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Comparison of plastic packaging waste management in Austria, Germany, Netherlands and Serbia

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Affidavit

I, **MAG.A RER. NAT. PETRA EISCHER**, hereby declare

1. that I am the sole author of the present Master's Thesis, "COMPARISON OF PLASTIC PACKAGING WASTE MANAGEMENT IN AUSTRIA, GERMANY, NETHERLANDS AND SERBIA", 74 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

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Abstract

As the world population is growing, so is production, consumption, and waste generation adapting. Climate change, environmental issues, and resource scarcity are only a few challenges we have to face in our everyday lives. Hence, it is vitally important to take long-term and prospective actions to leave the world a little bit better behind than we have discovered it.

One of the major issues regarding waste production is the overconsumption of plastics. Hardly anyone can imagine a life without macro- and microplastics. Several studies demonstrate that plastic affects the health of every creature here on earth.

That is why global actors, like the European Union (EU), need to take action in order to condemn this tendency. Therefore, the Member States of the European Union (EU) agreed on “A new Circular Economy Action Plan” in March 2020. In addition, and as part of the European Green Deal (November 2019) the EU introduced a plastic packaging recycling rate of 55 % reached by 2030. These mentioned strategies shall also contribute to reach the targets of climate neutrality in 2050 and repress upcoming environmental issues.

Several indicators can be adducted to monitor the process of achieving the undertaken aims. In regard to waste management, the collecting, sorting, and recycling rates are factors of interest.

To get a deeper insight how various countries in the middle of Europe perform, this thesis aims to compare the waste management systems of Austria, Germany, Netherlands and Serbia by comparing material flows of PET bottles and plastic packaging recycling rates. It could be shown that Germany and the Netherlands are on a good way to reach the determined targets, whereas Austria and Serbia need to rush on policies for plastic reduction. By implementing a deposit refund system in 2025 for PET bottles and tins, Austria took its first steps toward a greener future. In comparison to Serbia, where the informal sector is acting across the country, also in terms of waste management, monitoring processes based on reliable data are difficult to find. Nevertheless, it can be summarized, that the respective countries try to establish policies, which are able to contribute to a more sustainable and environmental-friendly future.

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List of Abbreviations

ABS	Acrylonitrile-Butadiene-Styrol-Copolymer
DKR	Deutsche Kodierichtlinie
DRS	Deposit Refund System
EC	European Commission
EEA/EFTA	European Economic Area/ European Free Trade Association
EPR	Extended Producer Responsibility
EPS	Expanded Polystyrene
EU	European Union
EUR	Euro
GDP	Gross Domestic Product
GHG	Green House Gas
LWP	Lightweight Packaging
MRF	Material Recovery Facilities
MSW	Municipal Solid Waste
PE-HD	High-Density Polyethylene
PE-LD	Low-Density Polyethylene
PE-LLD	Linear-Low-Density Polyethylene
PE-MD	Middle-Density Polytheylen
PET	Polyethylenenterephthalate
PP	Polypropylene
PPW	Plastic Packaging Waste
PU	Polyurethane
PVC	Polyvinylchloride
RDF	Refuse Derived Fuel
UNEP	United Nations Environment Programme
USD PPP	United States-Dollar Purchasing Power Parities

The sky is the limit.

1. Introduction

„A clean environment is a human right." – This quote by Dalai Lama stresses the importance of an intact environment. Through sustainable actions and commitments to a more prudent lifestyle, we can influence our children's future.

Cheap and durable – plastics are widely used in our current economy. However, their increasing popularity has also led to more and more plastic waste and litter, and thus also to environmental and health impacts. Plastic production has grown exponentially in the past years – on an international scale, this means a boost from 1.5 million tonnes in 1950 to 359 million tonnes in 2018. Consequently, this status adds up to the growing amount of plastic waste generated (EP, 2022).

Therefore, also global actors need to take measures in order to amplify resource efficiency and upgrade the circularity of plastic materials. Starting in 2015 the European Union (EU) agreed on a strategy paper with the name "Closing the loop – An EU action plan for the Circular Economy" (EPC, 2015), and upgraded this paper with the "A European Strategy for Plastics in a Circular Economy" (EC, 2018) in 2018 and precised it in 2020 with the following strategy, named "A new Circular Economy Action Plan" (EC, 2020). As part of the European Green Deal (EC, 2019b) the EU introduced a plastic packaging recycling rate of 55 % reached by 2030. This would require better designs for recyclability and measures to stimulate the market for recycled plastic.

In order to monitor progress in a transition, it is important to have a reliable indicator. For that reason, the recycling rate, which is often used in policy papers, indicates the volume of waste materials, that are returned to the economy (Van Eygen, 2018).

The aim of this thesis is to examine the various plastic packaging waste management systems in Austria, Germany, Netherlands and Serbia with a focus on PET bottle recycling processes, deposit systems, and recycling rates for the respective countries.

1.1 Hypothesis and Research Questions

The hypothesis of this thesis tries to analyze plastic packaging waste management in Austria, Germany, Netherlands and Serbia. By the demonstration of the material flow analyses (MFA) of PET bottles of the countries, the recycling rates are compared. Furthermore, it will be elaborated on (potential) deposit systems for plastic packaging. Hence, the aim is, to relate the EU plastic packaging recycling rate to the national plastic packaging recycling targets. These days 400 million tonnes of plastics enter the economy on a global scale annually (Umweltberatung, 2022), thus a life without plastics, especially plastic packaging, can hardly be imagined. Therefore, it is of great importance to research on the treatment of plastic packaging waste.

Research Question 1: What kind of waste management system is applied in the relevant country? What are the treatment methods?

In this part of the thesis, the aim is to demonstrate the different waste management systems in regard to collection, sorting and treatment matters, as well as the national legislation behind them.

Research Question 2: What treatment is operated on plastic packaging waste? Is there a deposit system installed? How are PET bottles treated?

In this section of the thesis, the aim is to present the process of use, preparation and pretreatment, as well as recycling, recovery and landfilling of PET bottles in the corresponding country. Further research is done on the existence of a deposit system.

Research Question 3: What is the relation between the EU plastic packaging waste recycling target and the national plastic packaging recycling aims?

In this segment of the thesis, the aim is to compare the EU plastic packaging waste recycling target with the national plastic packaging recycling targets and conclude in respect of the EU's plastic waste policy.

2. Material and methods

This thesis is primarily based on a literature review, which tries to examine several scientific papers, national guidelines, and legal gazettes with the aim to compare the treatment of plastic packaging waste (PPW) in the respective four countries. The visualization of data is supported by tables, diagrams, and graphs. The latter is foremost used for the demonstration of material flow analyses (MFA).

2.1 Material flow analysis

In the common literature, the definition of a material flow analysis (MFA) is outlined as the following: *"A material flow analysis is the quantification and assessment of matter (water, food, excreta, wastewater...) and substances (nitrogen, phosphorus, carbon...) mass flows and processes, in a system (city, country, etc.) during a defined period. The principle of MFA is based on the law of matter conservation; flows are expressed in kg/year or in kg/capita/year.*" (Yiougo et al., 2022) Consequently, a MFA is able to serve as a basis for information, which then can further contribute to demonstrate the processes of a material's stream in a system.

The outcomes of MFAs are often presented by a so-called Sankey diagram. Sankey diagrams are essential tools for visualizing energy and material flows, as well as inefficiencies and potential savings in the use of resources. The representation can also be applied to social science data, besides natural science, that changes over the course of time (Schmidt, 2006).

Matthew Sankey had introduced the diagram named after him rather casually and the following representations were oriented towards it. Thus, there are actually no rules for the creation of Sankey diagrams. Nevertheless, certain implicit assumptions are made: As a rule, quantity variables are depicted, which refer to a time period. The quantity quantities are extensive quantities and can be added together. The width of the arrow is proportional to the quantity shown. Furthermore, no stock quantities are taken into account (Schmidt, 2006).

3. Literature review

3.1 EU plastic waste policy

In the EU's New Circular Economy Action Plan (EC, 2020) for a cleaner and more competitive Europe of 2020, it is stated that the usage of materials, made of biomass, fossil fuels, metals, and minerals will rise to double by the next fourty years. This means an annual expansion of waste generation by
70 % in the year 2050.

With the European Green Deal (EPC, 2019b) the EU established a strategy for climate-neutrality, resource efficiency, and a competitive economy to overcome the extraction and processing of resources, which goes in line with more than 90 % of biodiversity loss and water stress by emitted greenhouse gases. In order to be able to condemn this environmentally exhausting circumstance, it was concluded to build upon a growth model that nourishes the earth more than it undermines.

The EU is also trying to become a global leader with its Circular Economy Action Plan by implementing the 2030 Sustainable Development Goals, which were introduced in 2015 in frame of the UN Sustainable Development Summit. It aims for a circular economy that influences people on a regional, national as well as on a global scale and drives forces for climate neutrality through research, innovation, and digitalization (EPC, 2015).

In addition to the mentioned action plans, a sustainable product policy framework – within the Circular Economy Action Plan – was set up. In this framework, it is declared to boost the recycling of materials by remanufacturing and high-quality recycling methods.

In 2017 packaging waste in Europe reached an all-time high level with 173 kg per inhabitant. As a consequence, the EC will revise Directive 94/627EC (EPC, 1994) to put an emphasis on binding packaging requirements. That includes the following measures:

- decreasing packaging, overpackaging, and packaging waste
- upgrading on designs for reusing and recycling of packaging
- reducing the complexity of packaging.

Aiming to harmonize separate collection systems the EU tries to implement EU-wide labelling in order to ensure a correct separation of packaging waste, initially. This includes the monitoring of the Drinking Water Directive, which tends to install public tap water stations, that are meant to reduce the use of water-filled bottles and diminish, therefore, plastic packaging waste.

Within the next 20 years, it is expected that plastic consumption will rise double times. Therefore, the EU introduced the EU Strategy for Plastics in the Circular Economy with a focus on reducing plastic pollution. The EC requests mandatory requirements for materials used as packaging, at construction sites, or for vehicles.

Another measure in order to ensure a sustainable future is the restriction of microplastics in the environment. The following points will be addressed:

- the restriction of added microplastics added by intention
- the standardization of measures tackling unintentional leaking of microplastics at every stage of the production, which aligns with the capturing of microplastic particles
- the focus on researching the risks of microplastics, occurring in the environment (EC, 2020)

In Directive (EU) 2019/904 the EC provides a new Directive of Single-use Plastic Products in order to label the issue of marine plastic. This regards to:

- the harmonization of products, listed in the Directive
- the prevention of producing litter by using tobacco, beverage cups, etc.
- the research on the development for a measurement of recycled content in a product

As the EU will not only promote an international shift towards a circular economy, rather on a global level the EC will try to strengthen its network with European economic actors. This includes the following measures:

- leading on efforts to establish a global agreement on plastics, approaching the EU's circular economy targets
- connecting knowledge and governance gaps within a Global Circular Economy Alliance by introducing initiatives and partnerships

- proposing an international agreement on the management of natural resources
- building bridges with African countries to increase the benefits of the circular economy
- ensuring the accession process of the Western Balkans by encountering through regional, bilateral and multilateral policy dialogues with the aim of installing environmental agreements (EC, 2020)

3.2 Usage of plastics in the EU

The term 'plastic' is deducted from the Greek word '*plastikos'* and the Latin '*plasticus'*, which means 'fit for moulding or being capable of being moulded into various forms' (Plastic Europe, 2022). A material made out of plastic is defined as an organic solid, most commonly combined as a polymer. Plastic monomers consist of natural or synthetic organic compounds. A commercial polymer can also be described by the term resin (EC, 2018b).

One way to classify plastic is by defining it towards its chemical structure, which are acrylics, polyesters, polyolefins, silicones, polyurethanes, and halogenated plastics. Through the process of synthesis, it can be classified by the chemical process, it has to alloy, for example, condensation or cross-linking. Another way for classification would be a description based on properties, which are applicable to the design of the product, like thermoplasticity, biodegradability, electrical conductivity, density, or resistance to various chemical products (EC, 2018b).

In our modern society, we are daily surrounded by various forms and types of plastics, as it has an outstanding functionality in our daily lives. Lightness, robustness, malleability, and durability are only a few factors, which make plastic an all-time useable material. It even drives research and innovation in the healthcare and medicine sector.

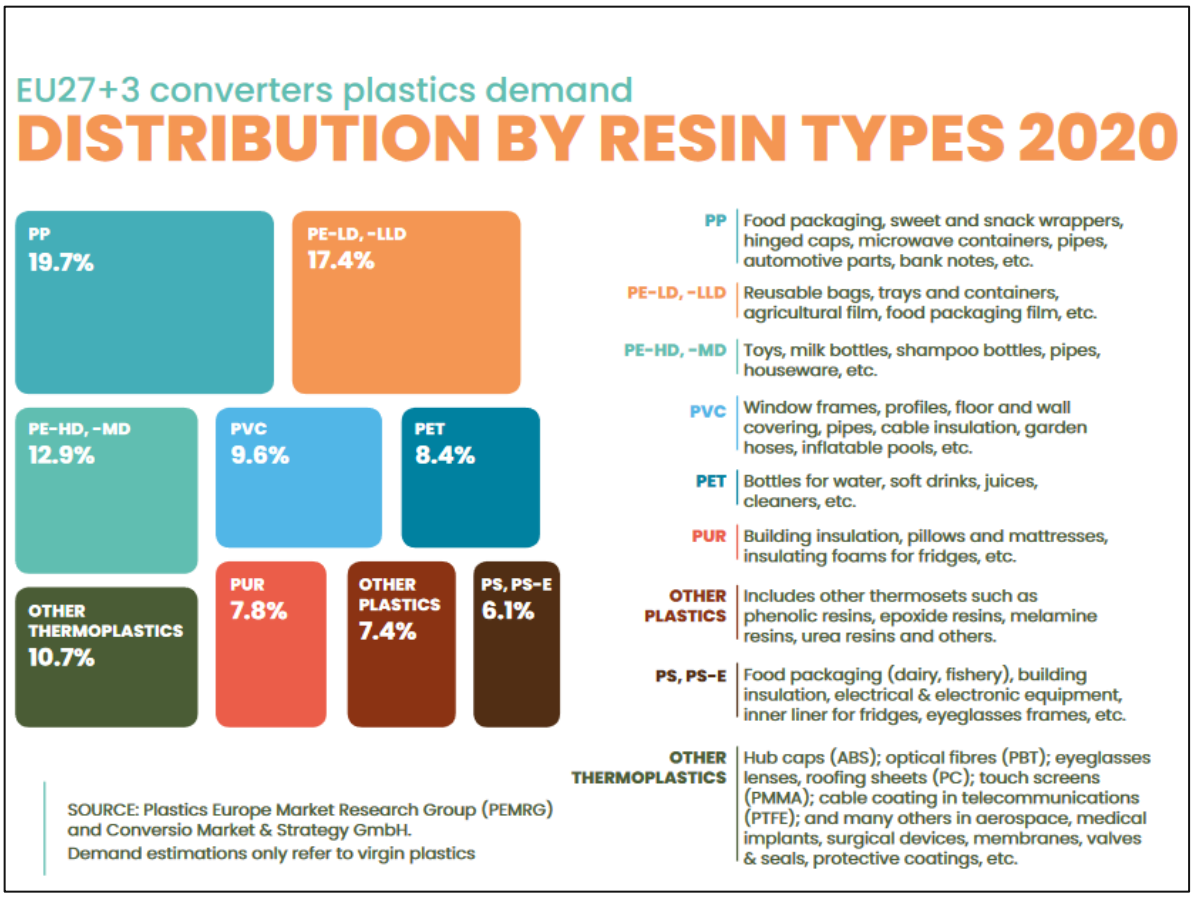

Figure 1: Plastic types in application in the EU27+3, (Plastics Europe, 2021)

In Figure 1 we can see that 19.7 % of polypropylene (PP) in Europe is used for food packaging, sweets, snack wrappers, etc. 17.4 % of low-density and linear low-density polyethylene (PE-LD, -LLD) is used for reuseable bags, trays, and containers, etc. 12.9 % of high-density and middle-density polyethylene (PE-HD, -MD) is used for toys, milk bottles, shampoo bottles, etc. 9.6 % of polyvinylchloride (PVC) is used for window frames, profiles, floor and wall coverings, etc. Finally, 8.4 % of polyethyleneterephthalate (PET) is used in the production of bottles for water, soft drinks, juices, cleaners, etc.

By the production of composite materials, plastic is combined with other materials of a different physical and chemical properties, like paper, glass, and ceramics, in order to acquire various functionalities (EC, 2018b)

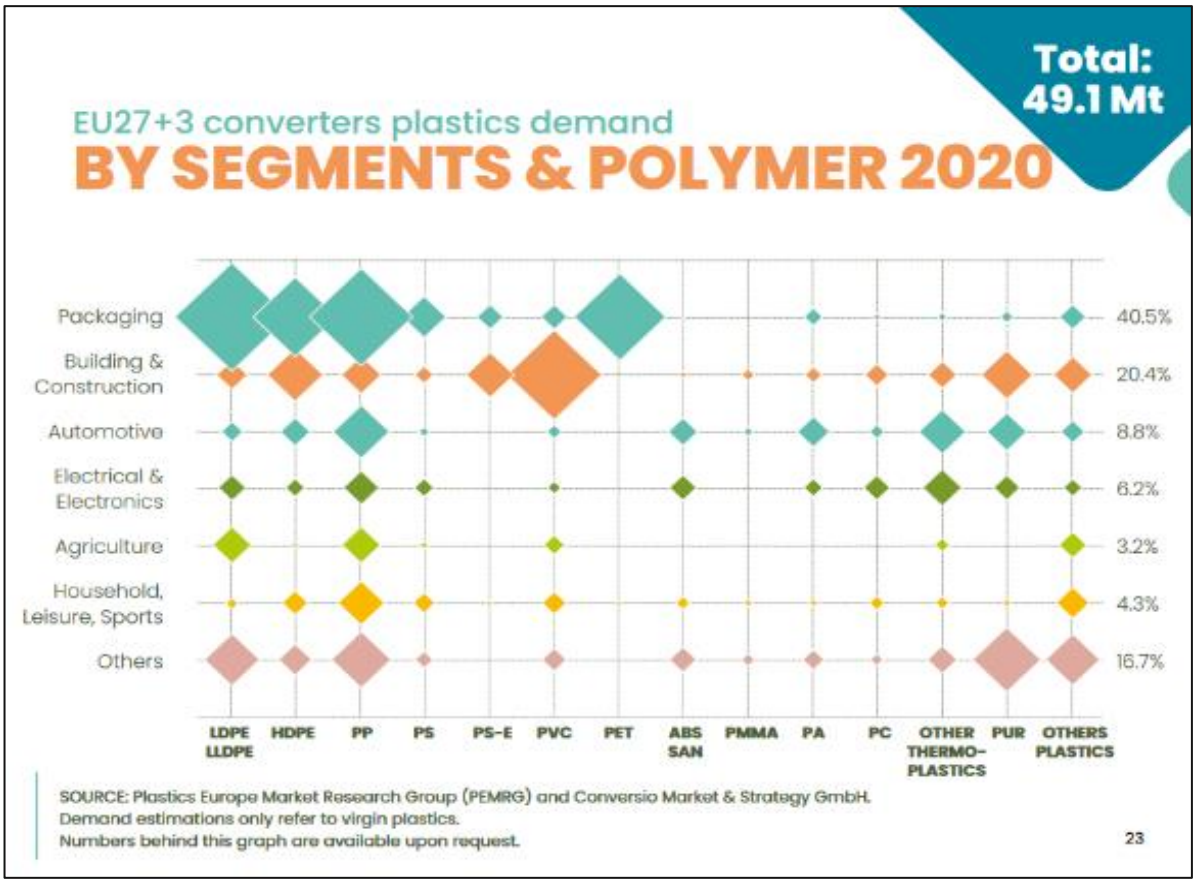

Figure 2: Plastics demand by segment & polymer in the EU27+3, (Plastics Europe, 2021)

In the EU plastics are basically used for packaging (40.5 %) and at building and construction sites (20.4 %), while in the automotive (8.8 %) and electrical and electronic sectors (6.2 %) it is also of importance (cf. Figure 2).

3.2.1 The production of plastics in Europe

Plastics are produced on a global scale: In China (32 %), Asia (without China and Japan, 17 %), Europe (15 %), the North America Free Trade Agreement States (9 %), in Africa and the Middle East (7 %), Latin America (4 %), Japan (3 %) and the Commonwealth of Independent States (3 %). The production of all these mentioned countries sums up to 367 million tonnes of plastics, which includes thermosets, elastomers, adhesives, coatings and sealants, and PP-fibers, but does not include PET-, Polyamide, and Polyacryl-fibers (Plastics Europe, 2021).

The European plastics industry includes the production of raw plastic materials, plastics converters, plastic recyclers, and the producers of plastics and rubber types of machinery. According to Plastics Europe (2021) close to 1.5 million people have been employed in the European plastics industry within approximately 52 000 companies, which generated a turnover of EUR 330 billion. Furthermore, it has to be stated, that the industrial plastics industry belongs to the ten most important value-added industries in Europe, on a comparable level with the electronic and pharmaceutical industries. Finally, in 2020 close to 10.2 million tonnes of plastic waste were collected and brought to recycling facilities inside and outside of Europe.

3.3 A circular approach of the plastics life-cycle

In correspondence to a linear model of material plastic, it is commonly recognized, that with the growth of the world's population a "*take-make-consume-dispose*" motive is not the most effective way of using plastics, as the sustainability factor is not efficient. However, a circular approach yields the limits of the earth's resources and tries to model itself in a dynamic circle. As there are happening several incidents in accordance with global climate change, it is of importance to keep the already added value of products in a circle, as long as it is feasible (EC, 2018b).

In 2020, 29.5 million tonnes had been collected as plastic post-consumer waste in the EU27+3 states. More than one-third (34.6 %) was transported to recycling companies inside and outside of the EU27+3, including 0.7 % chemical recycling. This means, that still 23.4 % was landfilled and 42 % was used for energy recovery operations (Plastics Europe, 2021).

Figure 3 regards to the treatment of post-consumer plastic waste in the EU27+3 states and shows an increase in total waste collected. From 2006 until 2020 we can see an increase of up to 117 % of recycled post-consumer plastic waste, furthermore an increase of 77 % of post-consumer plastic waste, which is used for energy recovery, and a decrease of 46 % in frame of a landfilling process (Plastics Europe, 2021). Additionally, it has to be mentioned, that these figures

derive from Plastics Europe (2021), which is the association of the European plastics manufacturers and might be overestimated in relation to reality.

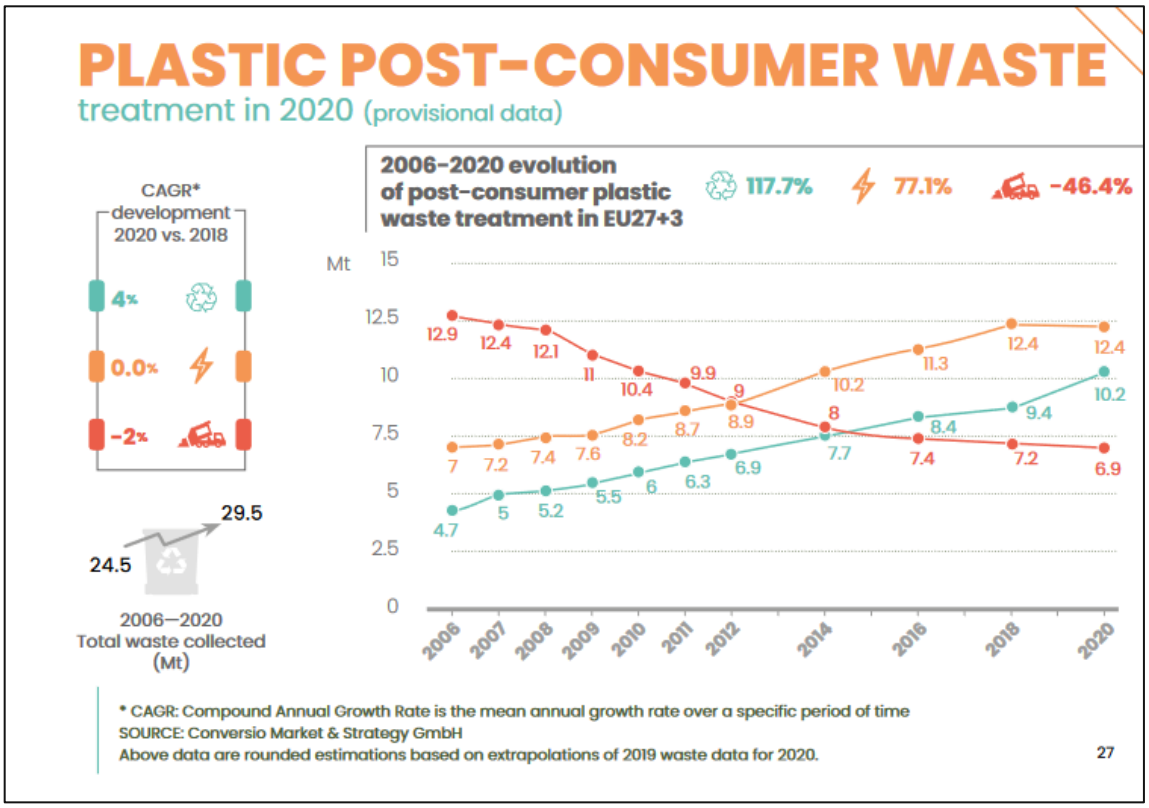

Figure 3: The treatment of post-consumer plastic waste in EU27+3 from 2006-2020, (Plastics Europe, 2021)

As one of the primary sources of CO_2 emission and aligned environmental pollution a linear flow of plastic can be mentioned, which means, that plastic materials are only used once, without a recycling treatment, and then disposed. Therefore a circular plastic economy can be an important alternative, which will contribute to a decrease in downcycling, incinerating, and landfilling of consumers' plastic waste. Post-consumer plastic waste will namely be a resource for new products in a closed-loop production and consumption system. One of the biggest challenges in the treatment of post-consumer plastic waste is the mix of various polymer types and additives, which vary in their lifespan of consumption. This is why researchers try to think beyond the point of recycling processes, but rather prefer researching the invention's process of the initial design of plastic products and packaging. Multiple polymers mixed together are often the basis of packaging and post-consumer plastics, which make it difficult for the recycling treatment process (Johansen et al., 2022).

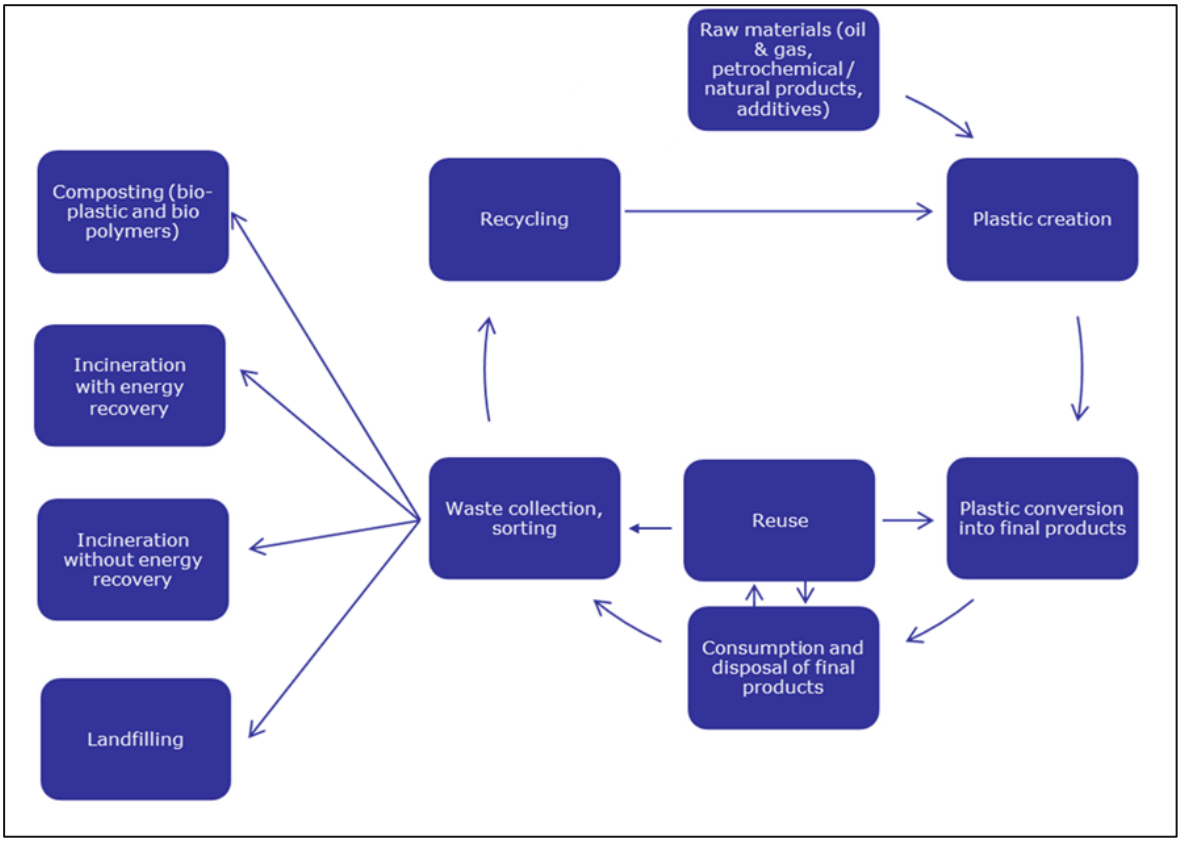

Figure 4: Circular plastics value chain, (EC, 2018b)

In Figure 4 we can see a circular plastics value chain: As the consumption of plastics is increasing with the growing population, the plastic sector responded with a more efficient way of plastic creation: The aim is to use less raw materials by incorporating recycled plastics material. The chart above shows, that raw materials, like fossil fuels, etc. are used for plastic creation, which is then converted into the final plastic item. After the consumption of this product, it can either immediately be reused by converting it into another final product or be collected and sorted as post-consumer plastic waste and ultimately be recycled and prepared for the production of a new item. In that way, the lifespan can be extended until the end of the value chain, which can be composting (of bioplastics and biopolymers), incinerating with energy recovery or without it, or landfilling. A circular plastic value chain has several advantages, such as a decrease in energy consumption, and the use of fossil fuels, including the aspect of protecting the environment and reducing Green House Gas (GHG) emissions. As the single-use of plastics has a short lifecycle it is obvious, that a linear model is inefficient

in terms of using resources and does not contribute to a sustainable economy (EC, 2018b).

3.3.1 Recovery and recycling rates of PPW

With the Council Directive 85/3397EEC of June 1985 national programs for reducing the volume of beverage containers, which are disposed as waste in order to promote the advantage of refillable containers, have been introduced. In1994 the European Parliament and Council Directive 94/62/EC repealed the above-mentioned Directive by the Packaging Waste Directive with the aim of harmonizing the national management of packaging and packaging waste. The highest goal tries to prevent packaging waste but also introduced a basis for reusing and recycling packaging material, as well as recovering packaging waste in order to decrease the final disposal amount of packaging waste. An amendment to Directive 94/62/EC has been made in 2018 by Directive 2018/852 (Eurostat, 2022).

The recovery rate can be described as followed: The total amount of recovered material divided by the total amount of generated packaging waste.
The recycling rate is the total amount of recycled materials divided by the total amount of generated packaging waste (Eurostat, 2022).

29.5 million tonnes of post-consumer plastic waste was collected across the European Union, Norway, Switzerland, and the United Kingdom (EU27+3) in 2020 (Statista, 2022). Compared to 2014, this means an increase of approximately 3.7 million tonnes of post-consumer plastic waste. Of this total amount 36.6 % was recycled, and 42.2 % was used for energy recovery, which relates to the largest share of post-consumer treatment, whereas landfilling accounted for 23.4 % (EC, 2018b).

The main application of plastics, as it is shown in Figures 1 and 2, is for the packaging of food and domestic products. 178 kg per inhabitant of packaging waste was generated in the EU. These values deviate between 74 kg, which was estimated in Croatia, and 228 kg per inhabitant in Ireland. The most frequently used packaging material in 2019 in the EU was paper and cardboard (40 %), followed by plastic (19 %), glass (19 %), wood (16 %), and metal (5 %).

It can also be stated that the total volume of packaging materials increased by 20.5 % from 2009 until 2019. During this period of time cardboard was the central packaging waste material adding 32 million tonnes to the total amount of packaging waste in 2019. This is an increase of 24 % compared to 2009, which could be explained by the rising market of postal shopping. Succeeded by plastic packaging material, which contributed 15 million tonnes, and therefore grew by 26 %. In contrast to 2009, in 2019 packaging material made out of glass generated 15 million tonnes (+14 %), wood packaging 12 million tonnes (+20 %), and metal packaging 4 million tonnes (+7 %).

Concerning recycling and recovery rates in the mentioned period, it can be shown, that the recycling rate of packaging waste increased by approximately 2 % within the last ten years. In regard to the recovery rate, which also includes the incineration process for energy recovery also grew from 75.8 % to 80.4 % from 2009 to 2019.

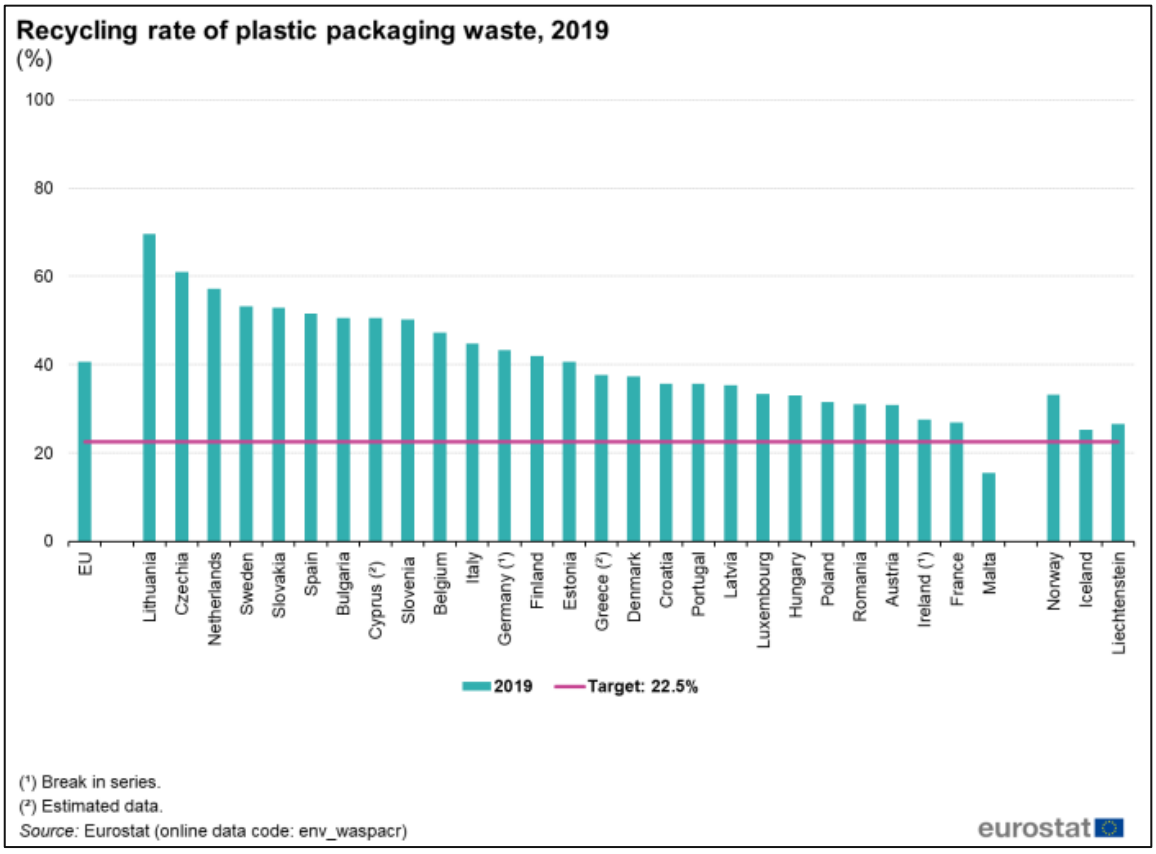

Figure 5: Recycling rate of plastic packaging waste, (Eurostat, 2019)

Figure 5 describes the recycling rate of plastic packaging waste for the EU Member States and also EEA/EFTA countries in the year 2019. The mentioned recycling rate only concerns material recycling and excludes material, that is recycled back into plastics. We can see that the target of 22.5 % (Directive 94/62/EC) recycled plastic packaging waste was met by all EU Member States, except Malta.

To sum it up, it could be examined, that the volume of packaging material amplified during the time period from 2009 until 2019. Moreover, in 2019 the amount of packaging waste acquainted the highest level since 2009.

Concerning the generation of the different types of packaging material, it can be stated that all of them increased but to an unequal extent. Plastic, paper and cardboard, and wooden package waste were detected with the highest increase rate. In addition to that, the recycling and recovery rate increased continuously (Eurostat, 2022).

3.4 Innovation of plastic recycling

Environmental and economic advantages can only be reached by improving the plastic recycling process. This can only happen through a change in the design, production, plastic waste collection, sorting, and recycling processes. All these components can boost the supply and demand of recycled plastic materials.

Plastics design process

Over 80 % of all negative environmental impacts are intended to start with the plastics design phase. By optimizing the design of the plastic item, it could be held even longer in the value chain, while producing it to be more durable, repairable, reusable, and recyclable. Additives, such as plasticizers or stabilizers in order to make it more flexible and resistant to chemical degradation of exposed UV light, basically enhance plastic performance. Nevertheless, in traditional mechanical recycling methods they cannot be removed, which means that they remain inherent in recycled items and can create safety problems. For some plastic products with additives that means, that recycling is impossible. The only solution would be to dissolve the plastic item and separate the polymer from the additive (EC, 2018b). As this process is inefficient and time costly, the best option

would be to weigh all the pros and cons of the plastic item's functionality, as well as other characteristics and in the worst case even relinquish the additive.

Plastic packaging

As the design of plastic packaging is most relevant for recycling processes the essential requirements are not defined in the Packaging and Packaging Waste Directive (EPC, 1994). At the World Economic Forum, supported by the Ellen McArthur Foundation (2017) it was found, that approximately 30 % of the plastic packaging weight needs a redesign, elsewise it ends up as mixed solid waste (MSW) and would be incinerated or landfilled. By improving the design of plastic packaging the costs of the resulting waste could be cut in half (BKV, 2016). Additionally, it could be found, that there is less incentive for sorting packaging materials, which value is low or the fraction in the waste stream is too little. A further cause of low quotas of plastic packaging recycling may also occur due to the usage of near-infra-red technology in the sorting process, where sorting is based on the type of the polymer, that is detected by the system. That might lead to extra costs because each stream needs special modification. If it is worth committing such investments depends on the waste of the value in the stream and the value, which is gathered by separating the material (EC, 2018b).

The following design imperfections make it difficult to reuse or recycle plastic packaging waste (BKV, 2016):

- Design might perplex consumers, who do not put the waste in recycling bins, such as multi-material packaging.
- Difficulties in separating multi-material packaging by hand, like plastic tags on a glass bottle.
- Plastic materials with different colors, which are problematic in the sorting process.
- Plastics, like Polyvinylchloride (PVC), Acrylonitrile-Butadiene-Styrol-Copolymer (ABS), and Polyurethane (PU), are produced of uncommon materials, because they have no automatic sorting system.
- Multi-layer materials are also difficult to recycle.
- Different types of PETs also curb the recycling process for example PET foils and semi-rigid PET foils.

Measures and actions

In the European Strategy for Plastics in a Circular Economy (EC, 2018a) it is stated that a product design, which encourages an entire life cycle, has to be considered. In frame of the accompanying document (EC, 2018b) of the above-mentioned paper it is proposed to implement a sharp definition of the design for recyclability. This definition is supposed to include operating waste streams and treatment plants, considering their sorting performance of plastic packaging. Furthermore, the sorting process needs to be updated with innovative technologies, for example, scanners for watermarks or tracers of polymers.

Additionally, all plastic packaging material should be designed to be recyclable by the year 2030. The EC will therefore revise the necessary requirements for placing plastic packaging on the market, which might also take into account updating the product design legislations (EC, 2018b).

Moreover, research and reflection on polymers and additives, which are on the one hand more durable and efficient in the recycling process – while not restricting the functionality of the product – and on the other hand less toxic and concurrent with essential requirements regarding safety and non-hazardousness (EC, 2018b).

Flexible cooperation towards the whole value chain will also be necessary, as different actors might come up with various solutions in the design phase. This should be supported by access to immanent information, the protection of intellectual property, and industrial secret (EC, 2018b)

3.5 Harmonizing separate collection and sorting

There are different factors, which have to be considered in the collection and sorting processes of post-consumer plastic waste. Issues, like logistics, infrastructure capacity, and waste management practices are varying throughout the EU. Prerequisites, such as sustainable designs, and flexible waste management systems, which warrant an effective waste management system and separate collection of plastic and organic waste, optimize resources for recovery. Also updating waste management infrastructure and capacity, like the

collection, sorting processes, and recycling plants will require supplementary investments and further development of technology (EC, 2018b).

Plastic waste in municipal waste

Although approximately 66 % of all plastic packaging waste is recyclable, only 40% of it is actually recycled. It is stated (EC, 2018b), that an improvement in the design phase cannot be the only solution, but advancements in the treatment and in sorting plants. As the Waste Frame Directives recommended the Member States to build separate collection systems for plastics by 2015, the results are not pleasing (EC, 2018b).

In 2015 the EC set up a study, which showed that in 18 Member States plastic was collected within a door-to-door system. Out of these 18, only four countries collected plastics as a separate section. The remaining 14 collected it together with two or three other fractions. Six Member States gathered plastics via bring-points. Four countries mixed residual waste up with plastics in the main collection system. The outcome of the study was, that a door-to-door collection system of a single type of plastic provides the best outcome in calculating quality and quantity factors for recycling. This result demonstrates, that although collection costs are higher, treatment costs are lower due to hardly any rejects and also higher revenues from recyclables (EC, 2018b).

Throughout the EU Member States, there is a trend to separate collection systems, which results in better collection and recycling outcomes. There is also another tendency to pay-as-you-throw schemes, which is applied as the polluter pays principle. Waste fees are calculated on a steady plus variable fee component in order to express the costs of waste management and operate in line with incentives for users, like decreasing the fee, when less waste is generated, and also waste collectors, which contribute to revenue stability from the fixed fee (EC, 2022).

Scarcity of investments in waste management processes

As there are several shortcomings in the collections systems of EU Member States, there is consequently a low rate of collected plastic waste. Moreover, once the plastic waste is collected, it is hard to break down the complexity of the separation process. Nowadays, there is less recycling capacity (approximately 50 %) than the waste sent to recycling. The other 50 % is sent overseas for recycling processes. This means, that the future capacities need to be increased, also in correspondence with the recycling targets of the EU: 55 % recycling of post-consumer plastic waste (Antonopoulos et al., 2021).

Moving forward improving the circularity of plastics, investments need to be made within the EU Member States. For this reason amounts in the range of EUR 0.7 – 1.3 billion per year must be aggregated. This estimation was calculated for an average plant capacity for sorting and recycling factories, as well as an assessment of the number of new plants, which need to be constructed. The assumption is the following: An average processing capacity of 45 000 tonnes per year for a new sorting plant and 35 000 tonnes per year for a new recycling factory, more or less 250 additional sorting plants, and 300 recycling factories by 2025 (EC, 2018b).

By introducing a more eager policy in the Circular Economy Action Plan (EC, 2020) with regard to the 2014-2020 Cohesion Policy funds, ex-ante conditions had to be fulfilled to guarantee new investments in the waste sector, which align with the plans of waste management. Investments in residual waste treatment facilities, like newly established landfills and incineration capacities, will only be allocated if the EU waste recycling targets are fulfilled (EC, 2018b).

On a national level, the support by State aid is of high importance. This is expressed by the guidelines on State aid for environmental protection and energy 2014-2020 (EC, 2014) and in the draft of 2022 State aid Guidelines on Climate, Environmental Protection and Energy (Latham & Watkins, 2022) with regard to indirect support of waste incineration with energy recovery. State aid needs to be in accordance with the EU legislation to guarantee separate waste collection (EC, 2018b).

Measures and actions

While the EC is following on actual implementation of the Waste Hierarchy, in which reuse and recycling are supposed to be preferred to incineration and landfilling, it is also important to observe, if Member States align with the current waste management legislation, established in the Waste Framework Directive (EPC, 2019).

Furthermore, the EC will emphasize pushing new guidelines on separate collection and the sorting process of waste. By revising the Plastic Packaging Waste Directive new targets will be set for the year 2030, as plastic waste will increase. The first results of the revision will be incorporated into a first draft, which is expected to be submitted in the first quarter of 2022 (Bioplastics Europe, 2022).

3.6 Reducing plastic waste

Generally, the volume of litter, which enters the marine environment per year is not known exactly. This is why most evidence is based on assumptions, which estimate, that most of the litter comes from the land and ends as micro- or macroplastics in marine areas. Moreover, issues like single-use plastics, over-packaging, and plastics generated by agricultural processes need to be addressed. The following chapter will deal with single-use plastics.

Definition and aim

"Single-use plastics are made wholly or partly of plastic and are typically intended to be used just once or for a short period of time before they are thrown away."

The Directive on single-use plastics ban became law in the EU Member States by 3rd July 2021. Market restrictions and marking of product rules are applied from July 2021, while the product design requirements for bottles apply from July 2024. The further extended producer responsibility measures will be applied from 31st December 2024 (EC, 2019a).

The Directive (EC, 2019a) acts in order to prevent and reduce the negative consequences on the environment of defined plastic products. Furthermore, it was installed to advance the process to a circular economy. This has happened and will be happening by applying various measures, which are designed for the

products designated in the directive. Throughout the EU Member States, counting can ban single-use plastic products whenever alternatives are available. The Directive even correspondents to the European Strategy for Plastics in a Circular Economy (EC, 2018a) as an important element (EC, 2019a).

Problems

In a report of UNEP (2016): Marine litter legislation: A toolkit for policymakers, States are urged to "*develop and implement laws to ban or diminish the production of single-use trash items and other waste that is commonly found in marine litter*". There are also surveys going on, that show, that there are massive amounts of plastic items found on the beaches, throughout Europe (EC, 2013).

As it makes no difference, if an item is used once or reused at all, in case it is littered, it harms the environment. Problems, which arise from cluttering, can have an impact even after hundreds of years. The plastic items will dissolve and the fragments of it damage not only the flora and fauna around human beings but also human health. Additionally, one can argue, that littered space is not attractive for tourism or leisure activities and therefore also impacts the reputation of recreation areas (UNEP, 2016).

Single-use items have a very short time of life, which is seen to be inefficient. Resources and energy could be saved if the product would be designed for reuse or even sustainable over years (UNEP, 2016).

Besides the aspect of inefficiency, it has to be mentioned, that waste always has to be collected and sorted, which are valuable economic factors. In most cases, single-used plastics are not recycled as there do not exist enough resources for public waste management infrastructure. Even contamination with food and organic material can occur, which makes the post-consumer treatment even harder to fulfill (UNEP, 2016).

Measures and actions

First of all, the Directive (EC, 2019a) aims to restrict the market by a ban of the following plastic products:

- cutlery (forks, knives, spoons, chopsticks)
- plates
- straws
- cotton bud sticks
- beverage stirrers
- sticks to be attached to and to support balloons
- food containers made of expanded polystyrene
- products made out of oxo-degradable plastic

Secondly, it promotes a reduction in consumption aligned with the EU's policy on waste (EPC, 1994). The EU Member States have to make sure to implement measures, which decrease the consumption of designated single-use plastics, in case there is no alternative to it, such as drinking cups including covers and lids or boxes for take-away food. The process is monitored by the EC and attempts to reduce the consumption of the above-mentioned products by 2026 compared to 2022.

Thirdly, a separate collection and design for plastic bottles are required, expecting the following measurements: The collection target is set by 90 % recycling of plastic bottles by 2029 with a temporary aim in 2025 of 77 %. The mentioned bottles should consist of at least 25 % recycled plastics by 2025 for PET bottles and 30 % by 2030 for all bottles.

Additionally, compulsory marking is obliged regarding a clearly visible, legible, and indelible marking, fixed to the packaging item or the product. This has to be applied on:

- sanitary items
- wet wipes
- tobacco products with filters
- and drinking cups

In order to extend the consumer's awareness, the producer is called to inform the user of the correct waste management or what option of disposal has to be avoided. Moreover, it should be stressed, that the presence of plastics in the item and littering has negative consequences on the environment. Producers are also expected to motivate consumers to responsible behavior.

Furthermore, the directive installs the 'polluter pays' principle. Producers will have to compensate for the costs of:

- waste management clean-up
- data-gathering
- awareness raising for the following products:
    - food and beverage containers
    - bottles
    - cups
    - packets and wrappers
    - light-weight carrier bags
    - tobacco products with filters

3.7 The European Green Deal

The European Green Deal (EC, 2019b) reaffirms the EC's commitment to deal with climate and environmental challenges. With each passing year, the temperature of the atmosphere rises and the climate changes.

This plan with its measures and actions can be a response to this. It sees itself as a new growth strategy to make the EU a fair and blooming society with a modern resource-efficient economy by reaching the target of zero net greenhouse gas emissions by 2050.

The strategy will also include measures for 'sustainable products' that will support the circular design of all products. The aim is to reuse materials over recycling. Therefore, the action plan will promote new business models and set minimum requirements to prevent harm to the environment. Extended producer responsibility will also be strengthened. While the Action plan for a new Circular Economy (EC, 2020) will guide the transition in all sectors, the measures will focus mainly on resource-intensive sectors like the textiles, construction,

electronics, and plastics branches. The EC will follow up on the Plastics Strategy 2018 (EC, 2018a) and will also work on measures to combat the targeted addition of microplastics and the unintentional release of plastics. The EC will develop requirements to ensure that all packaging placed on the EU market is economically viable.

This requires closer cooperation across value chains, such as through the Alliance for the Circular Plastics Economy (EC, 2020). The EC will consider regulatory requirements to stimulate the market for secondary raw materials through a mandatory recycled content, like packaging, vehicles, building materials, and batteries. In order to make waste disposal easier for citizens, the EC will also propose an EU model for separate waste collection. The EU should no longer export its waste and will therefore review the rules on waste shipments and illegal exports.

In addition, it is proposed that 25 % of the spending on all EU programs should contribute to the achievement of the climate targets. Moreover, the EU budget will also contribute to the investments. The EC has therefore stated to install new revenue streams, part of it will be based on payments for non-recycled plastic packaging waste.

The EC expects to reach the 2030 climate and energy targets by investing EUR 260 billion additionally, which is about 1.5 % of the GDP from 2018 (EU-28). The money will be mobilized by the public and private sectors.

4. Results and Discussion

4.1 Waste management system: Austria

The volume of waste generated in Austria in 2019 was around 71.26 million tonnes. This includes primary waste of 68.44 million tonnes and 2.82 million tonnes of secondary waste resulting from the treatment of primary waste, like ash from waste incineration (BMK, 2021a).

The following Figure 6 shows the development of Austria's total annual waste generation since 1990.

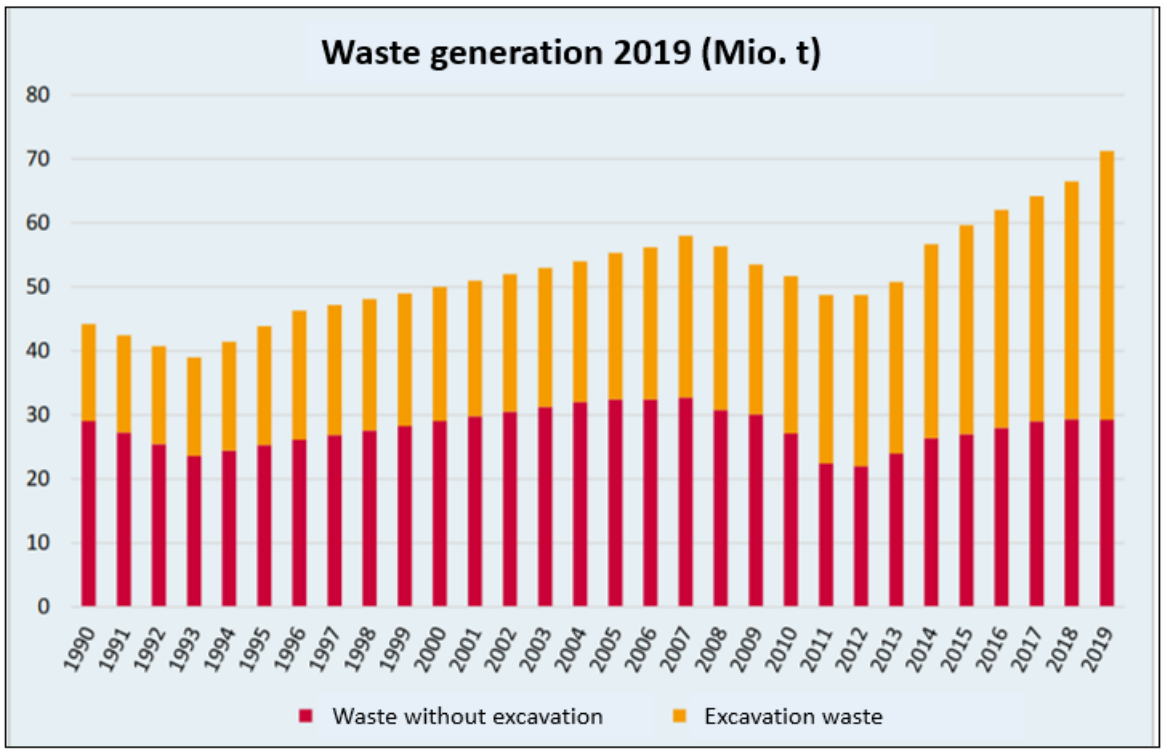

Figure 6: Waste generation (million t) in Austria, (BMK, 2021a)

Until 2010, however, this volume also included a part of the residues from the treatment and processing of waste and processing of materials which was included in the waste potential until 2010, so a direct comparison of the current figures with the historical waste volume is only possible to a limited extent (BMK, 2021a).

The volume of primary waste has increased from 57.1 million tonnes in 2015 to 68.44 million tonnes in 2019. In the year 2019, this means an increase of 20 %. The increase is mainly due to the rising quantities of excavated materials and waste from the construction industry (BMK, 2021a).

The separate collection of glass, metal and plastic packaging from the household sector increased from around 402 100 tonnes in 2015 to around 444 100 tonnes compared to 2019. This means an increase of 10 % (BMK, 2021a).

In 2019, the per capita waste generation (excluding excavated materials) was 3 294 kg per inhabitant. Figure 7 shows a comparison of the development of economic performance (GDP in EUR/EW) and waste generation (excluding excavated materials, in kg/EW). The GDP shows a clear decline of -1.6 % due to the economic crisis in the transition from 2008 to 2009. Moreover, the waste generation declined by -2.4 %, and subsequently decreases until 2012, with the strongest decline (-21.3 %) in the transition 2010/2011. From 2012 onwards, both indicators show an increase again. The course of the last five years (2015-2019) shows a continuous increase in both GDP and waste generation, but in comparison, it also shows a decoupling of waste generation (+5.3 %) from GDP (+12.3 %). It is assumed that this is also due to the intensified efforts in the area of waste and circular economy on the national and national and European levels.

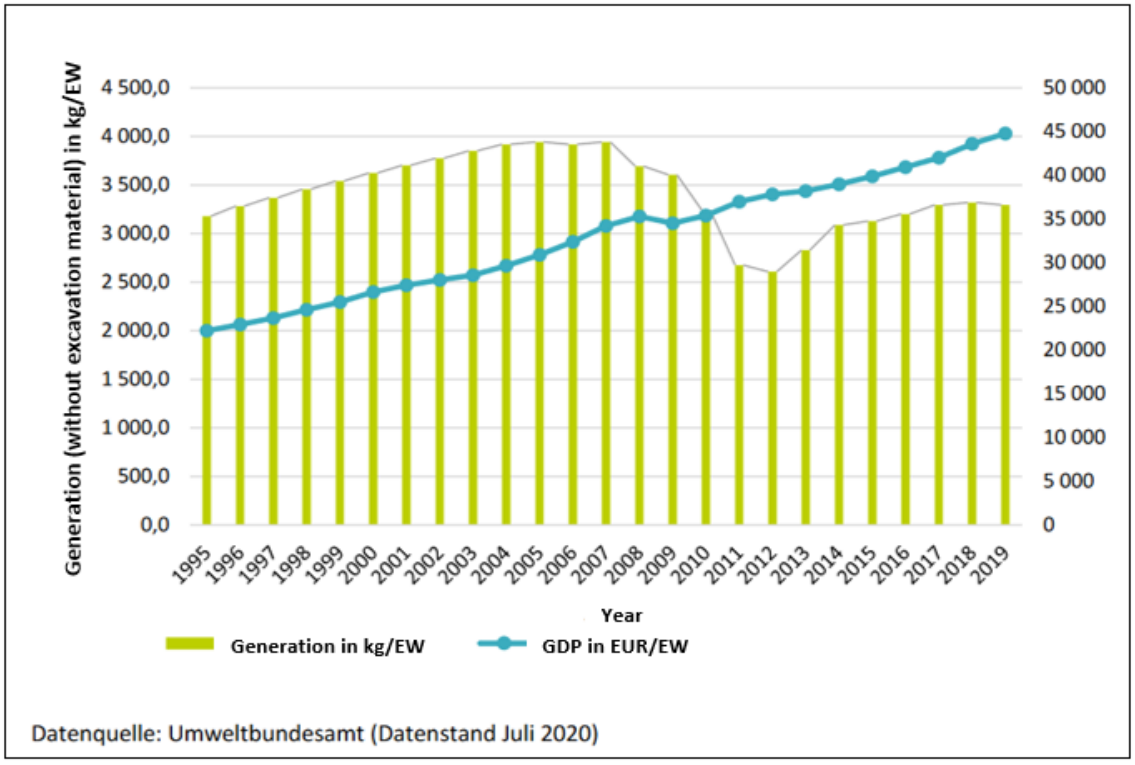

Figure 7: Per capita waste generation (masses without excavated materials) in comparison with gross domestic product 1995-2019, (BMK, 2022)

Overview of the waste treatment in 2019

There are about 3200 treatment plants in Austria. A considerable proportion of the waste is treated within the companies.

The treatment of all waste can be demonstrated as the following:

- 41 % was materially recovered (recycled and backfilled)
- 7 % was thermally treated in plants is subject to the waste incineration ordinance
- 46 % were landfilled
- 6 % of the waste was treated in other ways

Compared to 2018, the share of waste sent to landfills has increased by about 3 %. Whereas the share of recycling decreased by four percentage points. This can be attributed to the large increase in excavated materials, such as those produced during the construction of the Brenner Base Tunnel (BMK, 2021a).

4.1.1 National legislation

The most important legal basis for waste management in Austria is the Waste Management Act (AWG 2002). In addition to the AWG 2002, all nine provinces have provincial laws in force that regulate those aspects of waste management law that are the responsibility of the provincial legislators.

This mainly concerns the setting of waste fees and the legal framework for the organization of waste collection. The most important contents of the AWG 2002 concern the prevention, preparation for re-use, recycling, other recovery and disposal of waste, obligations of persons working in waste management, and specifications for waste treatment plants.

The AWG 2002 is enforced by the provincial governors and the Federal Ministry for Climate Protection, Environment, Energy, Mobility, Innovation, and Technology (BMDW, 2022).

In addition to the national provisions, there are a large number of legal regulations under European law, some of which are to be directly enforced in Austria, like the Ordinance on the Shipment of Waste, and some of which are to be transposed into national law, for example, the Waste Framework Directive. These regulations create the legal framework to ensure functioning waste management in Austria (BMDW, 2022).

The collection of municipal waste is regulated by the individual provincial waste management laws. The organization of municipal waste collection is also usually the responsibility of the individual municipalities or associations of municipalities. For more information on how waste collection is organized at your place of residence, what you have to observe - especially waste separation - and which costs you have to bear, please contact your municipality (BMDW, 2022).

Deposit system in Austria

From 2025 onwards, plastic bottles and beverage cans will be subject to a deposit system. This means that a deposit will be charged on the purchase of disposable beverage containers – this deposit will be returned to the customer when the packaging is brought back to the shop (BMK, 2021a).

"On 1 January 2025, Austria will introduce a deposit on plastic bottles and beverage cans. I want to prevent this waste from being thrown away carelessly. That's why we need the deposit - you'll get it back if you also return the packaging. Then we can recycle better and make sure that a bottle becomes a bottle again and a can becomes a can again," says Climate Protection Minister Gewessler (BMK, 2021a).

Already in 2024, the mandatory reusable offer will gradually return to the shops. From then on, all supermarkets are to offer refillable containers for all beverage categories – from beer to juices to milk. This does not only protect the climate but also saves valuable energy and resources. In the next step, the Climate Protection Ministry will work out the details of the deposit system, such as the specific deposit amount, together with partners from the business community (BMK, 2021a).

In a study, which was ordered by the Ministry of Climate in 2020 (BMK, 2020), there are four variants of the implementation of the deposit system. Unfortunately, none of the variants is clear on the plastic bottle’s size. Variant 4, for example, includes all PET bottles of all sizes. But in reference to the Minister’s quote above, one can assume, that there will follow up a more precise elaboration.

Advantages of the one-way deposit

One-way deposits reduce the tax burden. According to EU regulations, 90 % of plastic beverage packaging must be collected separately by 2029. Currently, Austria is at about 70 %. The introduction of a one-way deposit increases the recycling rate of PET and Austria has to pay less plastic tax to the EU (BMK, 2021a).

Only through a single plastic-type collection, the reprocessed post-consumer plastic waste can be considered as for example packaging for food or beverages. From 2025, PET bottles must contain 25 % recycled material and by 2030 this should be increased to 30 %. The goal for companies is to use around ten million tonnes of recycled plastics in their packaging by 2025 - quadrupling the current demand (EU-Recycling, 2020). These days, Austrian beverage producers and bottlers import food-grade plastic recyclates in large quantities because they are not available on the Austrian market. It will also be easier for consumers to recycle properly. Most bottles can simply be returned to the shop and will then be recycled (BMK, 2021a).

Further advantages of the mandatory reusable quota

All food retail outlets larger than 400 m² will gradually have to offer beverages in reusable packaging from 2024. This includes all beverage categories: Beer and beer-mixed drinks, mineral water, non-alcoholic soft drinks (such as lemonades), juices, and milk. By 2030, 30 % of the beverages sold in Austria are to be filled in returnable bottles (BMK, 2021a).

Furthermore, freedom of choice for consumers will be considered, as reusable bottles will be available in every shop in Austria. Reusable containers such as glass bottles help to significantly reduce the amount of plastic waste. They can be refilled up to 50 times – this saves energy and resources (BMK, 2021a). It also has to be stated, that the transport weight of the glass will then increase, and savings might not be that high, as assumed before.

In order to prepare and implement the introduction well in the retail sector, the reusable obligation will take place gradually. From 2024, reusable beverages must be offered in at least every third branch of a company, and from 2025 in 90 %. At the end of 2025, the reusable quota will also apply to the remaining branches (BMK, 2021a).

Plastic carrier bags ("Plastiksackerl"):

The Directive 94/62/EC (EPC, 1994) on packaging and packaging waste requires the individual Member States to take measures to reduce the consumption of light plastic carrier bags annually.

In total, 457 million lightweight plastic carrier bags were put into circulation in the year 2018 in Austria. 360 million of them with a wall thickness of < 15 micrometres and 97 million with a wall thickness between 15 and 50 micrometres.

In 2019 compared to 2018, significantly fewer, namely 330 million, lightweight plastic carrier bags were on the market. Of these, 261 million with a wall thickness of < 15 micrometres and 69 million with a wall thickness of between 15 and 50 micrometres (BMK, 2022).

4.1.2 Packaging flows on a national level

According to the Packaging Directive 2014, Federal Law Gazette II No. 184/2014 (BMK, 2014), the packaging is made of different packaging materials, packaging aids, or pallets for the protection, handling, delivery, and presentation of goods.

Packaging materials include the following materials:

- paper, cardboard, paperboard, and corrugated board,
- glass,
- wood,
- ceramics,
- metals,
- textile fibres,
- plastics,
- composite beverage carton, other material composites,
- other packaging materials, especially on a biological basis

Table 1: Packaging waste generation 2014-2019 in tonnes, (BMK, 2022)

Packaging waste generation 2014-2019 in tonnes						
Packaging material	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Paper	542 419	553 267	564 333	575 620	590 000	606 520
Glas	272 676	274 485	275 365	278 337	291 338	302 314
Metal	55 982	56 840	61 969	63 188	63 758	64 556
Plastics	291 968	294 888	297 837	302 306	302 000	295 752
Wood	93 338	89 352	96 888	112 960	109 525	111 925
Others	47 145	42 414	44 319	44 594	57 000	56 488
Overall	1 303 528	1 311 246	1 340 711	1 377 005	1 413 621	1 437 555

Table 1 shows the packaging waste generation in Austria in the years from 2014 until 2019 in tonnes. In all types of packaging material, we can see an increase in the mentioned time frame.

Throughout Austria, about 1.44 million tonnes of packaging material are currently put on the market each year or accumulate as waste (collected separately and in mixed fractions such as residual waste or commercial waste).

Depending on the type of packaging material, the type of collection, and the location of the waste/collection different ways of recycling and recovery mechanisms are applied. In the household sector, paper packaging is collected together with other paper products and subsequently put into recycling processes in order to make hygienic paper, newspapers, printed matter, etc (BMK, 2022).

Approximately 68 000 collection containers are available for the separate collection of white and colored glass in Austria. The collected waste glass is subjected to several sorting processes in the glassworks. This implies sorting processes, like manual sorting, magnetic separators, and sieves, which then are used for the production of new glass packaging (BMK, 2022).

Separately collected metal packaging material is sorted in sorting plants or shredder plants, where almost one hundred percent recycled. Aluminum is sorted out with the help of eddy current separators and then recycled without losing its specific properties (e. g. conductivity) (BMK, 2022).

In Austria, there are different models for the separate collection of light packaging (collective term for packaging made of plastics, material composites, wood, textiles, ceramics, and biogenic packaging materials) in the household sector (BMK, 2022).

There is either a joint collection of all light packaging in the yellow bag (collect system) or in the yellow bin (bring system) or a specific collection of plastic bottles (hollow collection). In some regions, lightweight packaging and plastic bottles are collected together with metal packaging and then separated from each other for further recycling (BMK, 2022).

Collected plastic packaging is sorted according to the different types of plastic and contaminants are removed. Afterward, the sorted plastic packaging is shredded, washed, dried, melted, and processed into granulate. The high-grade recycling processes include, for example, bottle-to-bottle recycling, in which separately collected PET bottles are sorted by color and subjected to a special cleaning process and then used for the production of new PET beverage bottles (BMK, 2022).

The collected wood packaging is sorted, shredded, and processed into wood chips. Wood chips are used in the wood industry for the production of chipboard, in thermal processes, and for the production of wood-based products (BMK, 2022).

Figure 8 shows a material flow analysis of packaging materials in tonnes in 2019. The total waste generation is accounted for 1 438 000 tonnes, 890 000 tonnes are material recycled, 419 000 tonnes recycled thermally, and 13 000 tonnes recycled in other ways (BMK, 2022).

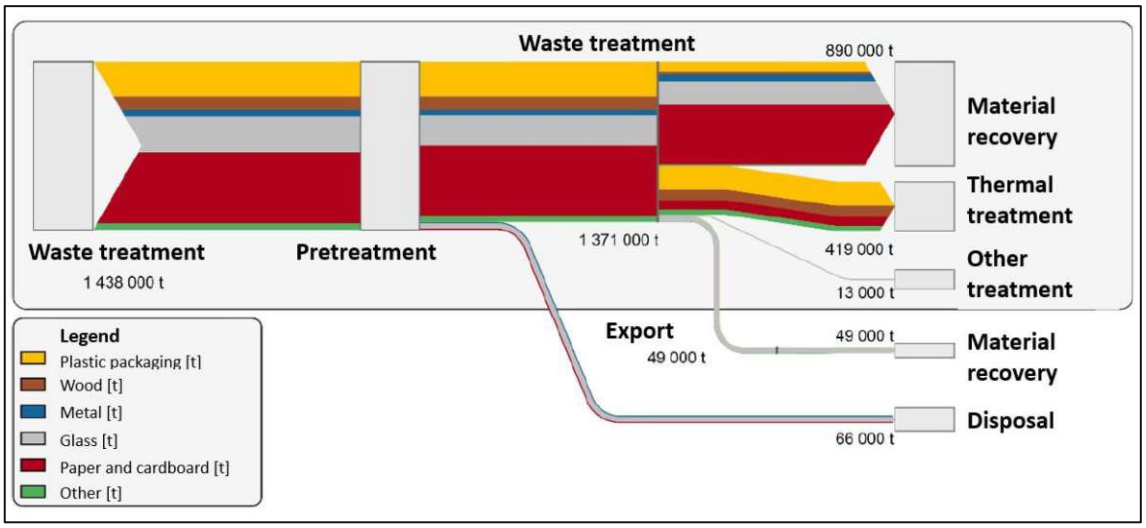

Figure 8: Material flow analysis of packaging materials in tonnes in 2019, (BMK, 2022)

4.1.3 Plastic packaging waste flows

The following plastic packaging waste flows in Austria (cf. Figure 9) are based on an article by Emile Van Eygen (2017) with the title: Circular economy of plastic packaging: Current practice and perspectives in Austria.

In the study, Figure 9 was designed in order to demonstrate the model of a MFA, which depicts the plastic packaging waste lows in Austria of the year 2013. Furthermore, all plastic packaging products are represented from the point of becoming waste until the process of post-consumer treatment, such as energy recovery, deposition, or even landfilling. The elected waste stream was divided into seven categories:

- PET bottles
- hollow bodies (< 5 l)
- hollow bodies (≥ 5 l)
- films small (< 1,5 m^2)
- films large (≥ 1,5 m^2)
- expanded polystyrene large (EPS) (≥ 0,1 kg)
- other products

In this analysis only products with a 100 % content of plastics are considered, composites like cartons for the use of food or drinks are not. For each of the categories a, separate waste stream was taken into account. The following eight

polymers are used for plastic packaging in Europe and represent 99 % of all plastics used:

- LDPE
- LLDPE
- HDPE
- PP
- PS
- EPS
- PET
- PVC

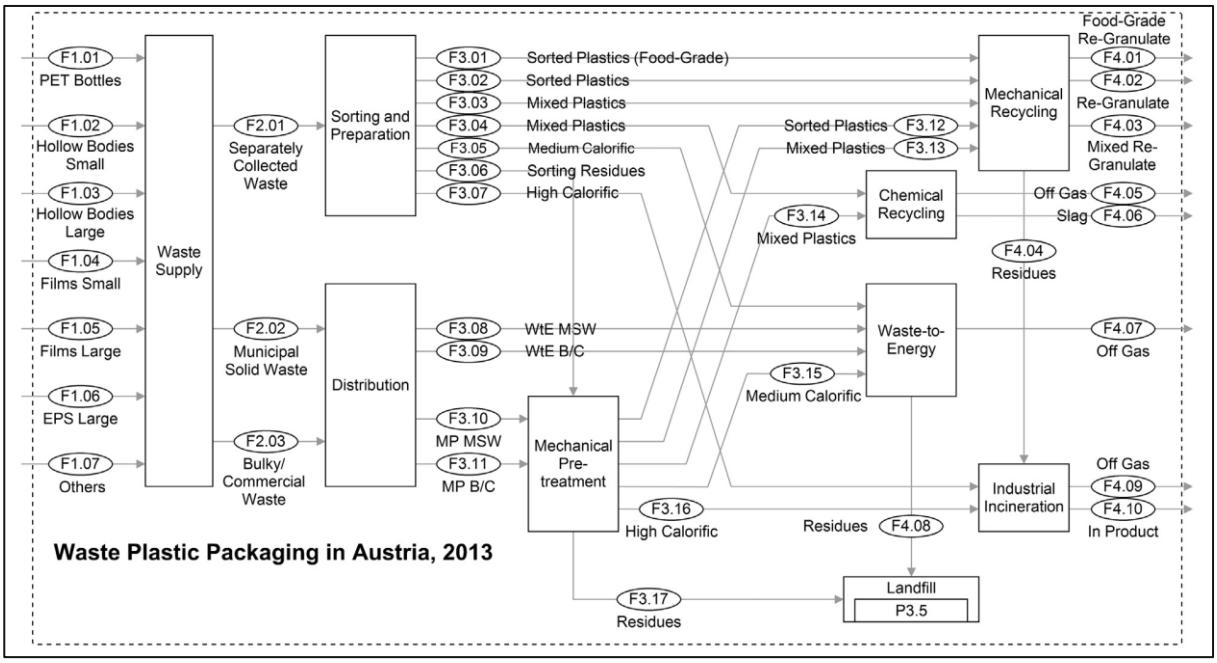

Figure 9: Plastic Waste Packaging in Austria in the year 2013, (Van Eygen et al., 2017)

In the model, Van Eygen et al. (2017, cf. Figure 9) describe plastic packaging material types, which had been collected separately or disposed in the municipal solid waste or in bulky and commercial wastes.

The stream of the separately collected plastic waste is then sorted into 18 segments, where each segment is based on polymer, product type, and color and then forwarded to single-polymer mechanical recycling. One part of the PET waste stream is processed to higher value food-grade regranulate. The mixed

plastic stream is treated in a mechanical recycling process, accounting for three types: Single-polymer recycling to result in food-grade re-granulate (e. g. PET bottles) and non-food-grade re-granulate and mixed-polymer recycling. Chemical recycling can also be used for mixed plastic streams, as the treated items can be an alternative reducing agent in the steel industry. Other sorting residues can be used in the cement industry as an alternative fuel (Van Eygen et al., 2017).

Due to the ban on direct landfilling of waste with an organic carbon content higher than 5 %, MSW and BCW are either used for energy production or pretreated in a Mechanical Biological Treatment (Van Eygen et al., 2017).

4.1.4 Collection, sorting and recycling rates

In Figure 10 the result of the MFA for waste packaging plastic flows in Austria in 2013 can be seen, in an article by Picuno et al. (2021a).

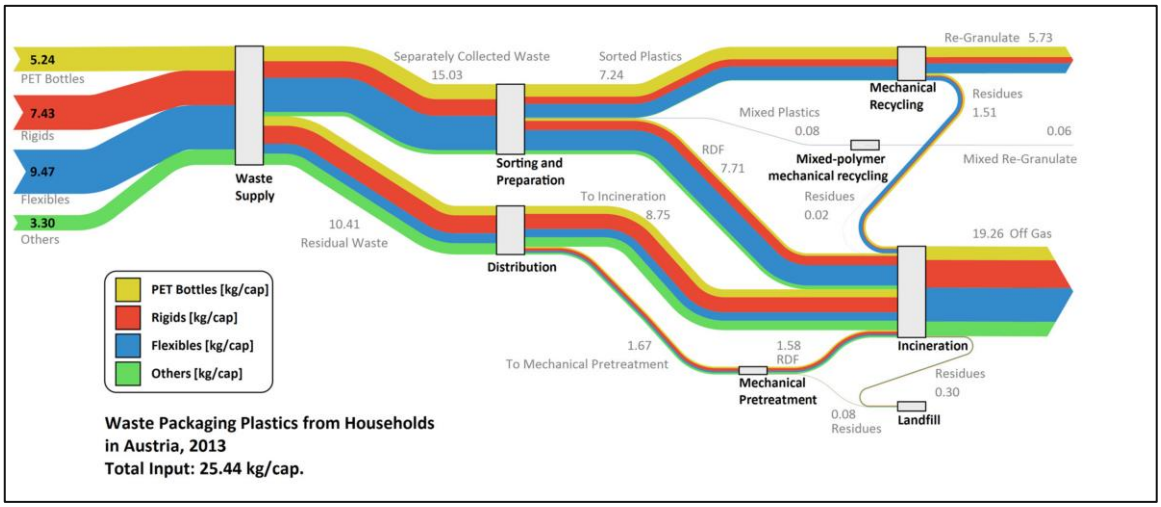

Figure 10: Waste Packaging Plastics from households in Austria in 2013, (Picuno et al., 2021a)

In the prementioned year, a total plastics packaging waste production of 25.44 kg per person was recognized. This value is composed of 21 % PET bottles, 37 % flexibles, 29 % rigids, and 13 % others. Approximately 60 % is collected in separate systems, where the highest value counts for flexibles (77 %) and PET bottles (61 %). Around 50 % of the waste input is recovered and put into recycling processes. The sorting process implies the process of fractioning for single-polymer recycling, where 99 % of the output will be recycled, and segments of mixed polymer, which are recovered thermally. Notably, PET bottles

demonstrate a high sorting rate of 83 %, whereas flexibles, rigids, and other types are recovered at a smaller level. In the recycling process the input accounts for 29 %, whereas the output is 23 % (Picuno et al., 2021a).

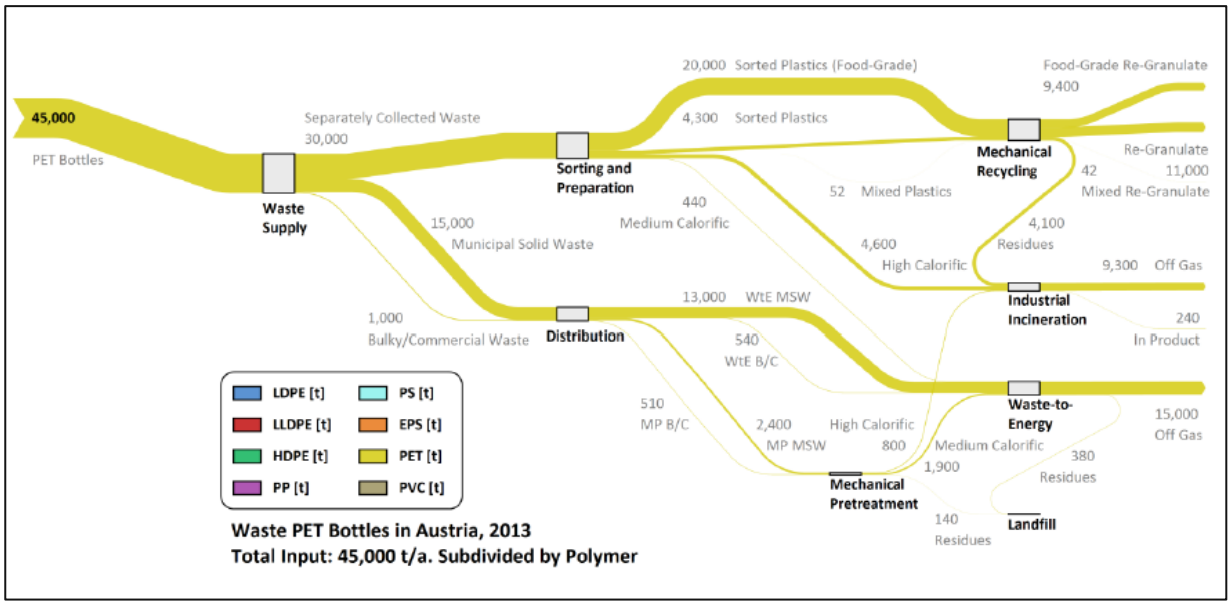

Figure 11: Results of the material flow analysis for PET bottles, (Van Eygen et al., 2017)

In Figure 11 we can see a MFA for PET bottles in Austria (Van Eygen et al., 2017). In 2013, 45 000 tonnes per year of PET bottles had been collected. After the sorting, and preparation process, a part of the PET bottles (11 000 tonnes) was mechanically recycled to re-granulate or mixed re-granulate. Another part was industrially incinerated or used for waste-to-energy processes.

Recycling rates for packaging in Austria

The following recycling rates for packaging must be achieved by 2025 according to the Federal Waste Management Plan of 2022 (BMK, 2022):

- in total: 65 %
- plastics: 50 %
- wood: 25 %
- ferrous metals: 70 %
- aluminum: 50 %
- glass: 70 %
- and paper and cardboard: 75 %

The following recycling rates for packaging must be achieved by 2030:

- in total: 70 %
- plastics: 55 %
- wood: 30 %
- ferrous metals: 80 %
- aluminum: 60 %
- glass: 75 %
- and paper and cardboard: 85 %

The achievement of the targets is subject to the following conditions according to Decision 2005/270/EC, as last amended by the Implementing Decision (EU) 2019/665.

Although, as previously mentioned (cf. Figure 11) PET bottles demonstrate a high sorting rate (83 %) compared to rigids or other types of material, the recycling output accounts for only 23 % (Picuno et al., 2021a). In the year 2025, the Austrian national PPW recycling target is set at 50 % (BMK, 2022), which means that Austria needs to improve and speed up in order to reach the goal. For 2030, the national PPW recycling target strives to reach 55 %.

In conclusion, this means, that Austria needs to implement a faster recycling process to increase the PPW recycling target by 32 % in the upcoming eight years. A solution would be to financially reward companies that bring easily recyclable or already recycled product packaging onto the market with the slogan: *"The higher the recyclability, the lower the fees, and the higher the competitiveness!"* Responding to regulatory pressure, more than 70 business associations have agreed to produce or use more recycled plastics to expand the recycled plastics market by at least 60 % by 2025 (EU-Recycling, 2020).

4.2 Waste management system: Germany

In the year 2020, 78 kg of packaging waste was collected per person from private households in Germany. This was an average of 6 kg more per person than in 2019. As the Federal Statistical Office further reports according to preliminary results, the total volume of packaging waste, which is mainly collected in the yellow bin, glass, or paper containers separately from residual waste, increased by just 0.6 million tonnes or 9.3 % to 6.5 million tonnes in 2020 (Destatis, 2022).

Almost 32 kg per person (a total of 2.7 million tonnes), of light packaging was collected from private households as part of the packaging waste collection effort. Light packaging is often composed of plastic, aluminum, or tinplate packaging. This was followed by glass packaging with 25 kg per inhabitant (2.1 million tonnes) and packaging made of paper, cardboard, and carton with 20 kg per capita (1.7 million tonnes) (Destatis, 2022).

This means that the per capita volume of paper, cardboard, and carton packaging collected from private households increased by 3 kg compared to 2019. In the case of glass packaging, 2 kg more were collected per capita. The per capita quantity of lightweight packaging has not changed compared to the previous year (Destatis, 2022).

4.2.1 National legislation

In Germany, the first uniform federal regulation of waste law was created in 1972 with the Act on the Disposal of Waste. Today, the Act on the Promotion of the Circular Economy and Ensuring the Environmentally Sound Management of Waste (Kreislaufwirtschaftsgesetz, KrWG) are the main regulatory instruments regarding waste law provisions. As a successor regulation, the KrWG retains the structure of Closed Substance Cycle and Waste Management Act. Additional regulations relating to specific products are found in the Packaging Act, the End-of-Life Vehicle Act, and the Packaging Recyclability Act (UBA, 2022).

In June 2012, the act to promote Closed Substance Cycle Waste Management (Closed Substance Cycle Waste Management Act, KrWG) came into force. The KrWG transposes the requirements of the EU Waste Framework Directive

(Directive 2008/98/EC) into national law. The circular economy is to be even more strongly oriented toward resource, climate, and environmental protection (UBA, 2022)

As a core element, the KrWG anchors the five-level waste hierarchy (previously three-level) in § 6. According to this, the following order of priority among waste management measures applies in principle: Avoidance, preparation for reuse, recycling, other recovery, in particular, energy recovery and backfilling, and disposal (UBA, 2022).

Dual System Deutschland

The dual systems in Germany organize the nationwide collection, sorting, and recovery of used sales packaging for industry and trade. For this purpose, industry, and commerce each report their sales packaging quantities placed on the market according to the material type and pay corresponding participation fees (also known as license fees) to the dual system with which they cooperate for the services to be provided. The basis for the work of the dual systems is the applicable Packaging Act (GSSD, 2022).

The introduction of the "dual system" as a private-sector collection system alongside municipal waste collection took place in 1990 with the first draft of the Packaging Ordinance. This was intended to involve companies that put packaging on the market in the collection and recycling of packaging waste for the first time. The Packaging Ordinance came into force in December 1991 and pursued the goal that packaging waste should be avoided, reduced, and recycled. It obliges manufacturers and retailers to take back and recycle sales packaging after use. Thus, for the first time, a product responsibility from production to environmentally sound disposal was created. Industry and trade were obliged for the first time with the Packaging Ordinance to take back their sales packaging and recycle it. In the beginning, alternatives to packaging collection, sorting, and recycling by the dual systems were still permitted. Since 2009, distributors of sales packaging have been obliged to participate in a dual system. On 1st January 2019, the Packaging Act replaced the Packaging Ordinance and forms the new legal basis for the work of the dual systems. The Packaging Act stipulates significantly higher recycling quotas once again (GSSD, 2022).

The dual systems are in duty of the nationwide collection of used sales packaging. In terms of collection, there are two main types: pick-up and bring. The most common pick-up system is the pick-up system, in which the used packaging is collected directly from private home of the end consumer. These are the paper bins where the paper, cardboard, or carton is collected (GSSD, 2022).

Concerning the bring system, on the other hand, consumers have access to collection containers near their households. These containers are mainly for glass and sometimes also for paper packaging. Packaging that is collected elsewhere via the yellow bin or yellow bag is occasionally gathered in the bring system's containers.In some areas, there are also recycling centers where packaging and other trash, such as bulky debris, discarded electrical and electronic equipment, residual paint, and so on, can be dropped off.According to the Packaging Act, municipalities are primarily responsible for determining the type of collecting containers and disposal schedules. In essence, however, the dual systems are responsible for arranging and funding the collection, sorting, and recycling of packaging. (GSSD, 2022).

Deposit system in Germany

The German deposit system distinguishes between two types of beverage packaging: Returnable and non-returnable packaging. In Germany, a deposit must always be paid on returnable bottles, regardless of whether they are made of glass or PET plastic and regardless of the beverage inside. This deposit system has been in place for a very long time (DW, 2021).

From 1st January 2022, all non-returnable plastic beverage bottles are subject to a deposit. A transitional period until 2024 applies to plastic bottles with milk drinks. All beverage cans, without exception, will also be subject to a deposit from 2022. One-way beverage containers that have already been put on the market may still be sold without a deposit until 1st July 2022 at the latest. The deposit system for one-way drinks bottles ensures that they can be recycled. New bottles or textiles, for example, can be produced (Die Bundesregierung, 2022).

Up to now, a deposit of EUR 0.25 has been charged on non-returnable bottles of beer, mineral water, soft drinks, and mixed drinks containing alcohol. Milk, wine, spirits, fruit, and vegetable juices have so far been excluded from the one-way

deposit. Even niche products such as cider, cider, or energy drinks are still deposit-free (Die Bundesregierung, 2022).

From 2025, non-refillable PET beverage bottles must contain at least 25 % recycled plastic, so-called recyclate. From 2030, this quota will be increased to at least 30 % for all beverage bottles made of single-use plastic (Die Bundesregierung, 2022).

PET beverage bottles already contained an average of 26 % recycled material in 2015. The Federal Environment Ministry considers the technical prerequisites for producing beverage bottles from 100 % recycled material to be given. The proportion of recyclable material is increasing by about 1 % by mass every year (Die Bundesregierung, 2022).

Deposit machines in supermarkets recognize what kind of deposit bottle is being returned and automatically calculate how much has to be paid back. Where there are no machines, staff accept the bottles (Die Bundesregierung, 2022).

4.2.2 Plastic packaging waste flows

In Germany, the MSW is collected via curbside collection and then transported to a municipal waste-to-energy facility for energy recovery. Throughout the country, a separate collection system of plastic packaging products is applied. Additionally, collection systems for plastic-, paper-, metal-, and composite-supported packaging and non-packaging are installed. Drop-off and curbside collection are in use. In comparison to Austria, a deposit refund system (DRS) for PET bottles exists. After the separate collection process, the plastic packaging waste (PPW) is brought to factories, where it is then sorted into twelve product types. Recyclable items are labelled with a purity level defined by the Deutsche Kodierrichtlinie (DKR) specifications. Among those polymers, there are four pure ones: PET, PE, PP, and PS (Schmidt et al., 2020).

The following results of the MFA for PET bottle waste in Germany are based on an article by Sarah Schmidt et al. (2020) with the title: Material efficiency to measure the environmental performance of waste management systems: A case study on PET bottle recycling in Austria, Germany and Serbia.

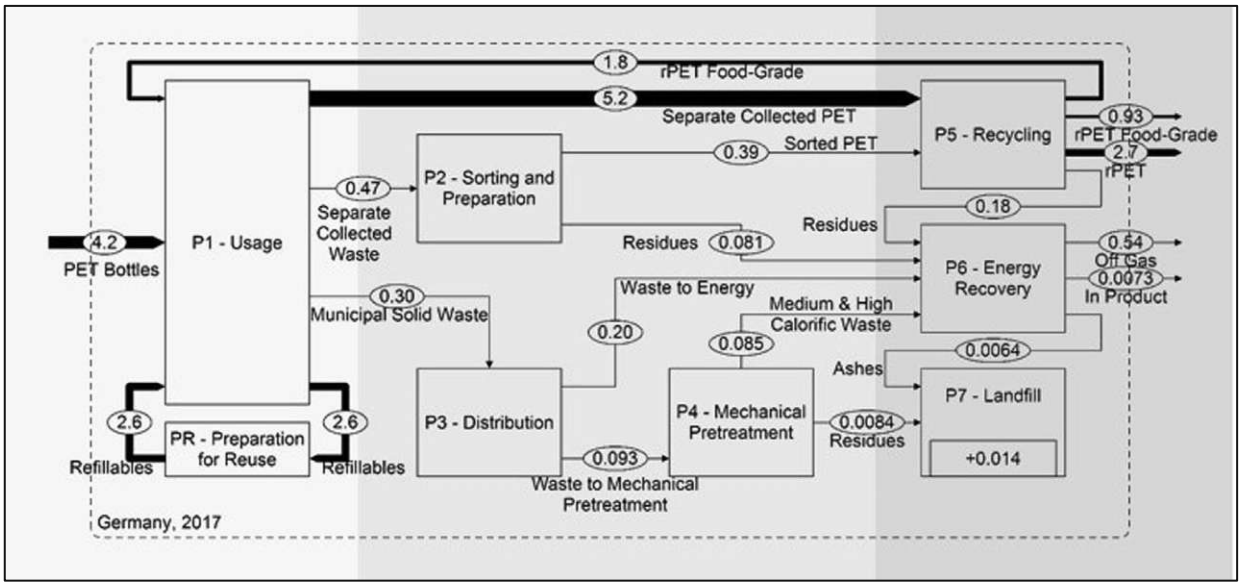

Figure 12: MFA for PET bottle waste management in Germany, 2017 (Schmidt et al., 2020)

In Figure 12 we can see that 6 kg per person and year (pa) of PET bottles were used in 2017 in Germany. Out of this amount, 30 % was recycled content. Additionally, for the non-refillable bottles, 2.6 kg/pa of refillable PET bottles were utilized. The separate collection rate *(separately collected waste divided by the total amount of waste)* can be accounted for 95 %. A final recycling rate *(recycling output [target fraction] divided by the total amount of waste)* of 91 % was then fulfilled (Schmidt et al., 2020).

4.2.3 Collection, sorting and recycling rates

In Figure 13 the result of the MFA for waste packaging plastic flows in Germany in 2017 can be seen, in an article by Picuno et al. (2021a).

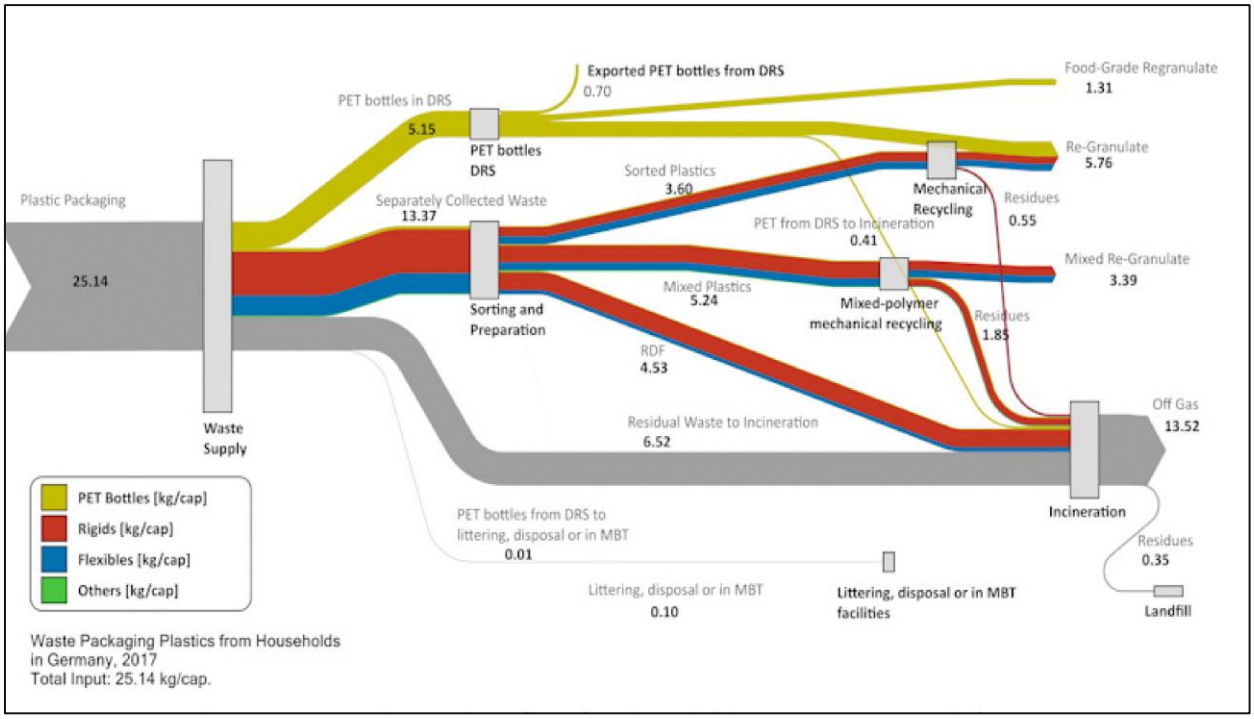

Figure 13: Waste packaging plastic flows from households in Germany in 2017 (kg/cap), (Picuno et al., 2021a)

In 2017, 25.14 kg per person of plastic packaging waste was created in households in Germany 88 % of all PET bottles, smaller and bigger than half of a liter, were collected by the respecting DRS system. Of this amount, 14 % went to export for recycling processes. For the separate collection stream, 13.37 kg per person PPW was collected separately, fractioned into 64 % of rigids, 29 % films, 5 % PET bottles, and 2 % of EPS-based packaging. In the sorting process 35 % of PET bottles, 39 % of films, 21 % of rigids, and 9 % of other items had been sorted correctly. Residues, resulting from processes of sorting and mechanical processes, along with fractions of PPW in residual waste were sent to incineration. The incineration bottom ash was then finally landfilled (Picuno et al., 2021a).

4.3 Waste management system: Netherlands

In 2018 the Dutch households produced 562 236 tonnes of plastic waste (Eurostat, 2022). This demonstrates that approximately 520 kg of waste was generated per inhabitant in households in the Netherlands. This value puts the country well above the EU average of 428 kg per EU citizen. Of these huge mountains of waste, a large part is nevertheless recycled. In the Netherlands, 78 % of household waste has been recycled for many years, 19 % incinerated and only 3 % landfilled.

In 2017 the Dutch packaging framework agreement defined a recycling target of 47 % for plastic packaging waste. The measurements are applied to sorted products of certified plastic recyclers. Each packaging producer is required to announce the amount of material in public, that is entering the market. In addition to that, they must pay a fee to the Extended Producer Responsibility (EPR) schemes, in order to transpose the responsibility to handle the collection to recycling processes. In the Netherlands, the respective producers have to pay fees to only one EPR operator, which is called Afvalfonds. Within the country separate several different collection systems for plastic packaging are in operation, in special cases also with further packaging material, such as pieces of metals, cartons, or wood. Drop-off containers and a curbside collection are in use. The Plastic Packaging Waste, which is collected separately, is then sorted into 20 different segments, which will be recycled. All the mixed fractions are entering the generation process of refuse-derived fuel (RDF) (Picuno et al, 2021a).

Lightweight Packaging (LWP) waste is treated in almost the same manner as in Germany. Alvalfonds requests municipalities for the collection of LWP. The sorting process and the paying of the fees will also be organized and handled by the before-mentioned company. Plastic packaging, metal packages, and beverage cartons are part of the LWP portfolio. Each municipality in the Netherlands can organize its collection system, but the most common ones are a curbside collection of LWP in bins and bags for districts with low-rise buildings and a drop-off collection system for high-rise buildings. The recovered, as well as the separately collected LWP, is then sorted in the respective segment, according to these specifications (Picuno et al., 2021a):

- PET bottles
- PE rigids
- PP rigids
- flexible packages
- mixed plastics
- PET-tray-sorted products

4.3.1 National legislation

Netherland's national legislation on waste management is part of the Environmental Management Act. The Dutch National Waste Management Plan (*Landelijk Afvalbeheerplan)* is based on the previously mentioned act. The act demonstrates the legal framework towards the national and municipal government levels in accordance with the EU Waste Framework Directive (Government.nl, 2022).

The Ladder van Lansink, introduced in 1979, describes the Dutch waste policy as the following and tries to standardize the handling of waste (recycling.com, 2022):

"Order of preference": In waste management, there is a hierarchy, the "Ladder van Lansink". This is a waste hierarchy, introduced in 1979, by the politician Lansink, which standardizes the management of waste.

At first, an effort is made to decrease the amount of waste, then to reuse the waste generated, or then to reuse it in recycling processes. The remaining waste is to be used energetically, e. g. in waste incineration plants, and deposited in landfills as a last option.

"Stringent waste treatment standards": The high standards for waste disposal protect the environment and assure good air quality.

"Planning at national level (in close cooperation with local governments)": The coordination of waste management is managed through close contact with the state, district, and local governments.

"Extended reproducer responsibility": Manufacturers and importers of products should be encouraged to take responsibility for the entire life cycle, including

disposal and recycling of their products. This can be done on a voluntary basis or by law, e. g. by levying taxes on hazardous waste.

"Use of various instruments to stimulate prevention and recycling": It includes taxation of household waste according to volume, waste separation regarding organic waste, waste paper, plastic, and glass, and communication with the population.

Deposit system in the Netherlands

Although there is a clear deposit regulation from 2003, it has not been actively implemented. However, the business community is following these guidelines. For years, a clearer introduction of a broad deposit system has been discussed in Dutch politics. The latest approach to implement a deposit on small plastic bottles took place in spring 2019. From 1st July 2021, there will also be a deposit of EUR 0.15 on small plastic bottles (≤ 1 l) (Dachist, 2021).

Whether a bottle is a deposit bottle or not is written on the label. In the case of a deposit bottle, "Statiegeld", "Statiegeldfles" or even the deposit amount is indicated there. In the case of the so-called mono bottles and also the small deposit-free PET bottles, clear recycling symbols indicate that the bottle in question should be disposed of in the glass container. (Dachist, 2021).

Mono bottles are disposable and deposit-free. The mono bottles often have a screw cap. Mono-bottles are available in sizes from 0.15 l to 0.50 l and should be disposed of in glass containers. In the Netherlands, there is currently no deposit on cans. Cans can be disposed of through the recycling system in many municipalities. Wine bottles are deposit-free in the Netherlands. Empty wine bottles should be recycled via glass containers. There is currently no deposit on juice packaging. There is currently also no deposit on milk packaging. Empty milk packaging - either plastic or beverage cartons made of multi-layer packaging materials should be disposed via the recycling container (Dachist, 2021).

4.3.2 Plastic packaging waste flows

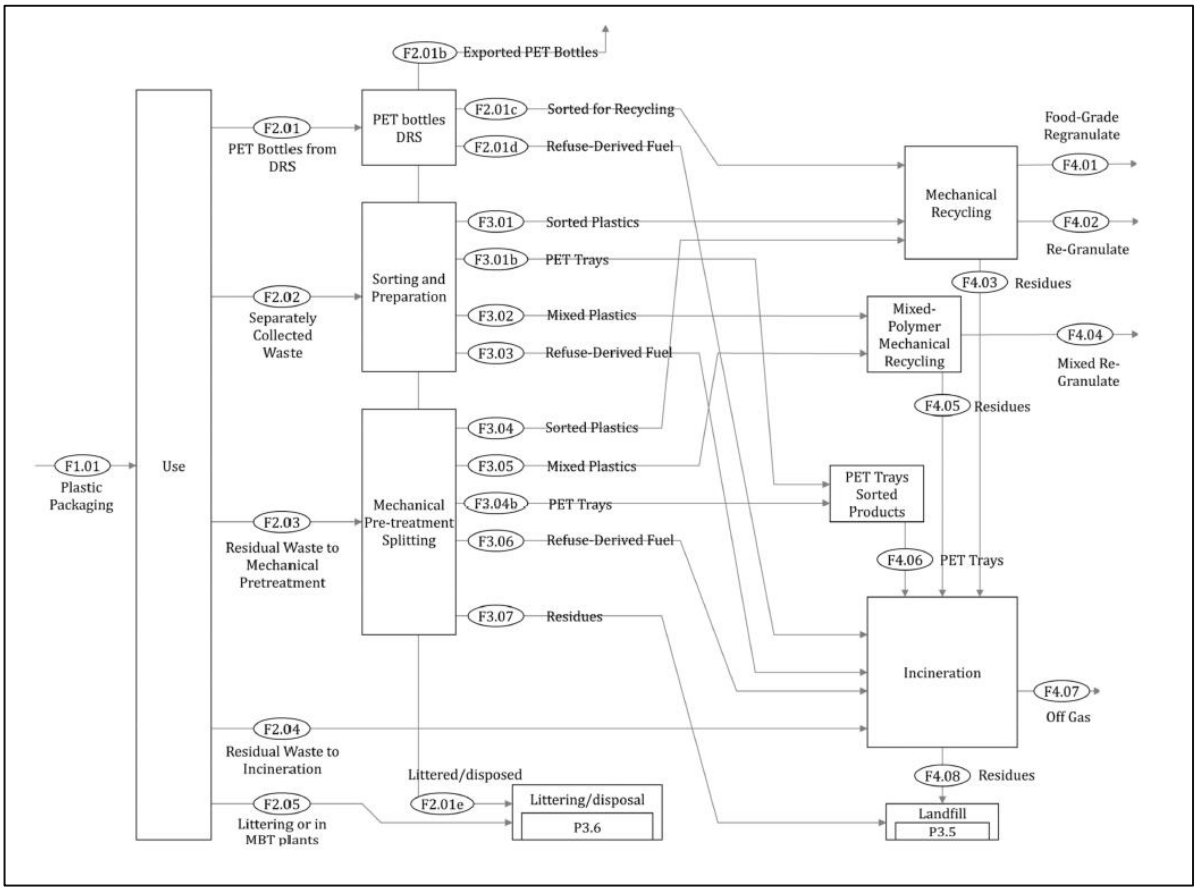

Figure 14: Overview of plastic packaging waste flows (Picuno et al., 2021a)

Figure 14 demonstrates the various processes of plastic packaging waste from households in the Netherlands. The flows are divided into four segments: PET bottles, rigids, flexibles, and others (including EPS-base, like trays, etc.). Four differing classes of destinations have been defined: PET bottles from DRS, separate collection system, collection together with residual waste transported to mechanical pretreatment or incineration. In the Netherlands landfilling is banned. In regard to the sorting output, it can be summarized, that the residues are forwarded to incineration or to cement kilns as refused derived fuel (RDF). Sorted PET trays, which are unique for the Netherlands in comparison to for example Germany and Austria, are remitted to incineration
(Picuno et al., 2021a).

Parts of the residual waste are sent to mechanical treatment processes. Residual waste is then refined for plastics recovery, which means an increase in the

amount of waste transported to the recycling phase, additionally to the separately collected fractions. Residuals from mechanical pretreatment have to be incinerated with the RDF fractions before they get incinerated
(Picuno et al., 2021a).

Deposit system in the Netherlands

Although there is a clear deposit regulation from 2003, it has not been actively implemented. However, the business community is following these guidelines. For years, a clearer introduction of a broad deposit system has been discussed in Dutch politics. The latest approach to implementing a deposit on small plastic bottles took place in spring 2019. From 1st July 2021, there will also be a deposit of EUR 0.15 on small plastic bottles (≤ 1 l) (Dachist, 2021).

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(Dachist, 2021).

In conclusion there is currently only a deposit on some types of beer bottles, beer crates and PET bottles. The size and type of packaging plays a role. There is no deposit on cans. There are plans to introduce a clearer and broader deposit system so that cans will also receive a one-way or returnable deposit in the future (Dachist, 2021).

4.3.3 Collection, sorting and recycling rates

In Figure 15 the result of the MFA for waste packaging plastic flows in the Netherlands in 2017 can be seen, in an article by Picuno et al. (2021a).

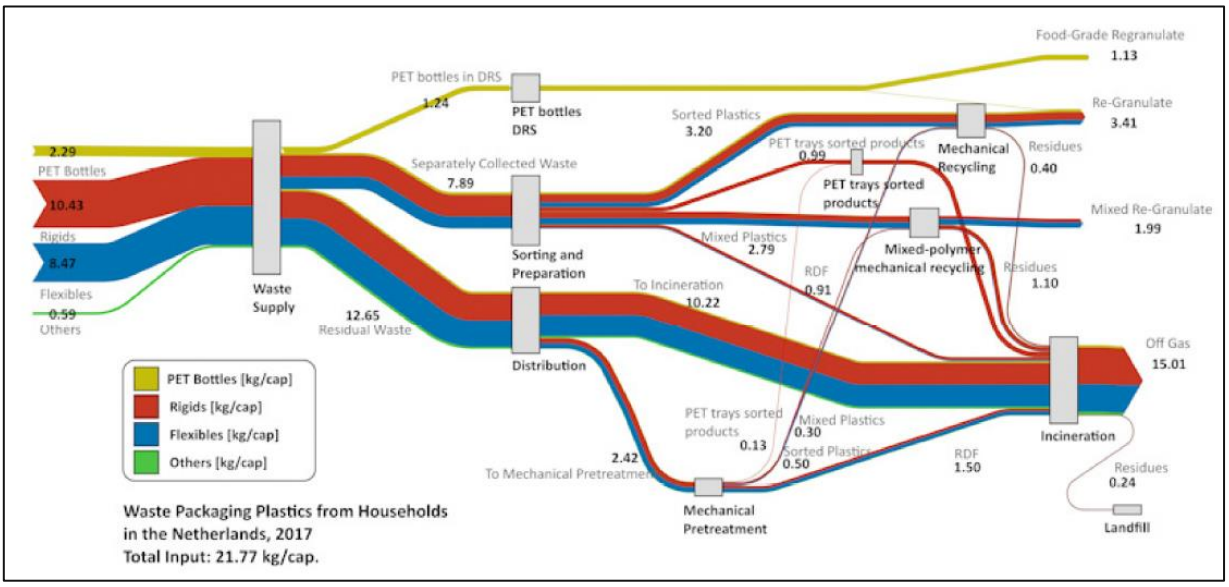

Figure 15: Waste packaging plastic flows from households in the Netherlands in 2017 (kg/cap), (Picuno et al., 2021a)

In the year 2017, 21.77 kg per person of plastic packaging waste had been generated in the Netherlands. Most of these materials are out of the categories of rigids (48 %) and flexibles (39 %). 95 % of the bottles have been collected via the DRS system. The collection rate of bottles > 500 ml can be quantified at 54 %. Out of the overall PPW collected in residual waste, approximately 11 % were recovered for energy and sorted for the recycling process, the rest was incinerated. For the separately collected waste, these sorting rates can be shown: 79 % PET-bottles, 39 % films, 37 % rigids, and 9 % for other types. In the mixed plastic fraction, 10 % PET bottles, 51 % films, 29 % rigids, and 46 % of other material categories were sorted.

4.4 Waste management system: Serbia

The total amount of waste generated in Serbia in 2018 was around 11.6 million tonnes, according to the Serbian Environmental Protection Agency (SEPA). Municipal waste accounts for approximately 20 %. However, the data is imprecise, as only some of the responsible bodies carried out measurements. Serbia's largest cities, Belgrade, Novi Sad, and Nis, have no disposal facilities where waste is treated. Huge amounts of municipal waste are dumped in uncontrolled landfills. A major challenge is the dumping of untreated municipal waste. The costs of future soil remediation and other environmental impacts have not yet been taken into account (GTAI, 2021).

4.4.1 National legislation

The Serbian Law concerning waste management tries to implement the waste's classification, stakeholders, obligations, and liabilities, as well as waste streams and monitoring processes. *"Waste management, according to the Law, is based on the best practicable environmental option, self-sufficiency, proximity and regional approach to waste management, waste hierarchy, responsibility and polluter-pays principles."* The waste management legislation framework is agreed upon the National Assembly and the Government of the Republic of Serbia (Živković, 2016).

Despite the existence of a legal basis, waste separation does not work. According to the National Waste Management Strategy, the recycling rate for municipal waste is only 3 %. In comparison to Germany, where the recycling rate can be accounted for 67 % in 2017, Serbia's waste management system urgently needs a functioning waste separation system that separates recyclable materials from biodegradable waste and hazardous waste (GTAI, 2021).

The following picture (cf. Figure 16), which was taken by Alexander Schelansky on 16th May 2022, in Belgrade demonstrates the problem very clearly. Mixed solid waste is disposed on the streets, without collection and any waste management system.

Figure 16: Post-consumer mixed solid waste disposal in Belgrade, (Schelansky, A., May 2022)

The four largest recycling companies Intercord, Brzan Plast, Ecorec, and Ivlajn have a share of more than 61 % in plastic packaging. The PET recycling sector is even more exclusive: The companies Greentech and Alwag are responsible for 95 % of the recycling. Currently, about 32 000 tonnes of plastics are recycled according to SEPA figures, which is more than one-third of the plastic packaging produced. In order to achieve both national of 22.5 % (2019) and European targets of 55 % (2030), the number of recycled plastics must be increased to 53 000 tonnes per year. Without separate waste collection with containers, however, this target will be difficult to achieve. There are also no plans yet for the announced introduction of a deposit system (GTAI, 2021).

It must also be mentioned that a big number of recyclable materials within the MSW stream are “reused”, but disposed to landfills. Additionally, various socio-economic factors such as low payments, refugee movements from the Kosovo war conflict in 1999, etc. had an impact on the establishment of waste picker groups. This results in little supply of recyclable materials from the MSW, which opens the gate for informal actors, outside of the formal recycling market. Therefore, these informal waste picker groups occupy the recycling market. Approximately 30 000 informal waste pickers, who collect recyclable PET, paper,

and cardboard, earn their livings in the respective informal sector by selling the collected waste to private licensed waste collectors and then to the recycling industry. Unfortunately, those quantities collected by waste pickers are not demonstrated in the official numbers (Mrkajić et al., 2018).

The waste pickers use various ways to collect the packaging waste from the MSW. In first instance and foremost in areas, where recycling programs are installed, curbside collection of mixed household waste is introduced and sorted in Material Recovery Facilities (MRF). This is the case in ten municipalities in Serbia. Additionally, some cities have installed systems for the primary separation of MSW by establishing infrastructure for the collection of organic waste (and non-recyclables) and recyclable segments of the MSW. This is why in some cities two on-street, or two underground waste containers can be found. There are also areas, mostly dominated by family houses, where a set of two plastic boxes are used for collection. These recyclables are also sorted in the MRFs and have a better quality than those, which have been recovered from the MSW. Another way of collecting waste in Serbia is human labor, where some organizations employ people to extract recyclable items from landfilling (Mrkajić et al., 2018).

4.4.2 Plastic packaging waste flows

Table 2: Quantities of municipal waste produced (P) and collected (C), the type and weight of overall packaging materials placed (P) on the Serbian market and collected (C) within the EPR system, (Mrkajić et al., 2018)

	2011		**2012**		**2013**		**2014**		**2015**		**2016**	
GDP per capita (€)	4200		4100		4300		4200		4300		4400	
						Municipal waste (kg/person)						
	P	C	P	C	P	C	P	C	P	C	P	C
	370	289	360	254	340	268	300	234	260	192	270	211
	P	C	P	C	P	C	P	C	P	C	P	C
Plastic	11.8	1.6	12.3	1.9	11.9	1.9	12.3	2.3	13.0	2.9	12.8	3.8
Glass	11.9	0.9	10.8	1.1	8.6	1.3	7.8	1.3	8.5	1.7	8.4	2.2
Metal	1.6	0.1	1.7	0.6	1.8	0.5	1.8	0.7	1.9	0.7	2.0	0.8
Paper	14.4	3.9	14.6	5.3	14.5	7.7	15.0	9.1	17.5	11.5	15.6	13.2
Wood	7.5	0.2	8.0	0.6	7.9	0.9	9.0	1.0	10.0	2.2	10.4	2.1
Overall (kg/person)	47.2	6.7	47.4	9.4	44.7	12.3	45.9	14.4	51.0	19.0	49.3	22.1
(%)	100	14.1	100	19.7	100	27.3	100	31.3	100	37.2	100	44.7

[a] collected and disposed by public utility companies
[b] http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&plugin=1&pcode=tsdec100&language=en.

Table 2 shows, that the amount of plastic packaging on the market in Serbia increased by 1.5 % between 2011 and 2016. In the respective six years wood (39 %), paper, and cardboard (8 %) as packaging materials also elevated. In 2016, the specific weight share of packaging waste was: Paper/cardboard (32 %), plastic (26 %), wood (21 %), glass (17 %) and metal (4 %). Aligned to the national binding targets the total number of packaging waste recovered through the EPR system increased up to 98 %. For the most part within the EPR system, 95 % of recovered waste is recycled. It can also be seen, that there is a linear rising proportion of packaging placed on the market and collected packaging waste for each segment of waste in the respective period from 2011 to 2016: Paper/cardboard (58 %), metal (34 %), plastic (17 %), glass and wood packaging (approximately 17 %) (Mrkajić et al., 2018).

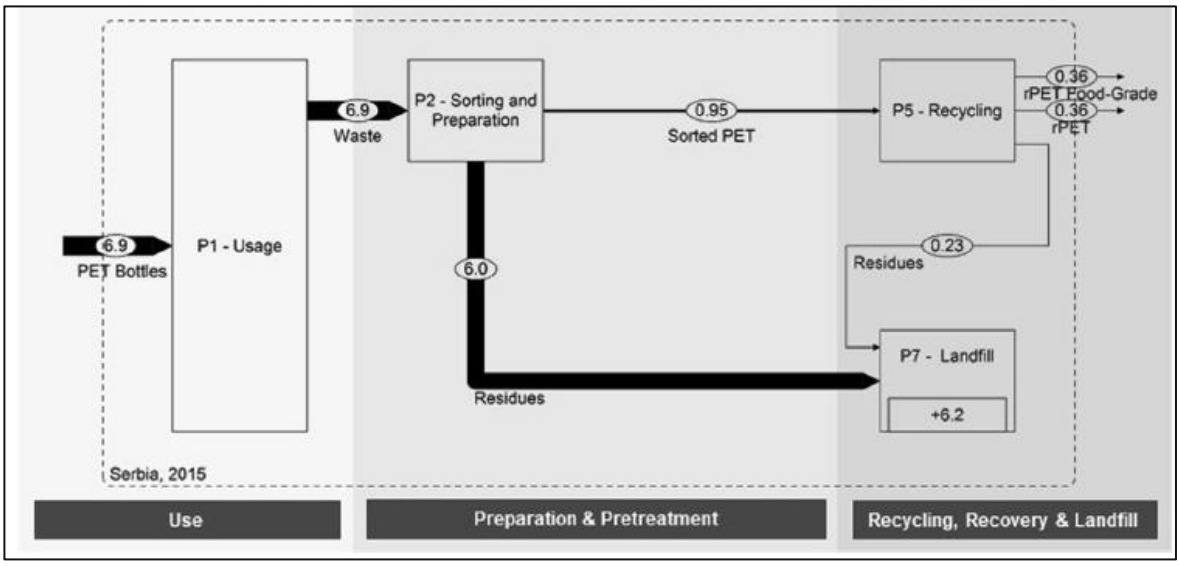

Figure 17: Results of the MFA for PET beverage bottle waste management in Serbia 2015 in kg/pa, (Schmidt et al., 2020)

Figure 17 shows the results of the MFA for PET bottles in Serbia in 2015 (Schmidt et al., 2020). There is no PET deposit system installed in the respective country. Moreover, PET bottles are collected as residual waste. The value of separate collections can be neglected. As mentioned before, to some extent bottle recovery is organized by the informal sector (not displayed in Figure 17). Waste pickers collect the recyclable material and sell it then. Collection infrastructure is just applied in bigger cities. The collected waste is sorted, but has different qualities and then send to recycling processes.

4.4.3 Collection, sorting and recycling rates

Table 3: Plastic packaging waste in Serbia 2016-2018, (GTAI, 2021)

Plastic packaging waste in Serbia			
	2016	**2017**	**2018**
Circulated plastic packaging material (SEPA, thousands of tonnes)	90.4	94.1	92.0
Plastic Packaging waste (CEVES estimations, thousands of tonnes)	116.4	118.0	119.6
Recycled plastic packaging waste (thousands of tonnes)	18.2	25.6	32.4
Plastic packaging recycling rate	15.6	21.7	24.9
National plastic packaging recycling rate target	17.0	19.0	21.0
Reference: GIZ-Studie “Circular Economy Impact Assessment” – Plastic Packaging Sector; CEVES (Center for Advanced Economic Studies)			

Around 90 % of plastic packaging from municipal waste is collected by waste collectors and disposed of in regular and uncontrolled landfills, according to a study by the consulting firm Deloitte. Conversely, this means that only around 10 % is brought into the cycle through separation in the municipalities or by municipal companies. The situation is better in the industry. There, plastic waste is often collected directly from the company (GTAI, 2021).

Eurostat (2021) reported that between 2015 and 2019 the quantities of treated waste increased by 47 %, whereas at the same time the waste generation increased by only 28 %. The values for recycled waste are stable. Due to a new methodology for data collection (SEPA, 2021) the increasing amount of waste generation could be justified. Current days there are no updated waste targets in Serbia set. In 2013 a coverage of collection up to 75 % was set, as well as an increase in reuse and recycling of packaging waste.

4.5 Comparison

In 2013 the PPW production in Austria was 25.44 kg/cap, of which 21 % had been PET bottles (Picuno et al., 2021a). Separate collected PPW in bags ("Gelber Sack"/LWP) is collected via curbside collection, organized by the municipal management. The PPW recycling rate in 2018 accounted for 31,9 % (König et al., 2021). PPW in residual waste is directly incinerated for energy recovery processes, landfilling is banned (Picuno et al., 2021a). A deposit system for PET bottles will be introduced in 2025. In the year 2025, the national PPW recycling target is set at 50 % (BMK, 2022).

In 2017 the PPW production in Germany was 25.14 kg/cap, of which 88 % PET bottles (smaller and bigger than 0,5 l) were collected via the DRS. No data for PPW in residual waste was collected (Picuno et al., 2021a). The overall PPW recycling rate in 2019 accounted for 36 % (Plasteurope, 2019). Residues, which derive from sorting and mechanical recycling processes, are sent to incineration, and landfilling is banned. Germany applies a deposit system for refillable and non-refillable bottles. In the year 2022, the national PPW recycling target is set by 63 % (BMUV, 2018).

In 2017 the PPW production in the Netherlands was 21.77 kg/cap, of which 95 % were collected by the DRS. Out of the total amount of collected PPW with residual waste, 11 % were mechanically recovered in a regranulation process, while the rest was sent to incineration, and landfilling is banned (Picuno et al., 2021a). The overall PPW recycling rate in 2018 accounted for 52 % (Nltimes, 2020). The Netherlands applies a deposit system. In the year 2025, the national PPW recycling target is set at 50 % (Friant et al., 2021).

There can hardly be found reliable data on the PPW production in Serbia due to intransparent data provision. In Serbia, the separate collection system can be neglected, as PET bottles are in most cases non-source separated. As mentioned above (cf. chap. 4.4.1), waste pickers collect recyclable items from residual waste and sell them to the recycling industry (Schmidt et al., 2020). The overall PPW recycling rate in 2018 accounts for 32 % (Kalkan, 2020). There is no deposit system installed. In the year 2019, the national PPW recycling target was set at

22.5 %. As there are several data on Serbia's PPW management available, I reference the data of the Serbian Environmental Protection Agency (SEPA).

Regarding the total mixed solid waste (MSW) generation (kg/cap), it can be concluded, that Austria (578 kg/cap) and the Netherlands (513 kg/cap) produced a high amount of MSW in relation to the number of inhabitants, which ranged from approximately 8.4 million to 17 million people, compared to Germany (624 kg/cap), which had around 82.5 million inhabitants. Serbia
(1651 kg/cap), which had approximately 7 million inhabitants, produced an immense amount of total MSW, of which most part is just landfilled. In this contrast, Germany had the best outcome.

With reference to the generation of packaging waste (kg/cap), it can be determined, that Austria (150 kg/cap) and the Netherlands (183 kg/cap) produced almost the same amount of packaging waste, although Austria accounted for half of the inhabitants of the Netherlands. In comparison to Germany (227 kg/cap), which had related to Austria ten times more inhabitants and related to the Netherlands five times more inhabitants, the packaging waste production is just 77 kg more for Austria and 44 kg for the Netherlands. In this comparison again, Germany has the best outcome, followed by the Netherlands and Austria. A comparison with Serbia is due to a lack of data not possible, but it can be assumed, additionally referring to Figure 16, that also the packaging waste production is very much related to the number of inhabitants.

Referring to the gross domestic product per capita (GDP in USD PPP) it can be stated that the Netherlands, Germany and Austria, all countries with a high GDP, produce a high amount of MSW, which can be related to a certain lifestyle. In comparison to Serbia, a country with a low GDP, produced more than double the amount of MSW compared to the above-mentioned countries, which may be based on the factor of practical usage of plastics.

Additionally, it can be concluded that Austria and Serbia need to speed up their PPW recycling rates, whereas Germany and the Netherlands are in the range or even above the EU's target (cf. Table 4). Regarding the production of MSW and packaging waste, it can be terminated, that Austria produced fairly high amounts in relation to its inhabitant number. Generally, it can be said, that countries with a high GDP tend to produce more MSW and packaging waste, but have a more

organized waste management system, which might be due to stricter national waste management legislation, compared to countries with a low GDP, and additionally more awareness towards the society regarding waste management.

Summa summarum, it can be terminated, that an immediate change in the consumption of (plastic) products and further the generation of (plastic) packaging waste is not possible. It also has been demonstrated that the recycling process of plastics does not meet the scale of environmental challenges. It seems that single-used plastic is still on the market, alternatives are only available on the niche market, which makes it even harder to provide these to most of the people. Plastics are still cheap and practical to use. This is why the consumer behavior needs to change: In the slowly, but constantly growing regional market for local food and beverages, sustainable packaging plays a major role, for example bringing your own cup for a coffee-to-go. And last, but not least the EU is trying to implement bans on disposable plastic types and tries to rethink its waste management policies (Fuhr, 2019).

For the comparison data of Table 4 was used, where different parameters, such as the total MSW production (kg/cap), packaging waste production (kg/cap), and the GDP per capita (USD PPP) are taken into account and compared with the number of inhabitants.

Table 4: Comparison of National plastic packaging recycling rate and national plastic packaging recycling target in % [based on (Picuno et al., 2021a)]

National plastic packaging recycling rate (%) vs. National plastic packaging recycling target (%)				
Parameter	Austria (2013)	Germany (2017)	Netherlands (2017)	Serbia (2017)
Population	8 451 860	82 521 653	17 081 507	approx. 7 021 000
Population density (/km2)	103	234	501	206
GDP per capita (USD PPP)	47 922	53 012	55 348	4 766
Total MSW production (kg/cap)	578	627	513	1651
Packaging waste production (kg/cap)	150	227	183	*
National plastic packaging recycling rate (%)	31.2 (2018)	36 (2019)	52 (2018)	32 (2018)
National plastic packaging recycling target (%)	50 (2025)	63 (2022)	50 (2025)	22.5 (2019)
References	Picuno et al. (2021a), Schmidt et al. (2020), BMK (2022)	Picuno et al. (2021a), Schmidt et al. (2020), (BMUV, 2018)	Picuno et al. (2021a), Friant et al. (2021)	Schmidt et al. (2020), * intransparent data

5. Conclusion

In these days of COVID-19, the Ukrainian-Russian war, and fast approaching climate changes, it might be hard to think of a sustainable and intact future environment. Thus, it is even more important to take immediate action in our everyday lives.

With the New Circular Economy Action Plan (EC, 2020) and the European Green Deal (EC, 2019b), the EU as a global actor, agreed on targets, which will also have an impact on our current consumption behavior. It might be manifold and complex to implement these new strategies and the accompanying policies, but one can see on the example of Austria, which is introducing a deposit system in 2025, that the efforts of negotiations among the government parties and a prospective look into a cleaner and greener future can make a difference.

It can also be stated that various factors influence the PPW management, which was shown in frame of the respective MFAs. By analyzing the waste streams, it can be recognized primarily on the collection and sorting rate, that the plastic packaging producers need to rethink steps in the composition and design phases of the plastic packaging items in order to assure an appropriate PPW management process, starting from separating, for example, the household waste, via sorting processes and last, but not least the recycling and recovery processes.

In this thesis, it was shown that Austria, Germany, Netherlands and Serbia have elaborated PPW strategies. In Austria, Germany and the Netherlands there are moderate differences in the PPW management. In Serbia research gets quite more difficult as the waste management system appears to be ambiguous due to a lack of data, as well as the fact, that the informal sector cannot be properly monitored.

Ultimately, it can be concluded, that apparently efforts are made, but still, a lot needs to be done in the sense of detecting waste management systems, which do even more calculate on environmental capabilities and resource efficiency to keep the objectives in a circular environment.

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