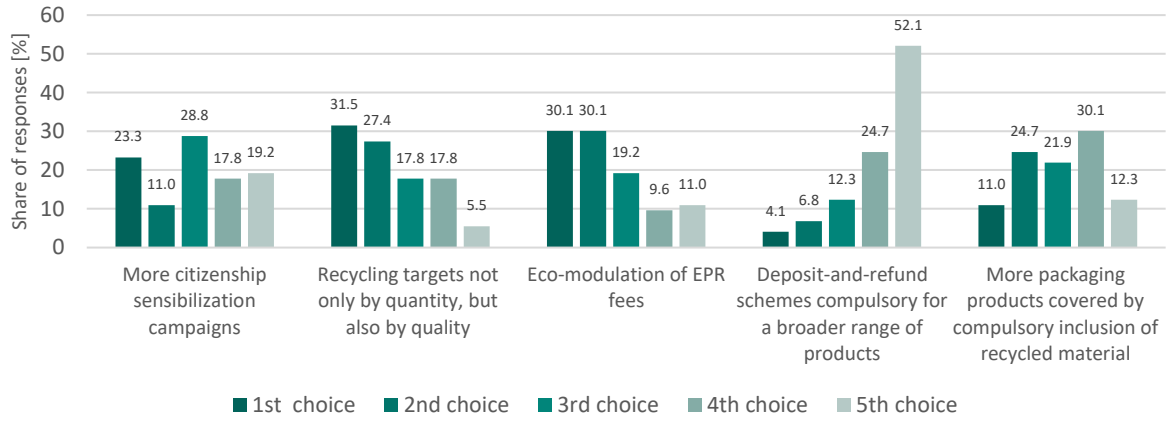

Figure 4.5: Results of the ranking question about the measures that respondents consider to have the greatest impact on the efficiency of plastic packaging recycling in the European Union

The respondents working in collection, sorting, and recycling have a similar opinion, favoring a strategy to enhance recycling by retaining quality in the process and incentivizing product design for recyclability. Compulsory quotas of recycled content incorporation and sensibilization campaigns are next in order of importance according to them. The opinions expressed by respondents representing EPR organizations are not as unanimous. Respondents from countries with a more developed and competitive waste management system, like Sweden and Germany, put sensibilization campaigns in the lower positions while other respondents, like those from Bulgaria, Romania, Cyprus, or Ireland, put it in the first two positions, giving less value to the targets for material quality. These respondents are more aligned to consider as important the eco-modulation of fees, and to consider less impactful the DRSs and higher quotas for recycled content. Two respondents added that it must be ensured an effective enforcement of

the legislation. Not surprisingly plastic converters, directly concerned with waste quality, value as the most important measure that quality should be accounted for in recycling targets, and have a higher opinion of DRSs. Compared to other categories, plastic converters value less the introduction of eco-modulation of fees.

For this question, there was the possibility to add an option (question 4). The most frequently added options were about prohibiting the commercialization of packaging products problematic for recycling, like multi-material and of small size. Two respondents wrote better infrastructure for separate collection and PAYT systems. Representatives of EPR systems wrote more effective enforcement of the legislation for all stakeholders and that the awareness campaign should be aligned among all organizations. Lastly, other mentioned measures were tax benefits on the percentage of recycled material, including all packaging in EPR schemes, a tax on virgin plastic, and higher fees for incineration.

Analyzing the differences of opinion between the PRO 1 and PRO 2 groups (Figure 4.6) indicates that the responses differ mainly for the options "recycling targets not only by quantity, but also by quality" and "eco-modulation of EPR fees". The PRO 1 group valued the option "recycling targets not only by quantity, but also by quality" more than the PRO 2 group (66.7% vs 58,9%), while the PRO 2 group valued more the option "eco-modulation of EPR fees" (81.3% vs 54.4%). A reason for this could be that since in some monopoly EPR systems, like the very represented Italian one, the eco-modulation of fees was already introduced, this is not seen as a disruptive measure anymore and incentives to a product design for recyclability lose urgency. Another reason can be that in the PRO 2 group, the EPR organizations have greater weight (31% vs 9% of PRO 1), and they are more conscious about tools like eco-modulation while waste management operators are more affected by the quality of recycled material, as the survey reflects. For the remaining options, the groups' opinions are closer, with both considering deposit-and-refund schemes compulsory for a broader range of products the least important measure.

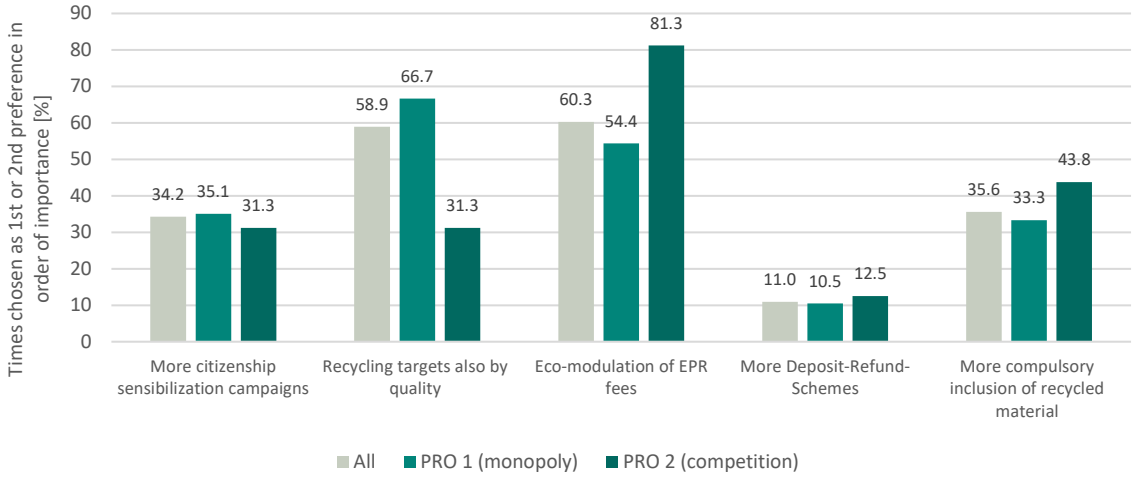

Figure 4.6: The two measures that respondents consider to have the greatest impact on the efficiency of plastic packaging recycling in the European Union

The results obtained for question 5, "How do you rate the effect of the following measures on the overall efficiency of the recycling value chain?", are presented in the Figure 4.7.

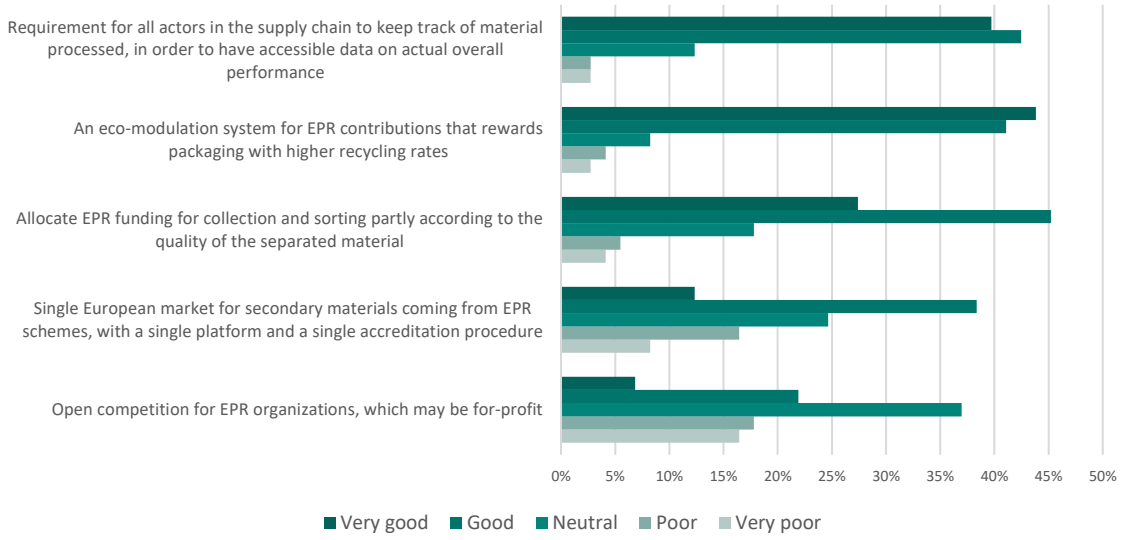

Figure 4.7: Respondents' assessment of the effect of different measures on the overall efficiency of the recycling value chain

There is a generally positive reception for keeping records of the material processed, for a fee modulation system that rewards packaging with higher recycling rates, and for the allocation of EPR funding for collection and sorting partly according to the material quality. The other two, a single European market for materials from EPR schemes, and open competition for PROs, are more divisive for every category.

Respondents in the collection, the sorting, and recycling perceive more neutrally the allocation of EPR contributions based on their performance. Recyclers also don't completely approve the keeping registers of the processed material, with 22% of neutral opinions and 12% of negative ones. This can be explained because these two measures would add a financial or bureaucratic burden on operators. The possibility of having a single, accessible market for secondary materials is received only slightly positively by collectors and sorters, and more positively (51%) by the recyclers. An open EU market could mean lower prices paid for the separated materials, especially for the Italian environment. For this groups of respondents the most negatively perceived option is the competition in EPR systems, that for waste management operators usually implies cuts in the environmental contributions.

For EPR organizations the options of keeping material registers and of modulating fees according to the recyclability of the material have unanimously positive opinions. Also the single EU market is very well received. For the EPR contribution depending on the material quality, there is a greater number of "Neutral" and "Poor" responses (36% and 18%), maybe because the concept doesn't align exactly with the "polluter pays" principle. Also here the most negatively received option is the competition in the EPR system, with 45% of respondents voting "Very Poor".

Plastic converters receive very positively the keeping of material registers, the lower fees for more recycled products, the contribution variation based on quality, and the single EU market for recyclates, and, compared to other groups, have a more positive opinion of competition in the EPR system, since they would be the first ones to have a direct advantage.

4.3.3 Comparison with Current and Discussed Measures

Among interviewed stakeholders across all categories, there was almost unanimous support for recycling targets accounting also the material quality, like the percentage of material that substitutes the equivalent virgin one, and for contributions to waste management operators depending on the material quality. It was identified as a key instrument also the modulation of EPR fees to encourage designs for recyclability. On this aspect, it must be noted that the clients of plastic converters, the ones that actually commission packaging designs that can be complicated for recyclability, were not surveyed in this work but they could be the stakeholders most opposing eco-modulation.

From the literature and reports consulted, transparency and effective data collection on the whole recycling value chain emerged as important factors for a well-functioning system. Based on the survey results, stakeholders also think it is relevant and are willing to take the bureaucratic burden of the

registration of their material fluxes. This may be heavier for plastic converters or PROs in competitive environments, and it would be useful to have a broader amount of responses from these categories.

A higher use of compulsory material incorporation quotas is a measure that overall respondents place after the ones mentioned above. A barrier to the market of secondary materials is the low price of the equivalent virgin ones, as was also mentioned in some contributions in the survey, and the incorporation quotas can increase the value of recycled material. Nevertheless, stakeholders believe that to increase the overall efficiency of recycling it would be more effective to act on facilitating and improving the process, through eco-modulation and efforts on quality, than to introduce actions to correct and favor the recyclables market.

An aspect deviating from other reports is the importance of citizen sensibilization campaigns, which in this survey was not judged as importantly. A reason for this could be again the overweight of the Italian ecosystem, where the separate collection rates are fairly high and the PRO already conducts relevant sensibilization campaigns. DRSs also were not regarded as very important for the overall efficiency, it could be because of the limited packaging product range they are currently covering, mostly single-use bottles, which also usually have recycling rates already higher than other PPWs.

The most negatively received features are the existence of a single market for EPR material, which in general in literature is regarded as a positive factor, and the competitive setup of the EPR system. This last feature was perceived more poorly by respondents operating in a competitive environment. The sample is not representative enough to suggest a conclusion, but this could be an insight for a future study. If for example a greater number of plastic converters operating in a competitive EPR system like Germany participated in the study, then this could possibly have been welcomed more positively.

4.3.4 Alignment with the European Union's strategy

This chapter explores in what measure the EU strategies for plastic packaging recycling align with this survey respondents' opinions. These strategies are contained in the "Proposal for a Regulation of the European Parliament and of the Council on packaging and packaging waste" (European Commission, 2022), a bill that traces the way for the EU's transition to a circular economy for packaging. The current regulatory framework for PPW recycling originates from a Directive, which has been transposed differently by each Member State. This has resulted in a chaotic framework and difficulties in collaboration for the improvement of the overall system. This proposal arises from the need for a single Regulation, which doesn't have to be transposed by Member States, to establish a set of common, harmonized rules.

Concerning packaging recycling, Article 6 of the proposal states that "*All packaging shall be recyclable*", with recyclability meaning that it is designed for recycling, it is efficiently separately collected and sorted, the secondary material can substitute the virgin one, and it can be recycled at scale. The recyclability will be scored with a percentage, given according to criteria that will have to be established in delegated acts produced by the Commission. Packaging in the lowest class of scoring will be banned. Articles 6 and 7 also mandate the modulation of fees paid by producers, that for plastic packaging should be based on the percentage of recycled content and the recyclability calculated with the parameters mentioned above. The proposal also increases the compulsory content of post-consumer PPW in new products. In 2040 this goes to 50% for contact-sensitive plastic packaging except for single-use beverage bottles, and 65% for single-use bottles and every other plastic packaging.

Regarding the enforcement of these measures, Article 35 mandates that "*Member States shall designate one or more competent authorities responsible for implementation and enforcement of the obligations*" of producers. In Member States where multiple PROs exist, a competent authority should be entrusted to oversee that these "*fulfill their obligations in a coordinated manner*", and the modalities to ensure compliance should be established. In the proposal there is also a strong call for transparency. An electronic register should be established for every Member State where producers should register, with a single format in the whole EU, that will monitor compliance with the obligations. If producers take part in a PRO, the organization can do the registration on its behalf. PROs also must publish on their websites at least once a year, subject to confidentiality, information on the levels of recovered and recycled materials in relation to the amount of packaging covered. The proposal confirms by 2029 the setup of DRS for single-use plastic beverage bottles unless a separate collection rate higher than 90% is achieved. There are no obligations for other PPWs.

Many points are in common with the opinions of the survey respondents. The eco-modulation of fees, the increased transparency, and the compulsory incorporation of recycled material in new products were measures important for the respondents and all are important measures also in the proposal. The implementation will depend on the delegated acts. On the contrary, stakeholders give great importance to the consideration of quality in recycling targets, and in general to increasing the quality of the collection, sorting, and recycling steps instead of aiming for the quantity only. This aspect is only marginally considered in the proposal. Article 6 states that to be considered recyclable a material should be able to substitute the virgin one, but this doesn't automatically imply that it will actually substitute virgin material. The EU on the other hand strongly relies on DRSs, almost mandating them for single-use bottles by 2029. This is a step that will require in a short time a major organizational effort and an important

investment for logistics and machinery, but according to the surveyed stakeholders it is far less impactful than other possible measures.

The proposal doesn't directly speak out on having a single market for secondary material in the EU, but eliminating trade barriers between Member States is a founding value of the EU in general. However, no particular measures are proposed in this sense specifically for waste and secondary materials. The other feature that was received with mixed opinions is whether or not there should be competition in the EPR system. The proposal and in general the EU policy doesn't favor one of the structures, and hardly it will ever impose one or the other. Nevertheless, the implementation of measures like fee modulation and material registers will be more challenging in competitive environments. The obligation of establishing in every Member State a competent authority to oversee and coordinate the work of PROs will help in this transition.

5 CONCLUSION

5.1 Conclusive Synthesis

Improving the efficiency of PPW recycling is a crucial challenge to achieve a circular economy in the EU. If it is accepted by the majority of stakeholders that the complexity and the differences in the EPR schemes are a barrier to the development of the sector, it is still not clear exactly how these impact its functioning and development.

The core feature difference is the monopolistic or competitive structure of the EPR scheme. Competitive systems, like the one of Germany and 15 other EU countries, typically optimize the operating costs, like waste collection and sorting, but need an overarching entity to monitor and ensure the correct delivery of the service. PROs operating in monopoly, on the other hand, face less economic pressure to compete, allowing them to focus more on the quality of waste management. Not having to confront with competition facilitates the introduction of measures aimed at improving recycling efficiency even if they are unfavorable for economic dynamics, such as publishing data on handled materials or the eco-modulation of fees. Today 9 EU countries have a monopolistic EPR scheme, but there has been a trend of systems shifting from monopoly to competition, like in the case of France and Portugal.

According to the sector's stakeholders responding to the survey, for the development of recycling the most important measures are the eco-modulation of fees, increased transparency, and to address also the quality of the recovered material. There are no major distinguishable differences in the opinions of respondents operating in a competitive or monopoly EPR system. The most evident discrepancy concerns indeed the PROs market structure. Waste management operators from a competitive system tend to perceive it more negatively, while the ones from a PRO monopoly have more of a neutral opinion on the matter.

If the eco-modulation of fees and transparency are also key points of the strategy the EU is tracing for the near future, the importance of maintaining quality in recyclates does not get the same priority, and most of the targets are still given in quantity only. The EU is addressing many of the aspects that emerged from reports and the stakeholder's feedback, first of all the lack of a strong and common regulatory framework. In the following years, its implementation in the single Member States will be the challenge to overcome, which can be dealt with only through close cooperation in the whole value chain.

5.2 Limitations of the Study

This study is exploratory in nature and should not be considered a representative analysis, but rather a foundation for future quantitative research. Given the great hetereogenity of EU's EPR schemes, it is necessary to collect a great number of inputs from operators in each country and role if the objective is to accurately portrait the entire recycling ecosystem.

The insights from this survey analysis can be influenced by the sample composition. The 58% of respondents operate in Italy, therefore the survey is likely to over-represent the most common features and issues specific to this ecosystem. At the same time, there are only two responses from Germany, which is the only large country in the EU with a competitive EPR system achieving a PPW recycling rate above the comunitary average. Concerning the categories, plastic converters are scarcely represented (only 8 responses), and for a comprehensive study it is important to collect the feedback of packagers too, the ones buying and demanding the standards for the products.

5.3 Guidelines for Future Research

The coming years are crucial for the development of recycling in the EU. Legislators are calling for a set of harmonized and stricter rules, but the implementation is still pending, and these are the rules that will really shape the future of recycling. For a functioning value chain, these rules should be developed in close collaboration with stakeholders.

This survey section of this study aims to give an initial insight on the stance of professionals towards the current system, to be developed in quantitative studies that can accompany and, if necessary, correct the efforts of legislators. For a quantitative study, it is crucial to gather a broader and more representative

sample. Establishing contact with recycling professionals can be challenging due to the industry's nature, which is often made up of medium-small companies and can be little responsive to non-business-related inquiries. One way to address this issue is by reaching out to sectorial associations, like for example EUPC (European Plastic Converters) or Plastic Recyclers Europe, which may be more collaborative and capable of connecting with industry professionals. It is important to ensure that more fragmented stakeholder groups, like waste collectors and sorters, are also included in the study to avoid only partial representation. In this regard, developing separate studies for different groups of professionals could be an effective approach.

If a survey is suitable for gathering an overview of insights and feedback from stakeholders, interviews may be more effective for investigating the specific research lines that emerge from this study. The survey results indicate a discrete alignment between stakeholders' priorities and the EU strategy as proposed in the new Regulation of Packaging and Packaging Waste (European Commission, 2022), particularly concerning eco-modulation of fees, transparency in the value chain, and compulsory incorporation of recycled material. Future work could follow the delegated acts for the implementation of these measures and assess whether the stakeholders are satisfied with the proposed targets.

Another research direction could focus on material quality in recycling, which the survey highlighted as crucial but is less emphasized in the regulation. Interviews could provide deeper insights from stakeholders on which measures they believe can have the greatest potential to retain value in the recycling value chain.

The market structure of the EPR system is a divisive issue, both in literature and in survey responses. Implementing measures like eco-modulation of fees or mandatory publication of material flows will be more challenging in competitive systems, yet it is unlikely that there will be a sudden shift to EPR monopoly. An additional line of study could address the challenge of implementing stricter recycling policies in competitive systems, leaning on insights from interviews with stakeholders.

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APPENDIX

Annex A: EPR Schemes' Structure

Country	Market structure	Type of producer responsibility obligation	Source of information
Czech Republic	Monopoly	Mainly financial	Expra, 2024a
Ireland	Monopoly	Mainly financial	Repak, 2024
Spain	Monopoly	Mainly financial	Ecoembes, 2024
Cyprus	Monopoly	Financial and partially operational	Expra, 2024c
Finalnd	Monopoly	Financial and partially operational	Expra, 2024b; Pruess, 2023
Italy	Monopoly	Financial and partially operational	Conai, 2024
Luxembourg	Monopoly	Financial and partially operational	Valorlux, 2024
The Netherlands	Monopoly	Financial and partially operational	European Environment Agency, 2022e
Belgium	Monopoly	Financial and fully operational	Fost Plus, 2024
Hungary	Monopoly	No data	Marosa, 2024
France	Competition	Mainly financial	CITEO, 2024; Nedey, 2024
Poland	Competition	Mainly financial	Eunomia Research and Consulting, 2024
Bulgaria	Competition	Financial and partially operational	European Commission, 2021
Greece	Competition	Financial and partially operational	European Environment Agency, 2022a
Malta	Competition	Financial and partially operational	European Environment Agency, 2022c
Portugal	Competition	Financial and partially operational	Novo Verde, 2024; Sociedade Ponto Verde, 2024
Romania	Competition	Financial and partially operational	European Environment Agency, 2022d
Slovakia	Competition	Financial and partially operational	Pruess, 2023
Slovenia	Competition	Financial and partially operational	European Environment Agency, 2022e
Sweden	Competition	Financial and partially operational	Naturvardsverket, 2024
Austria	Competition	Financial and fully operational	European Environment Agency, 2022a
Estonia	Competition	Financial and fully operational	Pruess, 2023
Germany	Competition	Financial and fully operational	Ahlers et al., 2021
Latvia	Competition	Financial and fully operational	Pruess, 2023
Lithuania	Competition	Financial and fully operational	Pruess, 2023
Croatia	No data	No data	
Denmark	No data	No data	

Annex B: Survey Used In the Research

Research survey on the plastic packaging recycling value chain

Good morning, I am Massimiliano Fontanari, I am conducting this survey as part of my master's thesis research at Nova FCT University in Lisbon.

My goal is to examine the factors that influence the efficiency of the plastic packaging recycling process along the value chain, and what measures can stimulate it. Besides its actors, the study will focus on Extended Producer Responsibility (EPR) schemes and their differences in the EU.

Thank you for your valuable contribution!

* Obbligatoria

1. Which of the following options better defines your role in the recycling value chain? (you can choose more than one) *

- [ ] Waste collection
- [ ] Waste sorting
- [ ] Recyling (= production of flakes, granules, ...)
- [ ] Plastic converter
- [ ] EPR organization
- [ ] Analyst/researcher
- [ ] Intermediation/brokering
- [ ] Altro

2. Where are you operating from? (or where are you based?) *

- ◯ Germany
- ◯ UK
- ◯ Italy
- ◯ France
- ◯ Spain
- ◯ Turkey
- ◯ Portugal
- ◯ Poland
- ◯ Belgium
- ◯ Netherlands
- ◯ Denmark
- ◯ Sweden
- ◯ Finland
- ◯ Altro

3. In your personal opinion, order the following measures according to the impact they would have on the efficiency of plastic packaging recycling in the EU. Efficiency is defined as the ability to substitute virgin raw materials in terms of quality and quantity.

   These measures are intended to be applied in a waste management system that can be considered fairly efficient by today's standards, so that already puts into practice for example door-to-door separate collection, has already established an EPR scheme, ... *

- More citizenship sensibilization campaigns
- Recycling targets not only by quantity, but also by quality (like % of material that substitutes the equivalent virgin one)
- Eco-modulation of EPR fees, meaning higher contribution for less recyclable packaging such as multi-material or containing PVC
- Deposit-and-refund schemes compulsory for a broader range of products
- More packaging products covered by compulsory inclusion of recycled material (like 25% for PET bottles)
- Other (please specify in the following question)

4. If you used other in the previous question, please specify:

5. How do you rate the effect of the following measures on the overall efficiency of the recycling value chain? *

	Very poor	Poor	Neutral	Good	Very g
Open competition for EPR organizations, which may be for-profit	○	○	○	○	○
Single European market for secondary materials coming from EPR schemes, with a single platform and a single accreditation procedure	○	○	○	○	○
Allocate EPR funding for collection and sorting partly according to the quality of the separated material	○	○	○	○	○
An eco-modulation system for EPR contributions that rewards packaging with higher recycling rates	○	○	○	○	○
Requirement for all actors in the supply chain to keep track of material processed, in order to have accessible data on actual overall performance	○	○	○	○	○