Inventory and characterization of the EoL PWS for the different applications

Deliverable 1.1

WP1 Waste streams mapping, methods for verifying recycled plastic content, requirements

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Executive Summary

Work package 1 (WP1) of Precycling project: ***Waste streams mapping, methods for verifying recycled plastic content, requirements,*** aims to screen and assess the recyclate definition and the best practices used for calculating, verifying, and reporting of recycled plastic content in products. Consequently, this WP has three strategic objectives:

- To map plastic waste streams and targeted value chains and analyze the methods for verifying the composition of the incoming waste stream (Tasks 1.1 and Task 1.2 of the project)
- To define the technical characteristics to be met for the recyclates to be used in domestic appliances, sports, toys, and textile applications (Task 1.3)
- To propose a definition of recyclate and deliver the PRecycling plastic recyclates Handbook (Task 1.4)

This report contains the information gathered for Task 1.1 ***Mapping of waste streams*** which comprises the inventory and registration/identification of the incoming plastic streams from different EU zones.

The following information is presented in the report:

- Identification of the incoming plastic streams (PWS) from different EU zones – 4 regions: plastics from WEEE in Western Europe (The Netherlands, Belgium, France and Germany) and East-South Europe (Turkey); and other plastic wastes in South-West Europe (Spain) and South Europe (Greece). More info is available in Section 2.1 of this report.
- Analysis of the current waste treatment processes of the PWS (Section 2.2)
- The targeted value chains in the PRecycling, including the plastic wastes collected for the project development, that is, toys waste, textiles waste, and home appliances waste (Section 3).
- An inventory containing information about the type of collected product, volumes, polymer and/or additive/filler identification (Section 3.4).
- Information on the first pre-selection of the adapted sensor-based technology among LIBS, FT-IR, MWIR and HIS based on the inventory, that will act as reference information for the next steps of the project (Section 4).

This report also contains the information gathered within Task 1.3 ***Materials requirements, properties and benchmarking***: Definition of technical characteristics for using recyclates to guarantee the compliance of the final products and represents verification of the MS2 'Materials requirements, properties & benchmarking (Section 5).

Material development studies in the following WPs of the project will be carried out according to available regulations' requirements. Key factors or the compliance of the final product (domestic appliances, toys, and textile applications) will be considered to define the maximum recycled content.

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LIST OF ABBREVIATIONS AND ACRONYMS

ABS	– Acrylonitrile butadiene styrene resin
CA	– Consortium Agreement
CCD	– Charge-coupled device
BE	– Belgium
DE	– Germany
DoA	– Description of Action
EC	– European Commission
EPRO	– European Association of Plastics Recycling and Recovery Organisations
EU	– European Union
EuPC	– European Plastics Converters
EU27+3	– EU Member States, Norway, Switzerland and the United Kingdom
FP	– Framework Programme
FR	– France
FT-IR	– Fourier-transform infrared spectroscopy
GA	– General Assembly
GR	– Greece
HIS	– Hyperspectral imaging
IPR	– Intellectual Property Right
IR	– Infrared
LIBS	– Laser Induced Breakdown Spectroscopy
LIF	– Laser Induced Fluorescence
LoD	– Limit of Detection
Kt	– kilo tonnes
MIR	– Mid Infrared
Mt	– million tonnes
NIR	– Near Infrared
NL	– The Netherlands
PC	– Project Coordinator
PE	– Polyethylene
PE-HD	– Polyethylene, high density
PE-LD	– Polyethylene, low density
PE-LLD	– Polyethylene, linear low density
PE-MD	– Polyethylene, medium density
PET	– Polyethylene terephthalate
PoP	– Persistent organic pollutants
PP	– Polypropylene
PS	– Polystyrene
PUR	– Polyurethane
PVC	– Polyvinyl chloride
SC	– Steering Committee
SME	– Small and Medium Enterprise
SVHC	– Substances of very high concern
TR	– Turkey
VIS	– Visible
WP	– Work package

1. INTRODUCTION

D1.1 aims to create an inventory of end-of-life (EoL) plastic waste streams (PWS) for different applications. The inventory contains information about the types of collected products, volumes, polymer and/or additive/filler identification, and substances of concern (SoC), including the preliminary characterization of the EoL PWS for the different applications.

For the development of this inventory, plastic waste streams from several EU zones were mapped, in terms of quantities, composition and treatment routes (recycling, incineration or landfill). Furthermore, a dedicated section (3. Target value chains) regarding the collection of the project's plastic waste streams (WEEE, toys and textiles) is included.

Comparing the data obtained from both studies, the identification of the most important waste streams at the European level has been focused on those applicable to the project. Specifically, the possible amount available from PSW *Electrical and electronics*, and *Household, leisure and sports*, has been considered. The PRecycling project focuses on these categories of PWS that, based on the data that have been collected in this inventory, seem to be of immense importance in the general European waste generation framework.

Therefore, the type of product/family of products collected, the total volume of these wastes and the types of polymers present in the wastes at a European level have been estimated and included in an inventory table. The type of polymer has been estimated from the demand data in Europe by type of material for these applications. These data can give an idea of the high growth potential of the recycling option compared to landfilling or incineration.

Regarding the identification of additives, fillers or substances of concern (SoC), no quantitative information has been obtained, but it has been estimated qualitatively, from general references and studies of emissions derived from that type of additives.

Based on the inventory, a first pre-selection of the adapted sensor-based technologies among LIBS, FT-IR, MWIR and HIS, for the identification of wastes that were collected for the activities of the project was made (Section 4).

Finally, all the technical specifications of recyclates that need to be achieved in order to be applicable in the project's manufacturing processes for domestic appliances, toys, and textile applications are reported in Section 5 Material requirements, properties, and benchmarking. Material requirements and properties have been compiled to ensure the compliance of the final products when developing the recycled formulations in WP2 and WP3.

2. MAPPING OF WASTE STREAMS

2.1 PLASTIC WASTE GENERATION IN EUROPE

2.1.1 General overview[1]

The demand for plastics was 50.3 million tonnes in Europe in 2021, being Germany, Italy, France, Spain, Poland and United Kingdom the European countries with more than 3 Mt plastics converters demand. PP, PE, PVA and PET are the polymers more demanded.

However, not all the demand becomes plastic waste during the same year. In 2020, 29.5 million tonnes of post-consumer plastics waste were collected in the EU27+3. 35% of post-consumer plastics waste was sent to recycling, 42% for energy recovery and 23% for landfill (Figure 1). When comparing the recycling of plastic waste, it is interesting to observe that the rates are 13x higher when collecting the mixed waste separated from the collection schemes, Figure 2.

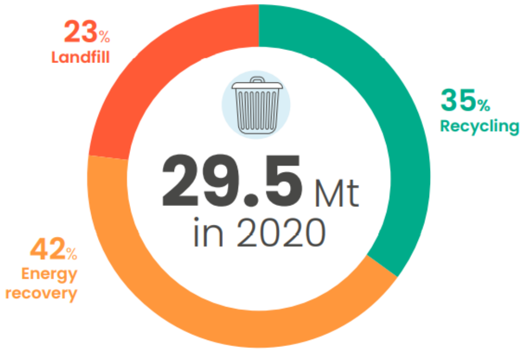


Figure 1. Overview of waste plastic being recycled, landfilled and for energy recovery.

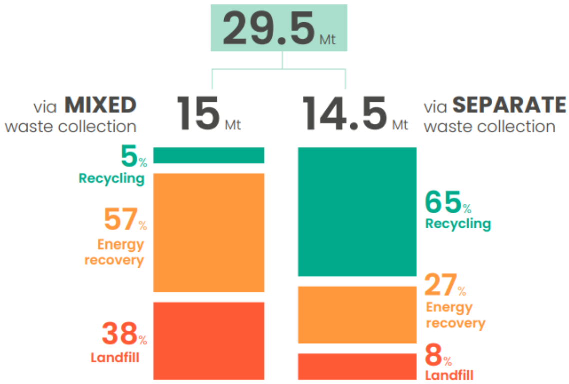


Figure 2. Comparison of plastic waste treatment via mixed and separated waste collection.

Separation before waste collection allowed a notable increase in recycling rates, from 5% to 65% and the reduction of plastics deposited in landfills from 38% to 8%.

The search for this prior separation is increasingly important for the recycling industry. With materials available for further separation and recovery, it allows the industry to invest in new technologies. In 2021, approximately 5.5 million tonnes of post-consumer recycled plastics were used in new products and parts, representing about 10% recycled content rate in plastics conversion and an increase of about 20% compared to 2020.

[1] https://plasticseurope.org/wp-content/uploads/2022/10/PE-PLASTICS-THE-FACTS_V7-Tue_19-10-1.pdf

2.1.2 Western Europe (The Netherlands, Belgium, France and Germany Coolrec)

Coolrec has collected general information of wastes production through the European association Plastics Europe related to Western Europe (WE) countries – The Netherlands, Belgium, France and Germany.

- **Collection and treatment of post-consumer plastic waste**

The Netherlands: According to Plastics Europe (2020 data)[2], the plastic products listed and managed as plastic waste correspond to post-consumer plastic waste, Figure 3. The overview of the Dutch plastics circular economy is presented in Annex 1. It provides an overview of 2020 plastics production, conversion, consumption and waste flows in the Netherlands. It also addresses the production of recycled plastics and their use in different sector applications in the Netherlands.

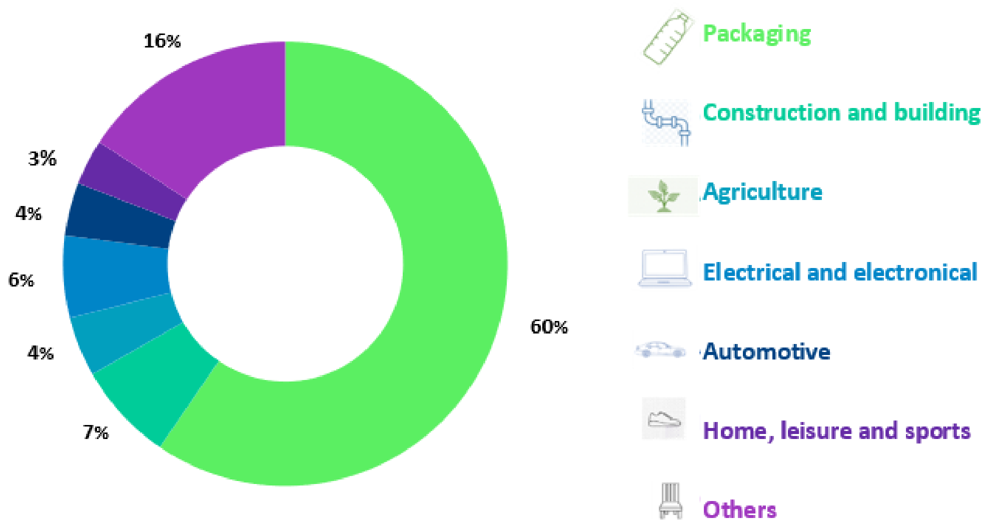


Figure 3. Graph of type of collected post-consumer plastic waste in The Netherlands.

Belgium: According to this entity (2020 data), the plastic products listed and managed as plastic waste correspond to post-consumer plastic waste, Figure 4. The overview of the Belgium plastics circular economy is presented in Annex 1.

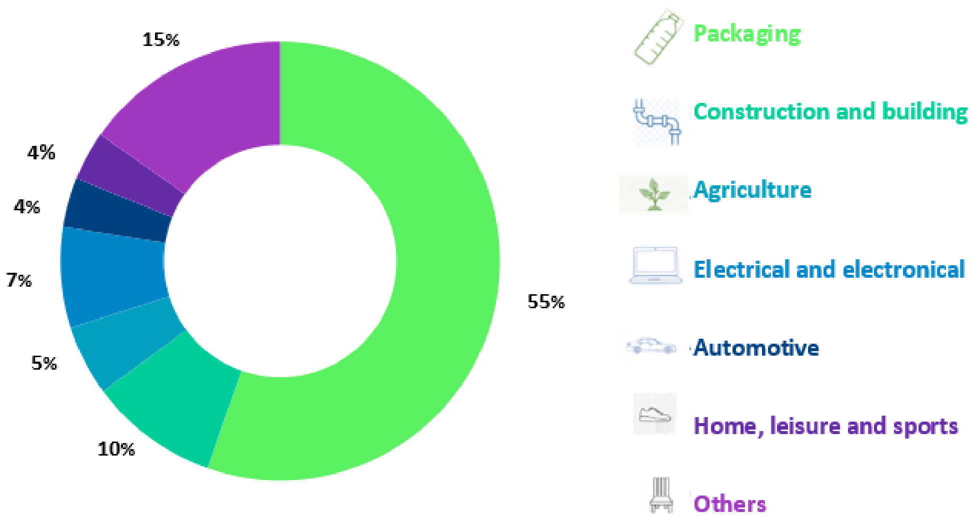


Figure 4. Graph of type of collected post-consumer plastic waste in Belgium.

[2] PE-PLASTICS-THE-FACTS_V7-Tue_19-10-1.pdf (plasticseurope.org)

France: According to this entity (2020 data), the plastic products listed and managed as plastic waste correspond to post-consumer plastic waste, Figure 5. The overview of France plastics circular economy is presented in Annex 1.

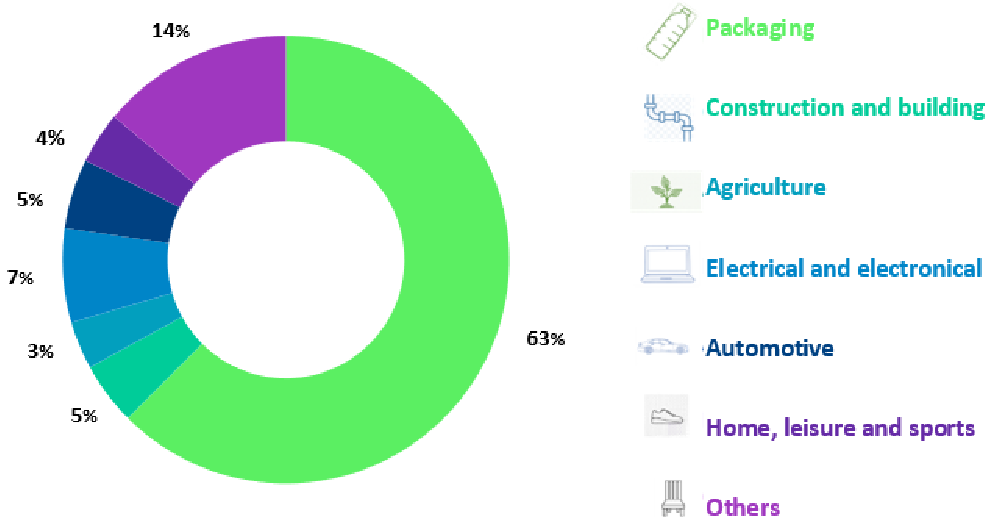


Figure 5. Graph of type of collected post-consumer plastic waste in France.

Germany: According to this entity (2020 data), the plastic products listed and managed as plastic waste correspond to post-consumer plastic waste, Figure 6. The overview of Germany plastics circular economy is presented in Annex 1.

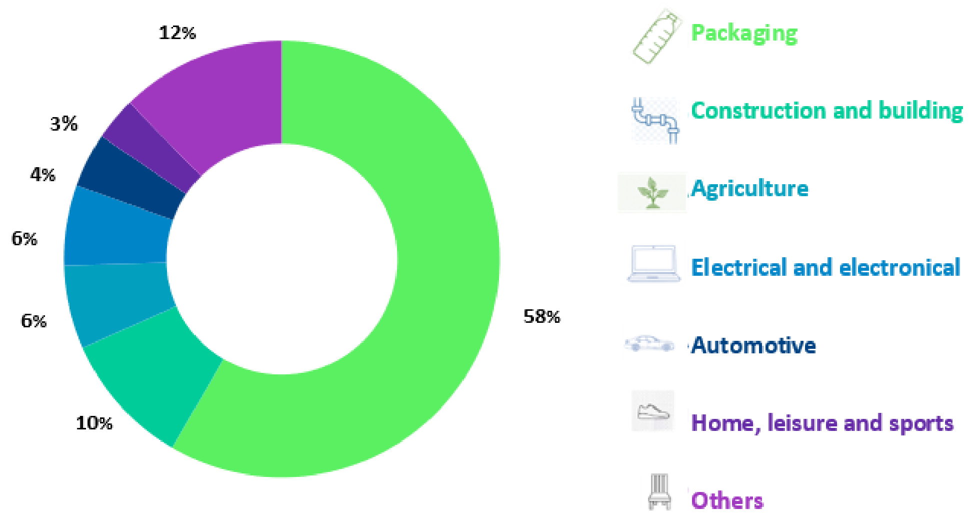


Figure 6. Graph of type of collected post-consumer plastic waste in Germany.

Annex 1 provides a clear overview of the circular economy of plastics in the different Western Europe countries in 2020.

- **Volumes**:

Country	The Netherlands	Belgium	France	Germany
Total plastic waste generated – 2020 (kt)	1058	578	3760	5419

The Netherlands: 1058kt of plastic waste were generated in The Netherlands in 2020. Being 500kt input for national recycling and as an output of the recycling process, 300kt of post-consumer was recovered. 9.8% of the post-consumer recycled plastic was used in manufactured products.

Belgium: 578kt of plastic waste were generated in Belgium in 2020. Being 210kt input for national recycling and as an output of the recycling process, 140kt of post-consumer was recovered. 7.6% of the post-consumer recycled plastic was used in manufactured products.

France: 3760kt of plastic waste were generated in France in 2020. Being 690kt input for national recycling and as an output of the recycling process, 440kt of post-consumer was recovered. 7.8% of the post-consumer recycled plastic was used in manufactured products.

Germany: 5419kt of plastic waste were generated in Germany in 2020. Being 1610kt for national recycling and as an output of the recycling process, 1050kt of post-consumer was recovered. 8.3% of the post-consumer recycled plastic was used in manufactured products.

Table 1 provides a summary of plastic consumption and recycling at the Western countries.

Table 1. Summary of tons of plastic consumption and recycling in The Netherlands, Belgium, France and Germany in 2020.

	The Netherlands (kt/year)	Belgium (kt/year)	France (kt/year)	Germany (kt/year)
Plastic consumption (raw materials)	**2,070**	**1,270**	**6,450**	**10,670**
Plastic waste generated	1,058	578	3,760	5,419
Plastic waste (post-consumer) recycled	300	140	440	900
Plastic waste (pre-consumer) recycled	280	160	330	1,050
Recycled plastic material used	232	191	387	1,039

2.1.3 South-West Europe (Spain, AIJU)

AIJU has collected general information of wastes production through a National Association of Plastic Recyclers (ANARPLA) and other sources for the inventory and registration/identification of the incoming plastic streams from Spain.

ANARPLA is the only association that brings together the main mechanical plastic recycling companies in Spain. As such, it represents the interests of the sector both nationally and at European level.

The companies grouped in the National Association of Plastic Recyclers are distributed throughout the national territory and their recycling capacity exceeds 70% of the total capacity of the sector. They performed a study on the recycling situation in Spain, i.e., number of companies of mechanical recycling, number of companies of total processed post-consumer products, percentage net recycling of production by region, evolution of post-consumer processing, etc.

- **The type of collected products in Spain:** According to this entity (2020 data), the plastic products listed and managed as plastic waste correspond to post-consumer and post-industrial plastic waste, in the percentages, is summarized in Figure 7[3].

[3] https://plasticseurope.org/es/espana-lidera-el-uso-de-plasticos-reciclados-en-europa/ (access January 2023)

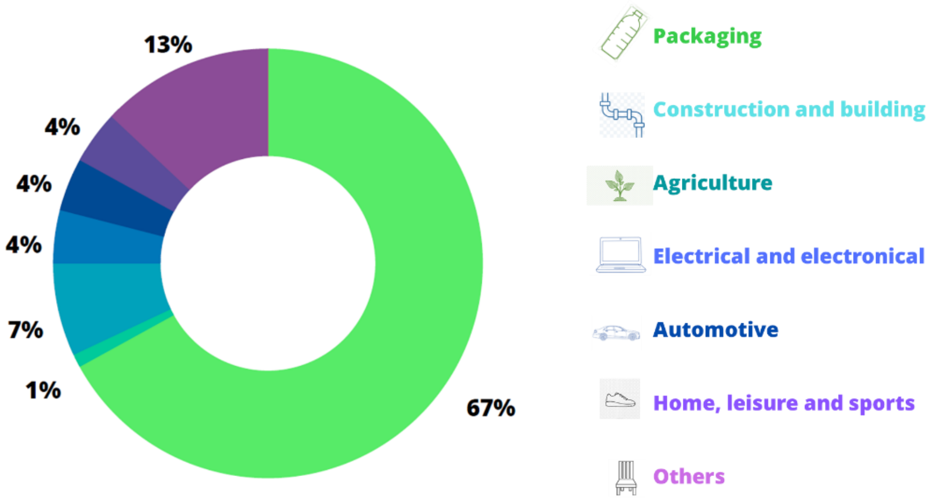


Figure 7. Graph of type of collected post-consumer plastic waste in Spain.

- **Volumes**: 2,566,690 tons of plastic waste were generated in Spain.

Considering that Spain is also a country that imports plastic waste, it was found that the post-consumer plastic waste taken for recycling was 1,133,451 tons and post-industrial plastic waste 70,000 tons. As a result, 902,519 tons (not counting the post-industrial) of recycled plastic material were obtained.

In addition, 292,056 tons of recycled plastic material were exported, and 229,772 tons were imported. Consequently, the recycled plastic material used in Spain was 840,235 tons.

In conclusion, in 2020, **20.5% of the consumed plastic material was recycled** (4,088,235 tons of required plastic materials, see Table 2).

Table 2. Summary of tons of plastic consumption and recycling in Spain in 2020.

	t/year
Plastic consumption (raw materials)	**4,088,235**
Plastic waste generated	2,566,690
Plastic waste (post-consumer) recycled (*)	1,133,451
Plastic waste (post-industrial) recycled (*)	70,000
Recycled plastic material obtained	902,519
Recycled plastic material used	840,235

Within the polymers that are recycled, the main recycled ones were PET, LDPE and Rigid polyolefins (HDPE and PP). Other polymers that are recycled to a lesser extent were PS, PVC and ABS (Table 3).

According to the study and forecast of Ken Research Company[4,5], at global scale the type of recycled plastic is nearly the same as the Spanish model, that is, PET and polyolefins (PP and PE) are the polymers with higher recycling use and intended applications. Others such as ABS, PVC or PS are also recycled in lower intensity, due mainly to the source, among other factors.

[4] https://issuu.com/kenresearchcompany14/docs/global_recycled_plastics_market_size_segments_ou
[5] https://www.kenresearch.com/business-research/global-recycled-plastics-market-outlook-2028/

Table 3. Types of polymers more and less recycled in Spain in 2020.

POLYMERS	HIGHER RECYCLING	LOWER RECYCLING
PET	X	
LDPE	X	
RIGID POLYOLEFINS (HDPE and PP)	X	
PS		X
PVC		X
ABS		X
OTHERS		X

2.1.4 South Europe (Greece, Attica)

Greece generates approximately 700 – 800 kT of plastic waste each year. The average waste composition contains about 13.9 % of plastic waste which leads to a potential of about 70 kg/ (cap x yr) for plastic waste[6], combined with the country's average waste generation of 504 kg/ (cap x yr). Taking into consideration the EU 2030 target of 55 % of plastic waste to be reused and recycled it is estimated that about 39 kg/ (cap x yr) should be recycled in Greece.

Figure 8. The national facts and plastic footprint overview in Greece 2019 (WWF report 2019).

- **Collection and treatment of post-consumer plastic waste**

In Greece, the predominant practice for waste disposal involves sending it to landfills. This includes plastic waste, which is not segregated and is instead disposed of along with general municipal solid waste (MSW) in residual bins. Approximately 81.9% of municipal waste ends up in landfills, with a total of 75 active landfill sites scattered throughout the country[7],[8]. This, mismanaged waste is a key source of terrestrial-based plastic pollution in Greece. With a recycling rate of only 18.1% and limited waste collection infrastructure, plastic waste leaks into the environment from the waste management system[9]. Moreover, the influx of tourists to Greece's coasts increases waste generation by up to 26%

[6] Guide on separate collection of municipal waste in Greece, final report bfs 2020 / 04-11
[7] WWF (2019) *Plastic pollution in Greece: how to stop it. A practical guide for policy makers*, accessed 1 May 2020, http://awsassets.panda.org/downloads/05062019_wwf_greece_guidebook.pdf
[8] Perchard, E. (2016) *Austerity-hit Greece faces further fines for poor waste management*, accessed 11 May 2020, https://resource.co/article/austerity-hit-greece-faces-further-fines-poor-waste-management-11368
[9] T. Elliot et al., Policy Measures on Plastics in Greece, A Report for WWF Greece, Eunomia, 2020

in peak season[10]. Uncollected waste leads to 40kT of plastic leaking into nature each year. 11.5kT of plastic enters the Mediterranean, including 28% from sea-based sources, such as ghost finishing nets and equipment. Almost 70% of this waste makes its way back to pollute Greek coastlines each year.

According to data provided by the Hellenic Recycling Agency (**EOAN)**, 202,100 tons of **plastic packaging** was produced in 2018 in Greece. The production of **packaging waste** was estimated at 814,700 t for the year 2018, marking an overall increase of 4% compared to 2017 (Figure 8). From this quantity, just 80,420 tons were recycled (39.8 %), otherwise recovered or incinerated in energy recovery incineration facilities inside or outside the country in 2018. The collaboration between the Hellenic Recovery Recycling Cooperation (HERRCO) and DIADYMA through 2021 lead to 9900 tons of packaging recovered and recycled, out of which 1600 tons were metallic packaging, 2700 tons were paper/cardboard packaging, and 5600 tons were plastic packaging. Moreover, in 2021, an agreement was concluded between HERRCO and Terna Energy for the certification of packaging material deriving from the Facility of Waste Handling of Epirus. HERRCO also recorded the packaging materials recovered via the Factory of Mechanical Recycling operated by EDSNA within the 1st Integrated Facility of Waste Handling in Western Attica. More specifically, in 2021, 3400 tons of packaging waste out of which 0.83k tons were metallic packaging, 0.74kt were paper/cardboard packaging, 0.28 kt were glass packaging and 1.5kt were plastic packaging.

Data regarding the country's performance in the collection and recovery of WEEE for the year 2018 as validated 2020, as mean value of three consecutive years statistics (2015-2016-2017) was 129,998,15 tons[11]. Based on the calculated percentage in WEEE, this means that around 26,770 tonnes were plastics.

Table 4. Summary of tons of plastic consumption and recycling in Greece based on available data collected 2017-2020.

	t/year
Plastic consumption (raw materials) produced	940,000
Plastic waste generated	730,000 (2017) 814,700 (2018)
Plastic waste (post-consumer) recycled plastic	78,420 (2018)

Volumes: > 800 ktons of plastic waste were generated in Greece per year.

Due to the limited information available for plastic waste collection and recycling in Greece, within the project ATTICA in collaboration with NTUA have collected information from EDSNA for plastic waste collection in the region of Attica. Attica region is located on the eastern edge of Central Greece,and covers about 3,808 km^2. In its area the cities of Athens, Elefsina, Megara, Laurium, and Marathon are placed, as well as a small part of the Peloponnese peninsula and the islands of Salamis, Aegina, Angistri, Poros, Hydra, Spetses, Kythira, and Antikythera. About 3,800,000 people live in the region (approx. 1/3 of population from all Greece), of whom more than 95% are inhabitants of the Athens metropolitan area.

In Figure 9 all waste categories and their percentage to total waste produced in Attica for the year 2022, according to the data collected from the weekly reports of EDSNA, are presented. The fluctuations in the waste composition per month can be observed. Figure 10 is presenting overall waste per category composition based on the data collected for whole 2022 year in the region of Attica (EDSNA). Plastic waste stream accounts for 14.3 % of all waste collected, and in particular, mainly assigned to polyolefins - polypropylene (2.2%) and polyethylene (2%), polyethylene terephthalate (2.6%) and other, non-identified/sorted plastics (7.5%).

[10] Dalberg Advisors, WWF Mediterranean Marine Initiative, 2019 *"Stop the Flood of Plastic: How Mediterranean countries can save their sea"*

[11] Απόβλητα ειδών Ηλεκτρικού & Ηλεκτρονικού Εξοπλισμού (ΑΗΕΕ) – ΕΟΑΝ

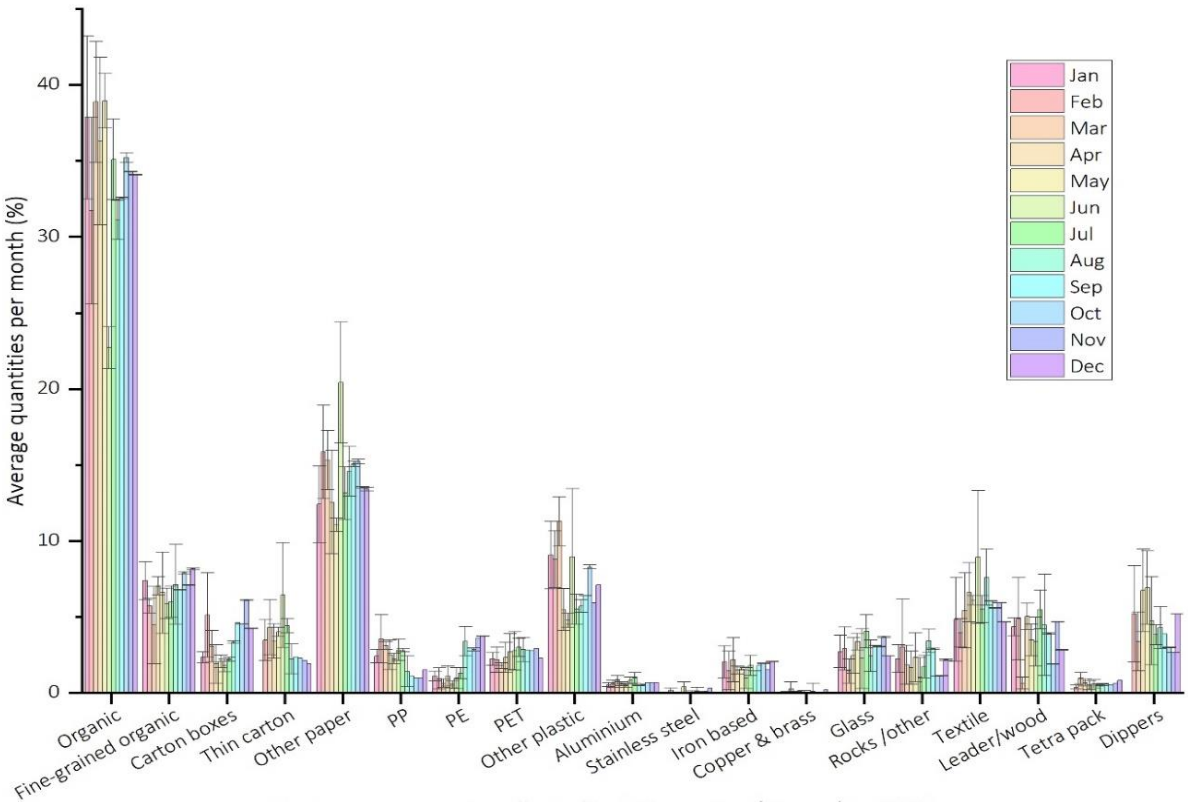


Figure 9. Postconsumer waste per category collected in Attica region during 2022, per month.

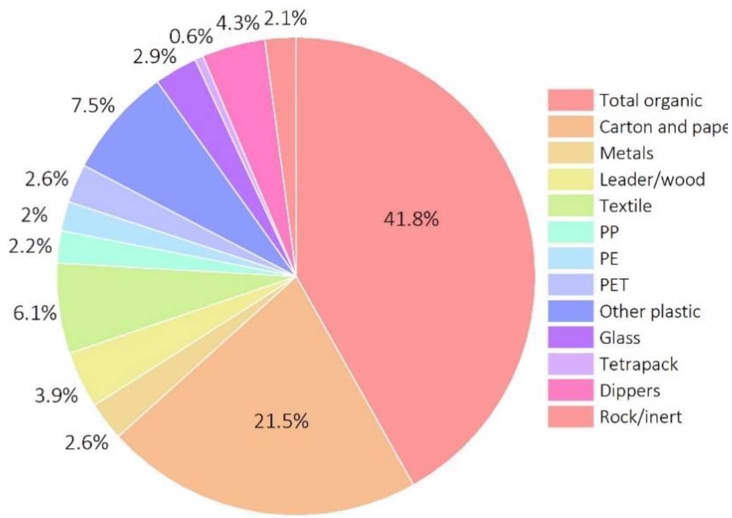


Figure 10. Composition of collected postconsumer waste in the Region of Attica during the 2022.

Analysing collected data regarding plastic waste streams, Figure 11 is presenting values in tons of collected PP, PE, PET, bulk plastic and film per month for year 2022. Following, in Figure 12, total distributions of collected PWS in 2022 by EDSNA are given. For 4598.47 tons of collected plastics in total, the largest fraction was PET (44.5%), followed by PP (24.3%), HDPE (19.2%), bulk plastic PP (10.8 %) and plastic films (1.2%).

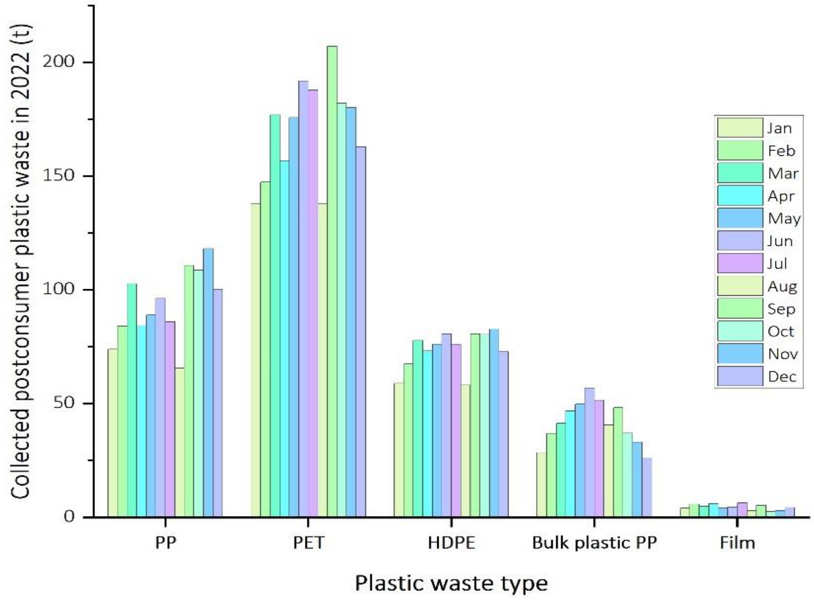


Figure 11. Collected postconsumer plastic waste in Attica region during 2022.

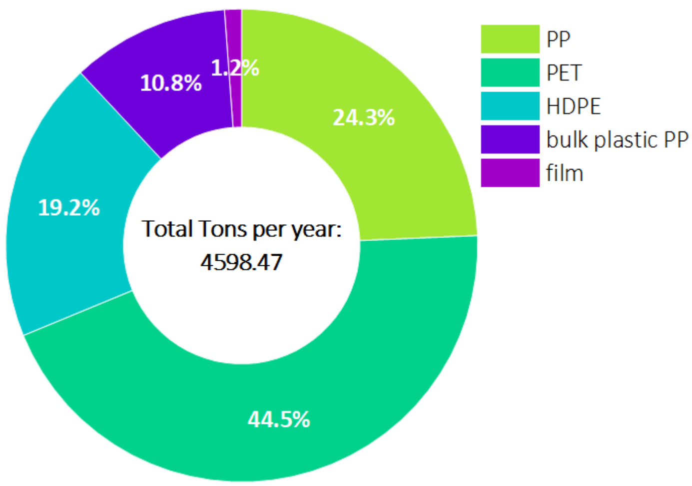


Figure 12. Plastic waste collected in Attica region during 2022.

According to the available data, at global scale the type of recycled plastic is, similar to Spain model, nearly the same as the Greek model, that is, PET and polyolefins (PP and PE) are the polymers with higher recycling use and intended applications (Table 5). Others as ABS, PVC or PS are also recycled by in lower intensity, due mainly to the source, among other factors.

There are no available newer data for plastic recycling quantities. There are several companies[12],[13],[14] in Greece that are recycling and after the completion of the proper processing, supplying, as recycled plastic raw materials, polyethylene (LDPE, HDPE) and polypropylene (PP), and occasionally other materials (PET, PS, ABS, PVC), some of them with a capacity of 6.500 MT/year. The industrial scrap from plastic factories, municipal plastic waste and used greenhouse films which are collected from the fields can be handled.

[12] Recyclable products management | ΚΑΝΕΛΛΑΚΗΣ (k-kanellakis.gr)
[13] Recycling of Plastic | KARATSIALI BROS. GENERAL PARTNERSHIP (anakyklosi-plastikou.gr)
[14] Plastics recycling - plastikakritis.com

Table 5. Types of polymers more and less recycled in Greece (2018- 2020).

POLYMERS	HIGHER RECYCLING	LOWER RECYCLING
HDPE - High-density polyethylene	X	
LDPE - Low-density polyethylene	X	
PP - Polypropylene	X	
PS - Polystyrene		X
PET - Polyethylene terephthalate		X
PVC - Polyvinyl chloride		X
ABS - Acrylonitrile butadiene styrene		X
SAN - Styrene acrylonitrile resin		X

2.1.5 East-South Europe (Turkey, Arcelik)

Based on the data derived from TÜİK (Turkish Statistical Institute), a total of 104.8 million tonnes of waste, of which 30.9 million tonnes was hazardous, was generated in manufacturing industry establishments, mining establishments, thermal power plants, organized industrial zones (OIZ), health institutions and households, in 2020. As given in Table 6, the total amount of waste increased by 10.5% compared to 2018. On the other hand, the annual amount of plastic waste produced in Turkey in 2021 is nearly 5.6 million tons. Figure 13 summarizes the Turkey's plastic consumption based on different plastic types in 2019. In addition to waste generated domestically, Turkey is the largest importer of plastic and scrap waste with 151 million USD and 6.2 billion USD worth, respectively in 2020. US, UK, Netherlands, Germany and France are among top 10 importing countries for both waste types.

Table 6. Waste generation in Turkey, 2018-2020 (TÜİK)

	Amount of total waste (T)		Hazardous waste (T)		Non-hazardous waste (T)	
	2018	2020	2018	2020	2018	2020
Total	**94,870,818**	**104,848,864**	**15,078,573**	**30,876,658**	**79,792,245**	**73,972,206**
Manufacturing industry establishments	22,881,144	23,867,866	3,677,320	4,597,274	19,203,824	19,270,593
Thermal power plants	26,127,134	24,375,356	13,805	10,012	26,113,329	24,365,343
Mining establishments	17,387,029	27,581,875	11,176,581	26,044,730	6,210,448	1,537,144
Organized industrial zones	286,843	279,067	111,733	116,720	175,110	162,347
Health institutions	89,454	109,683	86,916	106,570	2,538	3,113
Households	28,099,214	28,635,018	12,218	1,352	28,086,996	28,633,665

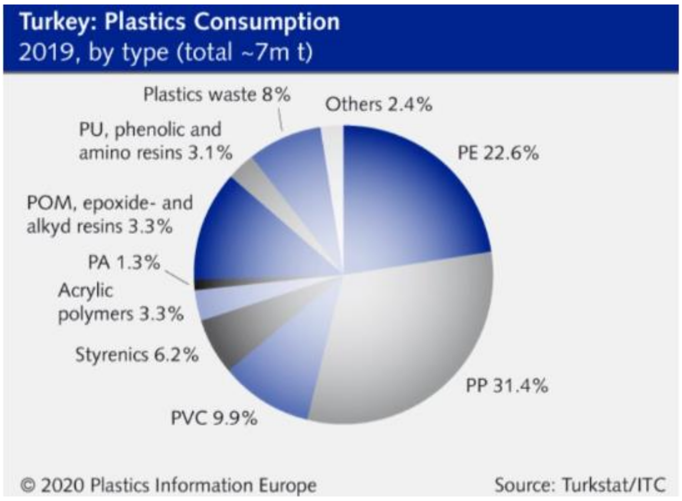


Figure 13. Plastic consumption in Turkey based on polymer type (TÜİK, 2019)

Volumes: > 560 kt of plastic waste were generated in Turkey per year (2019, based on Figure 13).

In line with increasing waste, number of facilities for disposal and recovery have also increased by 25% from 2018 to 2020. Amount of waste sent to landfill has almost increased by 50% from 2018 reaching roughly 78 million tons in 2020. Out of the total waste, 69.4% was sent to controlled landfill sites, 17% to municipal dumping sites, 13.2% to waste recovery facilities and 0.4% was disposed of by other methods such as burning in an open area, burying and dumping into river/onto land. The average amount of municipal waste per capita per day is calculated as 1.13 kg. Figure 14 compares the distribution of collected municipal waste by disposal and recovery methods between 2018 and 2020.

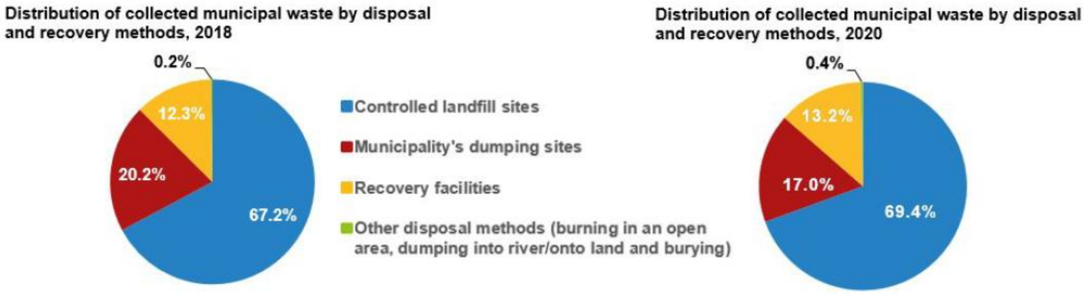


Figure 14. Distribution of collected municipal waste by disposal and recovery methods between 2018 and 2020 (TÜİK).

2.1.6 Textile waste in Europe

In 2020, 6.9 mt of textile products were produced in EU27, going from intermediate products like yarns and fabrics to finished products like clothing, carpets, and household textiles (**Figure 15**)[15]. Almost 15kg of textile waste is generated each year per person in the EU. The majority (85%) of this textile waste comes from home textiles and clothing discarded by households. The remaining part of textile waste comes from post-consumer commercial waste, post-industrial and pre-consumer waste.

In 2013, 5.6 million tonnes of textile waste were generated in the EU. 80% of this waste is lost, 20% is collected for reuse or recycling[16]. In 2020, already 30-35% of textile waste was collected, and this is expected to significantly grow when obligations of the Waste Framework Directive to separately collect end-of-life textiles will enter into force (**Figure 16**)[17].

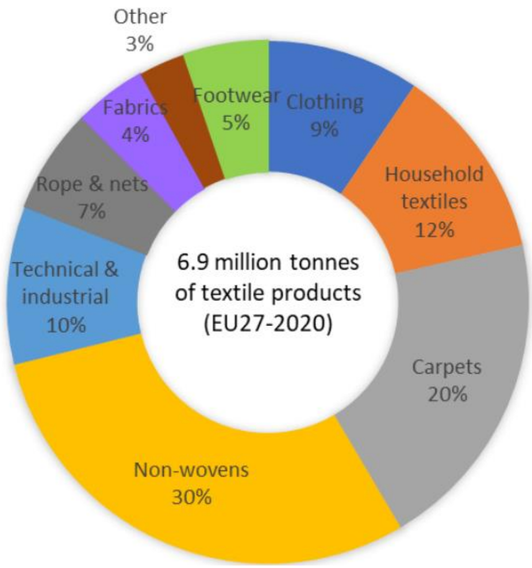


Figure 15. EU27 production of textile related products, 2020, in million tonnes

[15] Textiles and the Environment – the role of design in Europe's circular economy (2022). ETC/CE
[16] Textile waste — European Environment Agency (europa.eu)
[17] Scaling textile recycling in Europe – turning waste into value (2022) McKinsey & Company

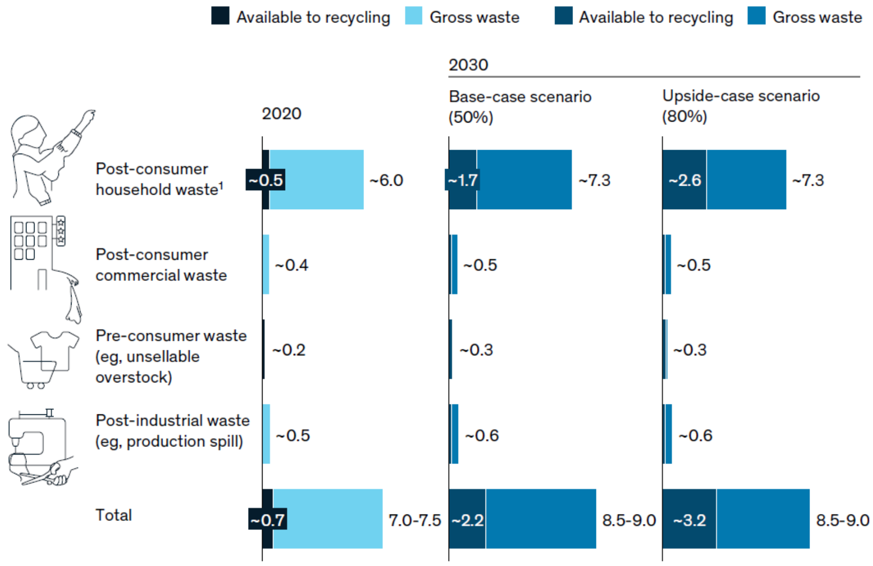


Figure 16. Total textile waste volumes (in million tons) available for recycling

Even though the average collection rate in Europe is around 30-35%, there are large differences per country, going from only 10% in Slovakia and Slovenia up to 64% in Germany (Figure 17).

Reports	Country	Gross volumes: JRC 2021, thousand tons	Gross volumes: Country reports base, thousand tons	Collection rate, %	Collected volume, thousand tons
Individual country reports	Germany	1,267	1,226	64%	811
	France	810	476	40%	320
	Italy	615	1,384	15–20%	277
	Spain	451	793	12%	95
	Netherlands	234	275	45%	122
	Austria	146	154	28%	43
	Lithuania	45	20	20%	11
	Latvia	20	12	20%	5
	Estonia	11	16	15%	2
Extra-polation by Euro-monitor indicative country shares	Poland	362	438	15%	66
	Belgium	213	258	45%	117
	Sweden	166	201	20%	41
	Switzerland	158	191	45%	87
	Romania	149	180	15%	27
	Portugal	144	174	12%	21
	Denmark	106	129	45%	59
	Greece	98	119	15%	18
	Hungary	79	96	15%	14
	Czech Republic	78	94	15%	14
	Finland	64	77	15%	12
	Ireland	58	70	25%	18
	Slovakia	44	53	10%	5
	Croatia	35	42	15%	6
	Bulgaria	33	40	15%	6
	Slovenia	14	17	10%	2
	Luxembourg	4	4	25%	1
	Cyprus	3	4	15%	1
	Malta	2	3	25%	1
	Total[1]	5,411	6,546	30–35%	~2 million

Volume estimates based on: JRC, 2021 · Country-specific reports · Country reports scale-up[2]

Figure 17. Estimated waste volumes per country in Europe (1-EU-27 and Switzerland, 2-For estimation of gross volumes based on the country reports, the country report data is scaled up using Euromonitor data on apparel retail volumes)

Within Europe, reuse and recycling capacities are limited, so a large part of textile waste is exported to Asia (41%) and Africa (46%), where it mostly gets reused or landfilled. In 2019, the exported textile waste was almost good for 1.7 million tonnes, equal to 3.8kg per person, which is 25% of the textiles consumed per person (Figure 18).[18]

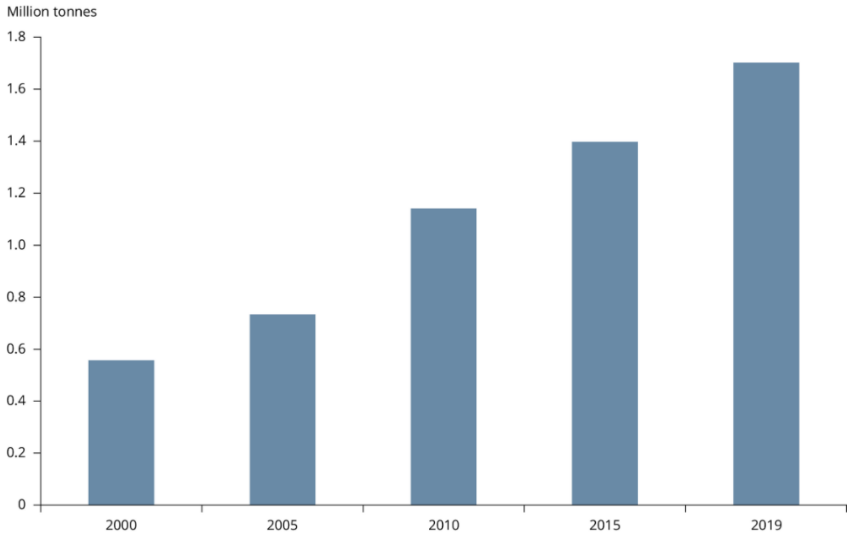


Figure 18. Exports of used textiles from the EU-27 & the UK to the rest of the world, 2000-2019, by weight (million tonnes)

2.2 PLASTIC WASTE TREATMENT IN EUROPE

2.2.1 General overview

As included in Section 1, 29.5 million tonnes of post-consumer plastics waste were collected in Europe in 2020. According to Plastics Europe[19], plastic (not only packaging) post-consumer waste was treated in the following way:

- 42 % Energy recovery
- 35 % Recycling
- 23 % Landfill

It is worth to remark that separation before waste collection allowed a notable increase in recycling rates, from 5% to 65% and the reduction of plastics deposited in landfills from 38% to 8% (Figure 2).

By studying the waste management in the different EU areas (Figure 19), it can be appreciated that 9 out of 30 countries recycled more than 37% of the wastes in 2020, and that eight countries landfill around 60% or more of the wastes.

The Netherlands was the country with the highest recycling rate in Europe, around 45% of the waste generated is recycled and landfilling is no longer allowed. Belgium has a recycling rate of 39% and 2% goes to landfill. France has 25% of plastics sent for recycling and 31% goes to landfill, being the highest landfill rate, and Germany 42% to recycling and 1% to landfill. The material recovery or recycling in Spain is also high, reaching around a 43%, whereas the landfill represents the 36% approximately and the energy recovery about 21%.

[18] EU exports of used textiles in Europe's circular economy — European Environment Agency (europa.eu)
[19] https://plasticseurope.org/knowledge-hub/the-circular-economy-for-plastics-a-european-overview-2/

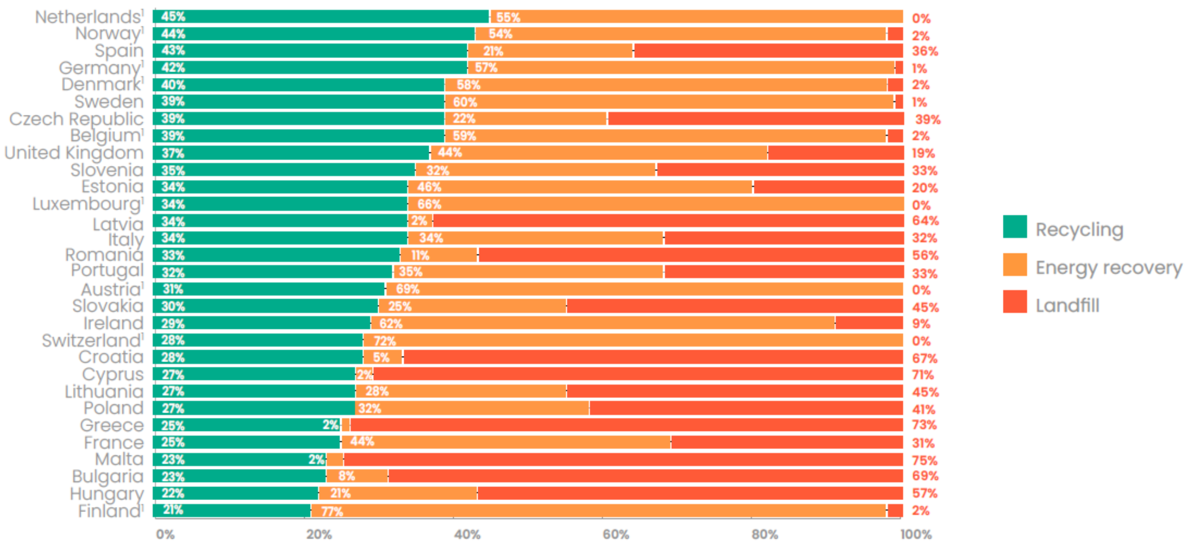


Figure 19. Post-consumer plastics waste treatment per country in 2020.

Annex 1 provides an overview of the different end-of-life management per country/per appliance, and Annex 2 provides an overview only focused on e-waste[20].

Regarding the recycling per type of material, Figure 20 reflects the capacity of the main recycling countries in Europe. As can be stated, Germany is the first country with the highest recycling capacity of PET material (25%), followed by Spain after (14%) and Italy (12%). Regarding the recycling of polyolefins, again, Germany, Italy and Spain have the highest rate of recycling LDPE, followed by Poland and The Netherlands, whereas rigid polyolefins (PP and HDPE) are highly recycled in Italy and Germany but also in UK, Spain and the Netherlands[2].

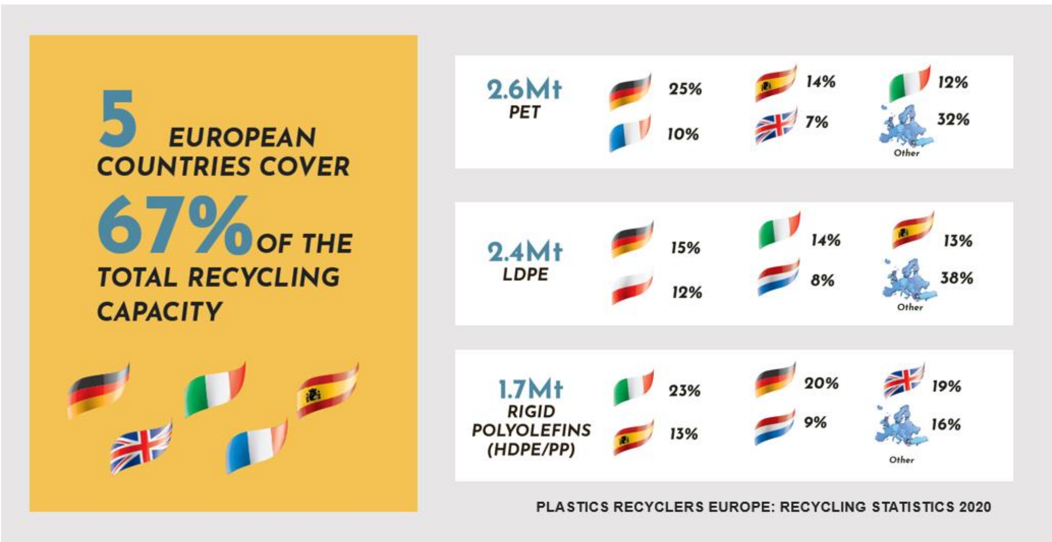


Figure 20. Recycling statistics per type of material and country in Europe.

By application, it can be stated that plastics packaging and agriculture, farming and gardening wastes have the highest recycling rates, as they are collected separately, which is very revealing. The electrical and electronic waste is approximately 25 % recycled. These types of products are currently deposited in specific clean points in municipalities, at many countries. Looking at the houseware, leisure and

20 https://www.europarl.europa.eu/news/en/headlines/society/20201208STO93325/e-waste-in-the-eu-facts-and-figures-infographic

sport application 7% is recycled, and the main treatment is energy recovery. For textiles, 30-35% of the waste is currently being collected, but only 40% of this waste is recycled by either reuse (second-hand shops), incineration or landfilling. A vast part of the plastic waste is still landfilled, the packaging waste has the biggest recycling rates, however, measurements to reduce landfill need to be taken to the other applications, Figure 21.

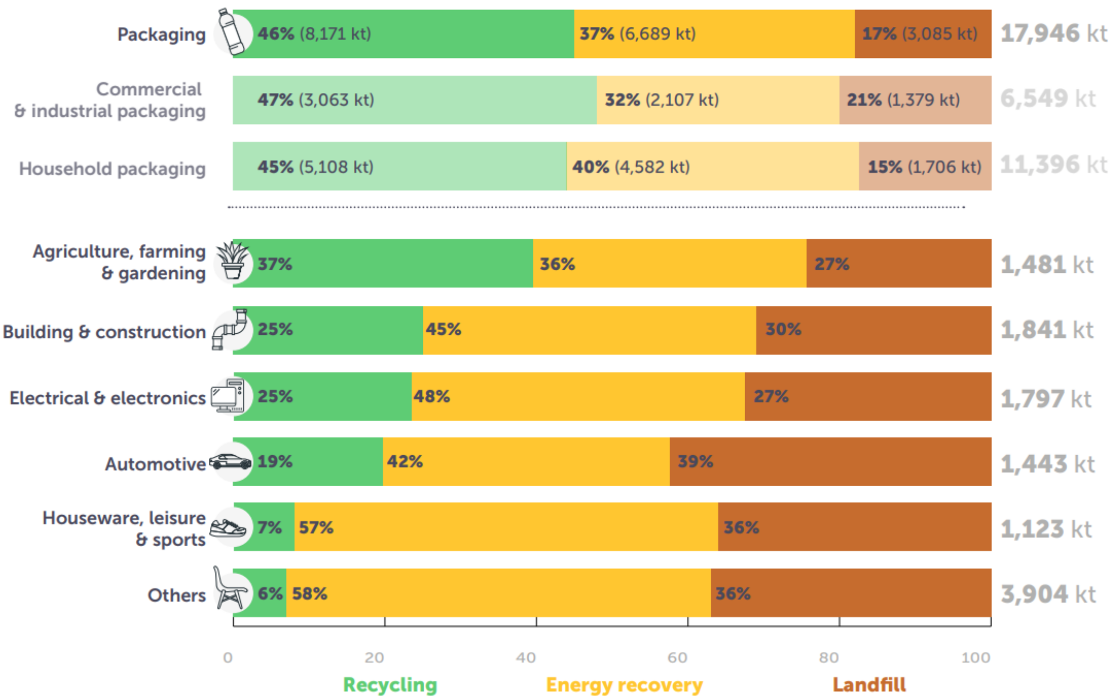


Figure 21. Treatment of total post-consumer plastics waste by application (2020, in the EU27+3)

2.2.2 Plastic waste management and recycling in Greece

A variety of stakeholders are responsible for waste management in Greece, including the Greek Ministry of Environment and Energy at the national level, the Hellenic Recycling Agency (EOAN) responsible for the approval, monitoring, and control of the existing operating systems in Greece;, the Hellenic Recovery Recycling Cooperation (HERRCO), which is the competent authority (Producer Responsibility Organisation) for the design and implementation of recycling policy, municipalities responsible for waste collection and management at the local level. Several NGOs and charities are also involved in improving waste management in Greece through voluntary actions such as awareness raising campaigns and pilot programs.

HERRCO Waste Recycling System, licensed by the Hellenic Recycling Agency (HRA), operates with its primary, but not the only, collection method being the blue bins and the blue bells. It is a member of EXPRA (Extended Producer Responsibility Alliance), the European collective organization which incorporates the national Packaging Recycling Systems established by the legally bound packaging administrators and operating on a non-profit basis. Based on the HERRCO Annual report, in 2021, approximately 425,000 tons of packaging material were made available in the Greek market by the companies affiliated with the system. Based on the extent of contribution by the HERRCO affiliates per category (commercial sectors: beverages, chemicals, detergents, food products, WEEE, clothing, shoes and toys), about 60% of the contributions results from companies active in the food and beverage sector in one year. The blue bins are placed to collect recyclable materials (packaging waste made of paper-cardboard, plastic, glass, aluminium and tinplate) and blue bells for collection of glass. In 2021, 518,.000 tons of packaging waste were collected by HERRCO[21].

Two main actors in Collective System for the Alternative Management of Waste Electrical and Electronic Equipment (WEEE), approved by the Hellenic Recycling Organization are Appliances Recycling S.A. and FOTOKIKLOSI S.A., with main objective to organize the collection, transport, temporary storage, separation and treatment of WEEE and their components, with the ultimate goal being the removal of substances which are hazardous for the environment and the reintegration of usable materials as raw material in the production of new products.

EDSNA is the Special Interlevel Association of the Prefecture of Attica established for Solid Waste Management of the Region of Attica. The purpose of the Association is the temporary storage, processing, transhipment, recycling and in general the utilization and disposal of solid waste, the operation of relevant facilities, the construction of processing and utilization units, as well as the rehabilitation of existing disposal sites (LLS) within of the territorial jurisdiction of the Attica Region.

The Waste Mechanical Recycling and Composting Plant (EMA) for the treatment and recycling of mixed municipal waste, is in the Integrated Waste Management Facility (OEDA) West Attica. The nominal capacity of the EMA is 1,200 tons, 100-120 tons of compost (soil improver) are produced, over 400 tons of Refuse Derived Fuels (RDF: plastic, paper, wood, fabric), approximately 0.5 tons of aluminium and 15-20 tons of iron are recovered, while residues accounts in the order of 300 tons including other losses (moisture and gases). The Mechanical Waste Recycling Plant (EMA) of the Ano Liosion area receives part of the waste from the Municipalities and Communities of the Prefecture of Attica. All vehicles are weighed once, either at the entrance or at the exit when receiving products or removing waste. The Mechanical Separation Unit consists of the receiving and feeding units, mechanical separation, dry fraction treatment and waste product management. From the Reception Unit, the waste, after removing the bulky ones, is smoothly dosed towards its processing. The objective of the mechanical separation unit is to separate the incoming mixed waste to produce four fractions: (1) The fraction to be composted, for the production of marketable compost after controlled biodegradation of the organics; (2) The fraction to produce RDF (Refuse Derived Fuel), from a mixture of paper, plastic and other light combustible materials, in the final form of bales; (3) Ferrous (magnetizable) metals; and (4) Aluminium (Figure 9).

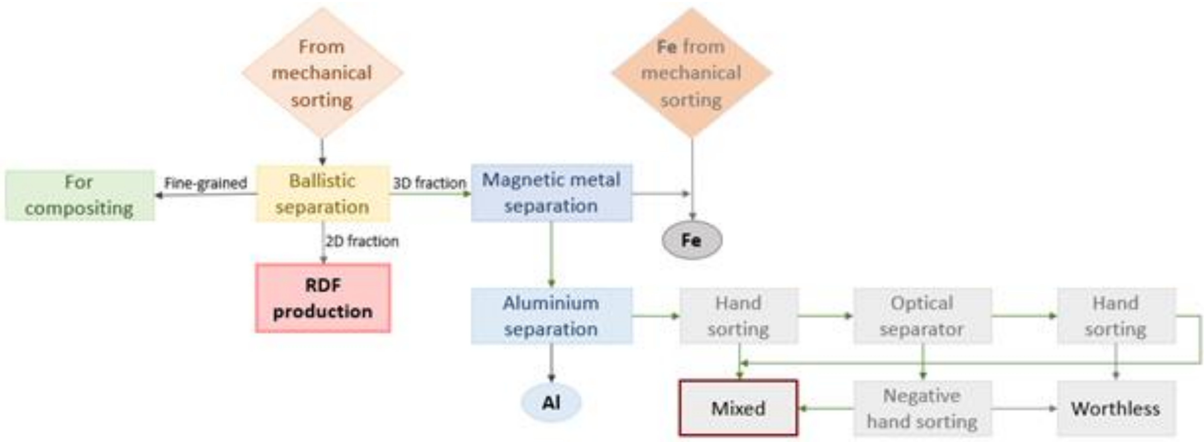


Figure 9. Workflow of waste separation and sorting

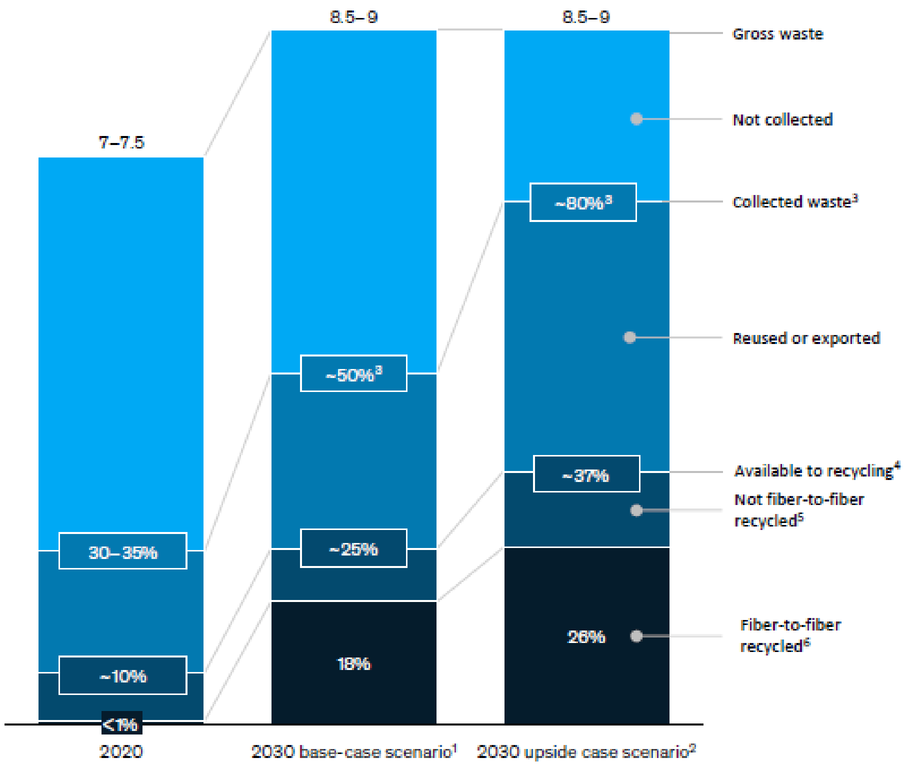
In addition to the separation of the above fractions, the whole design also aims at the separation of materials whose presence is undesirable, either during the further processing of the above fractions, or in the final products: (i) plastic bottles of soft drinks, water, etc. made of hard plastic (PET, PE, PVC), which on the one hand is undesirable as a component of the produced RDF (PVC), on the other hand it is advisable to separate it, for future recovery of the packages; (ii) any bulky waste, e.g. car tires, chairs, bicycles, etc., which may not have been removed to the Reception Unit. In dry fraction processing unit, the bulky wastes resulting from the secondary screening, as well as those resulting from the primary screening (after being shredded), pass through a magnetic metal separator, and are fed to the ballistic separator – sieve. Hard, rigid solids (e.g., plastic bottles, hard plastic, aggregate, glass, metals, woods, etc.) are collected and transported via a conveyor belt to a separation device for non-magnetized metals (mainly Al). After the metals are recovered, the remaining waste is disposed of as junk. The light, flat and flexible materials, are gradually transferred towards the anomers. They are mainly made of paper and plastic, suitable for feeding the RDF production line. The flexible lightweight materials (RDF) separated in the ballistic separator are then reduced in size by passing through appropriate shredders (one per ballistic separator). Shredded RDF is collected on a single conveyor belt and taken to the compression area, for final baling and commercialization. Mechanical screening waste management is performed on the waste of the tertiary sieves from the three (3) mechanical sorting lines. Once collected, the third-grade scraps are picked up from the final film. Then, in dry fraction unit waste management, the heavy fraction of ballistic separators has been observed to contain almost all plastic bottles of liquid packaging (water, soft drinks, detergents, cleaners, etc.). In terms of material category, PET dominates and to a lesser extent PE and finally PVC and PP. A manual sorting device has been installed to recover the materials from PET, PE. At the end, in the composting and maturation units, the organic fraction is introduced in composting channels. The produced compost is refined to ensure the production of high purity compost and therefore the marketability of the final product. In Figure 9 - Figure 12, data collected during 2022 were schematically presented.

2.2.3 Waste treatment of textiles

As already mentioned above, only 30% of the textile waste is currently being collected in Europe and the largest part of this waste is not recycled. This percentage will increase significantly in the coming years as the Waste Framework Directive states that member states are required to set up separate textile collection by 2025. Additionally, there is also the EU Strategy for Sustainable and Circular Textiles describing the 2030 vision for the European textiles market. This strategy says that textiles should be long-lived and recyclable, made from recycled fibres for a certain percentage, free of hazardous substances[22]. These actions from the European Union will result in a higher collection rate of 50% (base case scenario) up to 80% (upside case scenario), while also an increase in total waste amount is expected from 7-7.5 million tonnes to 8.5-9 million tonnes by 2030 (Figure 22).

Currently the textile industry is still a linear value chain, but due to the Waste Framework Directive and an increase in research for recycling of textiles, the value chain gradually changes towards a closed-loop textile circularity. However, there are still a lot that needs to be done before the loop can be closed. First, the sorting and pre-processing need to be improved. Most recycling technologies require a pure waste stream, so sorting needs to be done. For now, it is mainly done manually, based on the labels in clothes, but this is not always correct. It can be automated by using NIR technologies, but there are also limitations on this technique. Also, pre-processing is necessary to remove all hard parts and contaminations that can make recycling difficult are impossible, like the presence of zippers and buttons.

[22] Textiles strategy (europa.eu)



1. The base-case scenario refers to a situation where 50 percent of EU-27 and Switzerland's post-consumer household textile waste is collected, up from today's 30 to 35 percent.
2. The 2030 upside case refers to a situation where 80 percent of EU-27 and Switzerland's post-consumer household textile waste is collected.
3. Refers to the collection rate of post-consumer household waste. Total collection rate is slightly different due to other waste streams having other collection dynamics.
4. There are different ways of defining what share of textile volume is "available to recycling". This paper uses the term to describe textile waste that is collected and does not have an alternative use with a higher value that is further up in the waste hierarchy (for example, resale). Of the share that is available to recycling, there may be fiber fractions that technically are not eligible for fiber-to-fiber recycling. Our base-case scenario with allocated textile waste to the different recycling technologies assumes—based on our analysis of forward-looking feedstock purity requirements by recycling technologies—that 70 percent of what is available to recycling can technically be recycled.
5. Can either be open-loop recycled products like cleaning rags, or thermo-chemical recycling to create syngas.
6. Here defined as fiber-to-fiber recycled volume divided by total gross waste. The rate reflects the estimated full potential of fiber-to-fiber recycling of 70 percent of what is available to recycling. This number excludes open-loop recycling.

Figure 22: Current and estimated textile waste and textile collection rates in EU27 and Switzerland in million tons.

There are four main groups of recycling technologies for textiles, each with their own requirements and possible outcomes (Figure 23). The first technology is mechanical recycling where physical forces are used to convert textiles into usable fibres. This method is a low-energy and cost-efficient recycling method that is commercially proven. All types of fibres can be used for this method, but there is always a fibre-length reduction and quality degradation, so it is mainly used for open-loop applications such as cleaning rags, padding and shoddy fibres. The second method is thermo-mechanical recycling that can only be applied on synthetic fibres, as they are melted again for recycling. This method is only at demonstration scale yet for textiles, as there are still some technical challenges to solve, and feedstock requirements are very strict (>99%). Chemical recycling is a third recycling method that can be used for textiles. This is a broad category of different technologies that use chemical processes to break down fibres to polymer or monomer level, depending on the technology and the targeted materials. These technologies can return to virgin-quality fibres but doesn't yet exist at commercial scale. The last recycling technology is thermos-chemical recycling where gasification is used to produce syngas; making it a technology that can be used for all fibre types. However, this is not a closed-loop technology and not commercially available yet for textile waste.

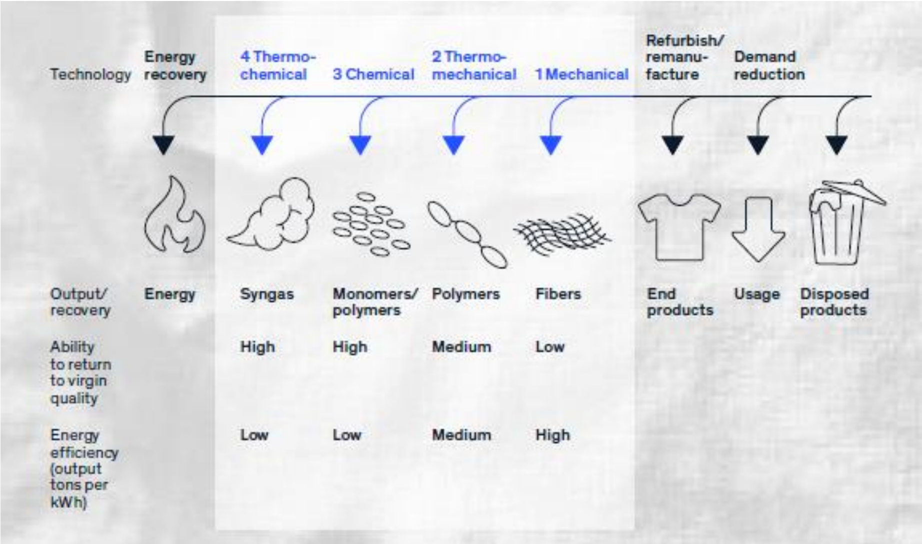


Figure 23: Four recycling technologies and their outputs

2.2.4 Additive / filler identification and SoC assessment

The additives are widely used in plastics, in higher amounts in long life expectancy products (i.e., electrical and electronic or construction materials). Although, limited information on amounts of legacy additives in the current plastic waste streams is available. Different studies carried out[23,24,25] are focused on the environmental impact due to the potential proportion of the emission of plastic additives during the use of end products and disposal. Plasticisers, flame retardants, antioxidants, ultraviolet-absorbing agents and PVC stabilisers are the most used additives in plastics that can produce relevant emissions. Fillers are also common additives in plastics, but they are not collected in these emission studies, as they do not produce significant emissions. This information can give an idea of the more likely type of additives present on the wastes, although not in a quantitative way.

Plastic waste streams that may contain legacy additives, should be treated in order to separate safely these type of additives[26]. Processes of sorting or solvent based technologies may help recyclers to commit and adopt the concept of decontamination; to ensure complete removal, the definition of technically feasible hazard threshold levels is required for a high decontamination rate and the potential impact they have on recycling. Although, a high degree of transparency is required for recycling technologies to track the fate of POPs and SVHCs in such processes.

A large database on WEEE plastics composition at the WEEE category level, comprising information on both the overall share of plastics in different equipment types or categories, as well as on the relative shares of various polymers (including distinction between BFR-free and BFR-containing for ABS, HIPS and Epoxy resins) has been released recently[27]. More than 800 data points were compiled in total, from a wide variety of sources including published studies as well as process data provided by WEEE recyclers, WEEE plastic recyclers and take-back schemes and the consolidated results, based on averaging data considered to be of high quality, are displayed in Figure 24.

[23] https://one.oecd.org/document/ENV/JM/MONO(2019)10/en/pdf
[24] https://www.miteco.gob.es/images/es/estudiojrc_tcm30-530967.PDF#page=252&zoom=100,90,104
[25] https://echa.europa.eu/documents/10162/17228/expo_plastic_addives_guide_en.pdf/ef63b255-6ea2-5645-a553-9408057eb4fd
[26] S. Wagner, M. Schlummer, Legacy additives in a circular economy of plastics: Current dilemma, policy analysis, and emerging countermeasures, Resources, Conservation and Recycling 158 (2020) 104800, https://doi.org/10.1016/j.resconrec.2020.104800.
[27] Haarman A., Magalini F., Courtois J., Study on the Impacts of Brominated Flame Retardants on the Recycling of WEEE plastics in Europe, SOFIES 2020.

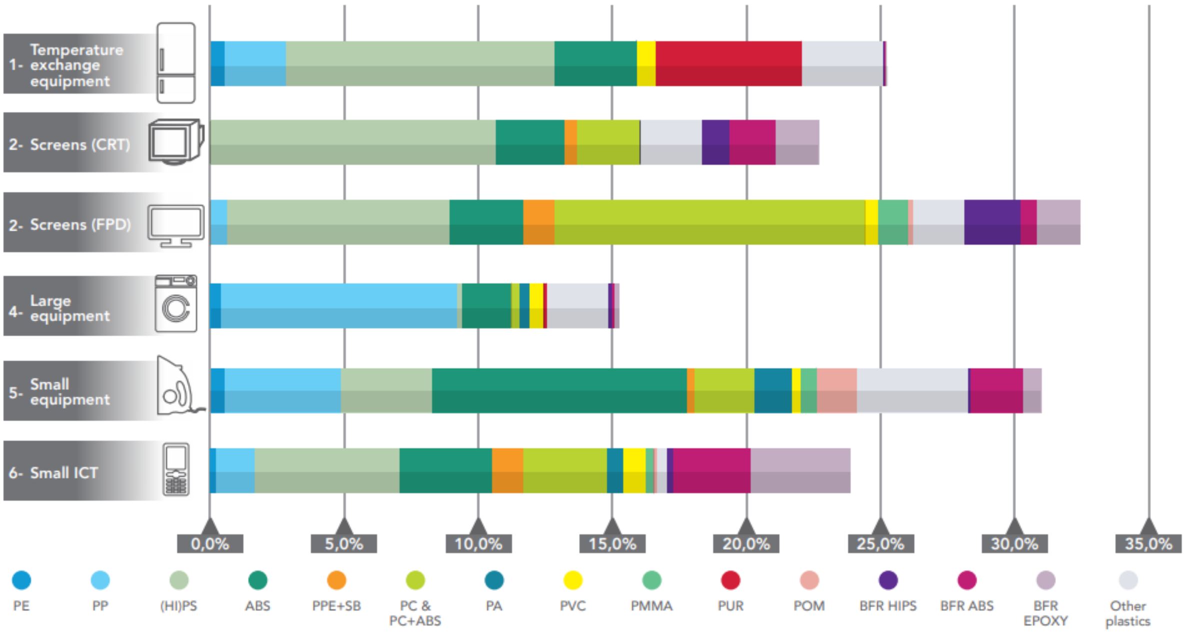


Figure 24. WEEE plastics composition, per category (Sofies[27], 2020).

Figure 25 illustrates the distribution and fate of brominated flame retardant (BFR)-containing plastics in the context of WEEE generation, with the aim of providing a clearer visual representation.

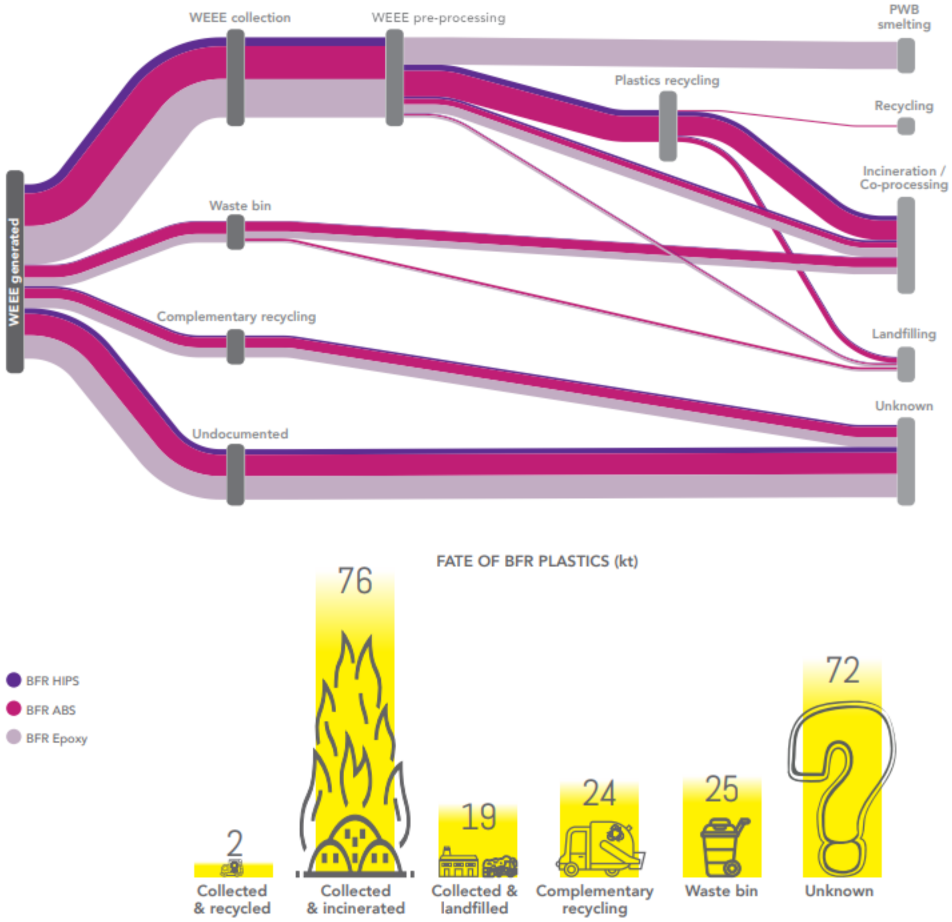


Figure 25. Fate of BFR plastics from WEEE, 2020, EU-28 + Switzerland & Norway (Source: Sofies report 2022[Error! Bookmark not defined.])

Annually, approximately 220 kt of BFR plastics are generated from WEEE. Out of this total, 45% (98 kt) is collected, 12% (25 kt) is discarded in regular waste bins, 11% (24 kt) undergoes complementary recycling treatments, and 33% (72 kt) is part of WEEE with an unknown destination. Within the 98 kt of BFR plastics collected from WEEE, 76 kt are incinerated, including 22 kt of BFR Epoxy in smelters, while 19 kt are sent to landfills. Only 2 kt are recycled, accounting for 1% of the total BFR plastics generated and 2% of the BFR plastics collected. This means that currently, 98% of the BFR plastics collected can be effectively separated and disposed of through official WEEE recycling channels. However, it is concerning that 55% of all BFR plastics generated do not enter these channels due to improper sorting by consumers or substandard treatment practices for WEEE. Consequently, an unknown but potentially significant portion of these uncollected BFR plastics might find their way into uncontrolled plastic recycling settings. This situation raises the risk of contaminating recycled material streams with BFRs due to the absence of BFR removal procedures.

Evidence of inadequate recycling practices is apparent in the elevated levels of persistent organic pollutant brominated flame retardants (POP-BFRs) found in children's toys and food-contact articles manufactured on the Asian continent[28].

[28] Guzzonato, A., Puype, F. & Harrad, S. J. Evidence of bad recycling practices: BFRs in children’s toys and food-contact articles. Environ. Sci. Process. Impacts 19, 956–963 (2017).

3. TARGETED VALUE CHAINS

3.1 TOYS PWS

Collection of materials for use in WP2 once identified by type of polymer.

Although there are different initiatives in Spain through NGO for the collection of toys with the intention of donating them to children in need or giving them a second life, there is not a system for collecting or recycling toy wastes.

The main recycling chains are focused in three types of products: packaging/containers (plastic packaging, cans, tetrabricks, etc.), paper and cardboard, and glass. Specific recycling bins are available in the street for the consumers to deposit these types of residues.

Other products such as batteries, oils, metals, computers, household appliances and toys are also recyclable. The municipalities offer solutions for the collection of these types of wastes in the so-called "Clean Points". These are hazardous waste collection centres where all kinds of products at no cost can be left, thus avoiding polluting the planet.

Some specific measures are adopted in Spain in order to support reuse of products such as a textiles, toys or electrical appliances, among others[29]. In 2015, Spain transposed the EU Directive 2012/19 on Waste Electrical and Electronic Equipment (WEEE) into national law, for the reuse-target for e-waste, separate from recycling. On the other hand, Law 7/2022, on waste and contaminated soils for a circular economy, enables public administrations to establish measures to promote reuse, and introduces direct measures, namely the prohibition to destroy unsold surpluses of non-perishable products such as textiles, toys or electrical appliances, among others. These surpluses must be destined for reuse as a priority and, only when this is not possible, they can be destined for preparation for reuse or other options.

Therefore, the post-consumer plastic toys wastes collected for the study of PRecycling project come from a Charity Campaign: Share and Recycle[30], driven and supported by the Spanish Toy Manufacturers' Association[31] (AEFJ). Figure 26 shows the banner of the campaign in the AEFJ website.

Share and Recycle campaign is a circular economy action in the toy sector, which aligned with the planet's sustainable development objectives, advocates respect for the environment, solidarity and labour integration of people with disabilities. The objective is to give a second life to toys through donation.

Figure 26 Share and Recycle campaign

[29] https://www.eea.europa.eu/themes/waste/waste-prevention/countries/2023-waste-prevention-country-fact-sheets/spain_waste_prevention_2023
[30] https://www.comparteyrecicla.com/
[31] https://www.linkedin.com/company/aefj/about/

Share and Recycle works with a simple mechanism: the children check at home the toys that they are not going to use anymore and that are suitable for other children. They donate the toys so as other children can enjoy with them. Toys are delivered to collection points and then transferred to a reprocessing centre, a centre of special employment, where the toys are reviewed one by one to verify if they are suitable for a second life. If so, they are organized in a toy bank, which stores the toys and then they are sent to different NGOs and charities that request them through the website www.comparteyrecicla.com.

If they are not in a condition to be reused, they are discarded. The AEFJ helped AIJU with the collection of the discarded toys produced in one reprocessing centre during one of these campaigns.

A first selection of toy plastic products was made in the above-mentioned reprocessing centre, discarding electronic toys, metal parts, textile fractions of toys, dolls (of mainly PVC), etc. (Figure 27).

Figure 27. Premises of the reprocessing centre where toys are received, reviewed and managed

AIJU collected about 200 kg of toy wastes of this type and brought them to a pilot plant for the recovery of waste and its transformation into raw materials (Circular Industry Pilot Plant), developed in another project with other partners (Figure 28). The Circular Industry Plant is capable of recycling multi-composition products (up to 40 different materials) that end up in landfills or incinerated. This plant is mainly devoted to recycling footwear, textile and toy wastes and is addressed to help companies to accomplish the new waste law by reducing their waste, reuse their surpluses, and to convert them into raw materials that can be used in other sectors such as furniture or automotive, and improve their carbon footprint, thus becoming a circular company.

Figure 28. AIJU Circular Industry Plant

In the Circular Industry Plant premises, a second re-selection was carried out. Blisters and other flexible items, both packaging (blisters, films…) and P-PVC toys, were removed, leaving, as far as possible, only the rigid toy wastes (as shown Figure 29 and Figure 30).

Figure 29. Example of package parts removed

Figure 30. Example of collected rigid toys.

Then, all the amount of toy wastes were grinded by dumping the products into the hopper/ripper directly (Figure 31). The Pilot plant can separate the different particle sizes of the grinded wastes. There are three meshes: < 2.5 mm, 2.5-5 mm and 5-10 mm.

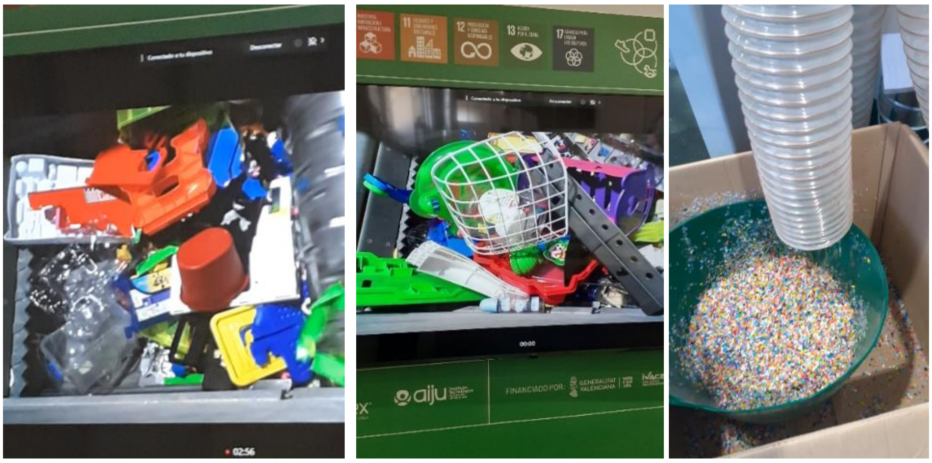


Figure 31. Grinding process and separation by flake size.

After evaluating the resulting flakes, it was decided, based on the experience, that the 2.5-5 mm fraction will be easier processed afterwards in WP2 and WP3 by extrusion for the recycling and compounding tasks. The fraction of 2.5-5 mm was later treated through a densiometric table to remove more "lighter" particles from film residues, etc. that could remain in the processed waste. Figure 32 shows some flakes of each size obtained after grinding the toy wastes. The encircled fraction is the selected one for working in the project. A total amount of 150 kg of this fraction was obtained.

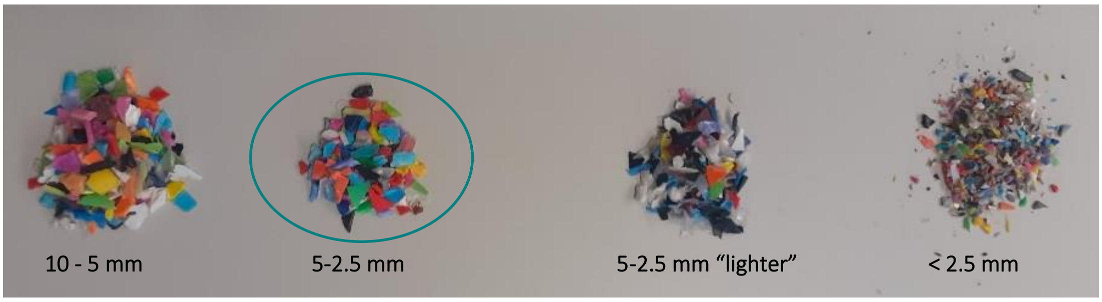


Figure 32. Obtained grinded fractions for toy wastes

3.2 TEXTILE PWS

Regarding the textile residue, AIJU provided CTB two types of wastes from two textile companies (Figure 33):

- a first batch of 25 kg of scraps 100% polyester fabric, from a woven loom, collected from a collaborator in a regional project. At the end of the process, the edges are cut (widthwise) because they may have imperfections., These edges are the residue.
- a second batch of curtain residues 50 kg of polyether fabric from a company of curtain manufacturing.

Figure 33. Textile residues collected from two textile companies. Left: scraps from polyester fabric. Right: curtain residues

Discussions have been done with multiple textile companies to collect additional wastes for improving the recycling process as well as the production of the demonstrators. CTB contacted a curtain company, Lampe Textiles, that is willing to provide their wastes for the project. The wastes will be 100% polyester fabrics coming from their weaving process and will be white or lightly coloured (Figure 34).

Figure 34. Textile residues collected from Lampe Textiles

3.3 WEEE PWS

Arçelik, the leading white goods manufacturer in Turkey and the 2nd largest white goods company in Europe, continues its activities in line with its vision of "Respectful to the World, Respectable in the World." The products produced by Arçelik become WEEE when the product is at the end of their useful life. Arçelik, as part of the Expanded Producer Responsibility, established in 2014 its own WEEE recycling facilities to encourage evaluating the products as resources and to return products to nature: the plants in Eskişehir and Bolu. Approximately 1.6 million WEEE units in its recycling plants since 2014 have been recycled. By recycling refrigerators in Eskişehir and other white goods and small domestic appliances in Bolu, Arçelik targets minimize the environmental impact of the products throughout their life cycle. Figure 35 summarizes the amount of waste items collected in 2021.

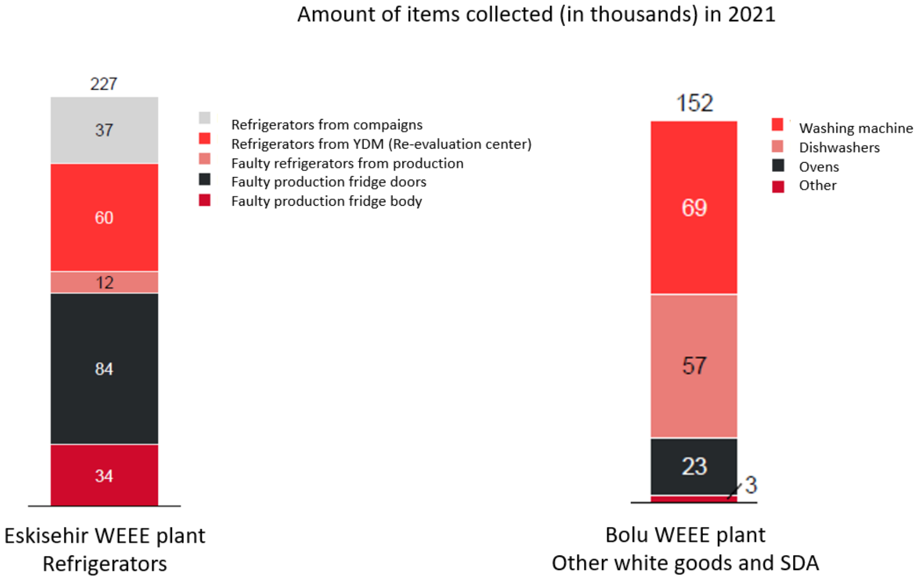


Figure 35. A summary of amounts of wastes collected by Arçelik in 2021.

Within the scope of PRecycling project, the following wastes collected from Arcelik Turkey WEEE plants, separated from metallic wastes, shredded and sent to COOLREC for further analysis:

- Wastes from Bolu WEEE plant Turkey: including detergent drawer, motor protection plastic, washing machine panel, dishwasher kick plate, dishwasher bottom protection plastic, oven cover plastic and dishwasher salt box (Figure 36)
- Wastes from Eskişehir Refrigerator plant: contains shredded plastic wastes such as HIPS, GPPS, ABS, PP. Although the PU was separated, it may still include few amounts of PU as well (Figure 37).

Figure 36. Shredded wastes from WEEE

Figure 37. Shredded wastes from Refrigerator plant

3.4 INVENTORY OF PWS

Table 7 summarises the inventory and identification of the incoming plastic streams of the collected waste materials from the different EU zones studied in previous sections. It includes information about the type of collected product, volumes, polymer and/or additive/filler identification.

Considering the data of total volume of plastic waste generated in the different countries (see section 2.1) and the data of type of collected post-consumer plastic waste (in %) (Figures 3 to 7), the inventory has been focused in the analysis of the two streams more applicable to the project, considering the targeted value chain in PRecycling (toy, textiles, and home appliances wastes). The two streams are *Electrical and electronics* and *Houseware, leisure and sports*. Kilotons of plastic waste have been calculated by applying the % of type of collected post-consumer plastic waste to the total volume of PW generated in each country.

In the same way, the possible amount available from PWS Electrical and electronics, and Houseware, leisure and sports, has been calculated per type of product or stream.

Table 7. Waste identification of the type of collected product (Electrical and electronics and Household, leisure and sports wastes) and volumes of those wastes generated in Europe, and per participant countries.

Country	Total plastic waste generated (kt) (2020)	Type of products		Total PW of the two streams (kt)
		Electrical and electronics	Household, leisure and sports	
The Netherlands	1058	6% 63.48 kt	3% 31.74 kt	95.22
Belgium	578	7% 40.46kt	4% 23.12 kt	63.58
France	3760	7% 263.2 kt	4% 150.4 kt	413.6
Germany	5419	6% 325.14 kt	3% 162.57 kt	487.71
Spain	2567	4% 102.68 kt	4% 102.68 kt	205.36
Greece	814.7	3.3% 26.8 kt	4% 32.6 kt	59.4
Turkey	9540	10% 954kt	10% 954 kt	1908
Total plastic waste generated of those fractions (kt)		1775.76	1457.11	3232.87

In the countries studied, or at global European level, the calculated amount of electrical waste produced is 1775.76 kt and for the houseware, leisure and sports waste is 1457.11kt. If the selective collection scheme were optimized for all countries and these quantities could be collected in good conditions, a very relevant amount of PW could be reinserted in the same manufacturing chain and/or in other products from other sectors, including toys and non-consumer goods.

If these data are compared with the current consumption of post-consumer recycled waste in those two applications (106 kt Electric and electronics and 64 kt houseware, leisure and sports) as shown in Figure 38, an idea of the high growth potential of the recycling option compared to landfilling or incineration for these targeted value chains can be given.

WP2 will study how to condition the wastes to optimise their properties to effectively reinsert them in the targeted value chains.

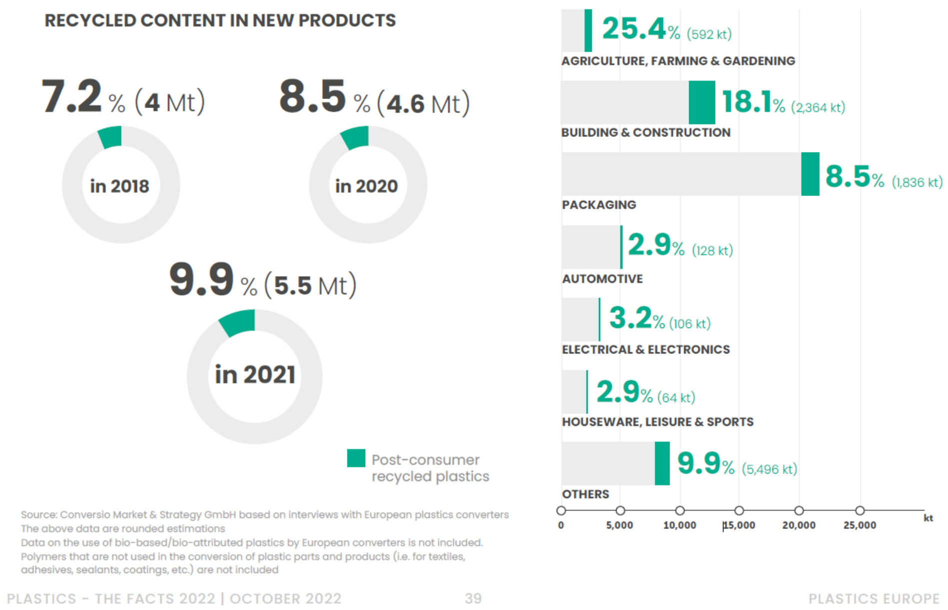


Figure 38. Post-consumer recycled content in 2021[32]. Source: Plastics Europe

Regarding the types of polymers constituting the wastes at European level (Table 8), they have been estimated from the demand data in Europe by type of material for these applications, as shown in Figure 39. Also, by the identification of fractions of toys and home appliances collected wastes in the project, carried out in WP2.

It is important to notice that in the toys PWS collected in Spain, no substances of concern detected over legal limits in the analysis of this sample according to legislation and standards, according to the tests carried out in the project: no migration of heavy metals, no formaldehyde, BPA, phosphate flame retardants, no PHTALATES, no Polycyclic aromatic hydrocarbons, No Metals content: Cd, Pb, Cr, Hg nor VOLATILE COMPOUNDS (benzene, xylenes, cyclohexane, ethylbenzene, toluene) were detected.

Table 8. Waste identification of the polymer and/or additive/filler identification per type of collected product.

	Type of products	
	Electrical and electronics	Household, leisure and sports
Type of polymers **(see Figure 39)**	PP, LDPE, PS, ABS, PUR and others	PP, PVC, ABS, PET and others
Type of additives[33,34] and SoC[35,36]	Colorants, stabilisers, flame retardants, plasticisers, antioxidants, ultraviolet-absorbing agents and fillers.	Pigments, fragrances, plasticisers, UV absorbers, flame retardants, fillers

[32] Plastics – the Facts 2022 OCTOBER 2022
[33] Plastics, Additives and Compounding. Volume 4, Issue 9, September 2002, Pages 12-15
[34] COMPLEMENTING DOCUMENT TO THE EMISSION SCENARIO DOCUMENT ON PLASTIC ADDITIVES: PLASTIC ADDITIVES DURING THE USE OF END PRODUCTS. Organisation for Economic Co-operation and Development. NV/JM/MONO(2019)10
[35] N. Aurisano et al., Chemicals of concern in plastic toys. Environment International 146 (2021) 106194
[36] J.N. Hahladakisa, et al. An overview of chemical additives present in plastics: Migration, release, fate and environmental impact during their use, disposal and recycling. Journal of Hazardous Materials 344 (2018) 179–199

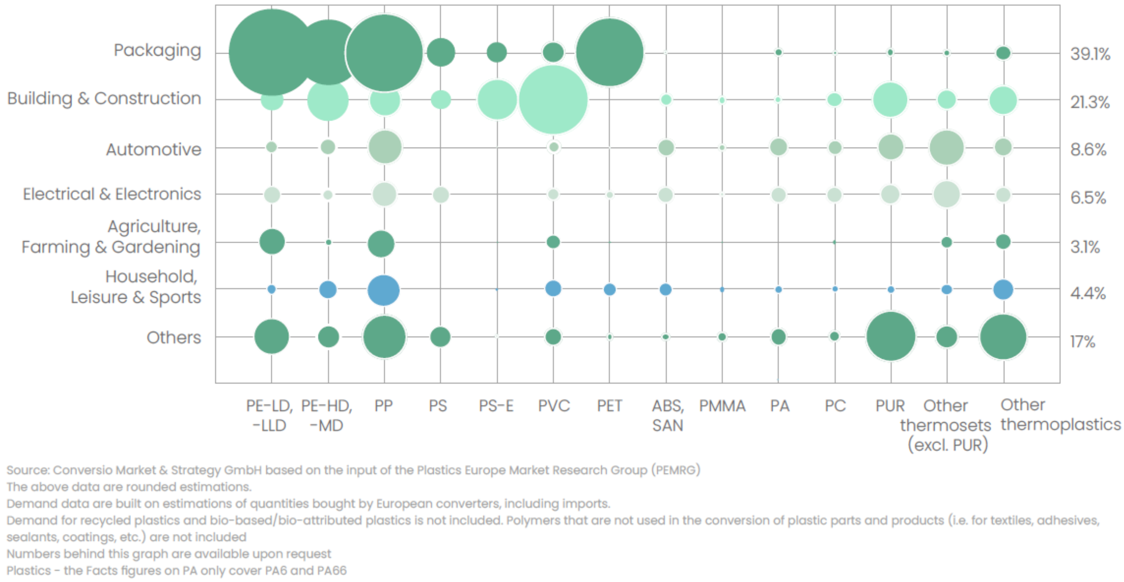


Figure 39. European plastics converters demand by application and type in 2021[37]. Source: Plastics Europe 2022

Finally, for the identification of additives, fillers or substances of concern (SoC), no quantitative information has been obtained. They have been identified only qualitatively, from general references and studies of emissions derived from that type of additives. Plasticisers, flame retardants, antioxidants, ultraviolet-absorbing agents and stabilisers are the most used additives in plastics that can produce relevant emissions (Table 8). Fillers are also common additives in plastics, but they are not collected in these emission studies, as they do not produce significant emissions. This information can give an estimation of the more likely type of additives present on the wastes, although not in a quantitative way. The quantitative assessment of PWS, from the targeted streams, are under analysis to determine all fillers and additives within the WP2.

Based on the inventory, a first pre-selection of the adapted sensor-based technologies for the identification of the recyclates collected for the project was performed, explained in next section.

[37] Plastics – the Facts 2022 OCTOBER 2022

4. SENSOR BASED TECHNOLOGIES

Sensor-based sorting is a generic term used in recycling applications where waste streams are detected by a sensor technique and separated by an automatic separation system, typically mechanical or pneumatic. The main steps in sensor-based sorting are material conditioning, material presentation, detection, data processing and separation. In industrial plastics recycling plants, the most widely implemented sorting solutions are those based on physical properties, i.e., manual identification, identification based on density and those based on electrical properties to separate metal fractions from plastic fractions.

In the context of PRecycling developments aiming to increase the circularity of PWS value chains, it is necessary to develop finer identification techniques for multi-material polymeric waste streams (PWS). In this section focuses on the material identification phase, which takes place after collection and/or other previous sorting operations. Several spectroscopic technologies, based on the analysis and measurement of light, were evaluated for polymer and additive identification that can be applied to obtain recoverable plastic fractions from pre-sorted plastic waste: IR absorption spectroscopy, Hyperspectral Imaging (HIS), Laser Induced Fluorescence (LIF), Laser Induced Breakdown Spectroscopy (LIBS) and Raman Spectroscopy (RS). The working principles of these methods and their applications in the identification of polymers and additives are presented in following paragraphs.

4.1 INFRARED ABSORPTION SPECTROSCOPY

This molecular spectroscopic technique works by measuring the absorption of electromagnetic radiation by molecules exhibiting an electric dipole moment for wavelengths matching vibrational transitions of the molecules. The collection of the analysed signal is mainly carried out in a reflection geometry. Depending on the analysed spectral range (light and detector) Near-infrared (NIR)- and Mid-infrared (MIR)- based techniques can be distinguished. The setup consists of a broadband excitation source, for instance a halogen lamp, that is directed to the sample. In transmission geometry the fraction of the incident light transmitted through the sample is directed to a spectrograph, where it is dispersed and detected by a semiconductor sensor. In reflection geometry the fraction of the incident light reflected by the sample is directed to the spectrometer (Figure 40).

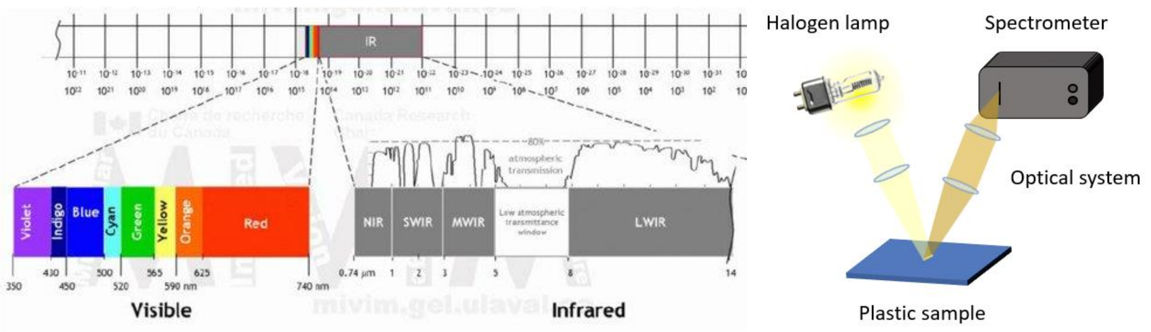


Figure 40. Left) Electromagnetic spectrum showing the visible and infrared wavelength intervals. Right) Schematic setup for IR absorption measurements in reflection geometry using a broadband halogen lamp and spectrometer.

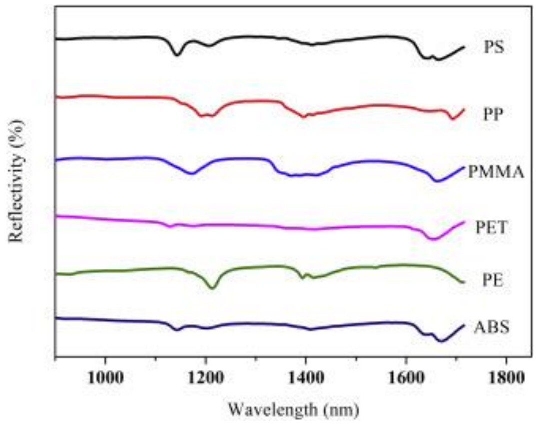
4.1.1 NIR spectral range

Near-infrared absorption spectroscopy uses electromagnetic radiation between 780 and 2500 nm. Depending on the detector used, the upper wavelength limit might be significantly lower (around 1800 nm for InGaAs-based detectors) The absorption in this spectral region comprises overtones/ combinations of the fundamental molecular vibrations (Figure 41). It is a fast technique that is comparably easy to set up. However, due to the broad and overlapping absorption bands data evaluation is more demanding and often relies on the development of a machine learning algorithm using a large set of known (labelled) samples to identify polymer spectral fingerprints. In addition, the NIR spectral range is not suitable for identifying and differentiating black plastics.

NIR absorption spectroscopy has been integrated into industrial sorting machines for plastic recycling. It usually comprises a conveyor belt, a lighting unit emitting in the NIR, and a camera recording the light being reflected. With the necessary software in place, the system detects the plastic type and eject the parts/flakes (normally with localized pressurized air) of the material to a specific downstream process.

4.1.2 MIR spectral range

The concept and experimental setup are analogous to the ones described above. However, in this case the absorption of light above 2500 nm is studied. In this spectral region absorption is due to transitions between different states of the fundamental molecular vibrations. An advantage over the NIR range is the absence of strong carbon absorption, allowing for the analysis of black plastic. In addition, the analysis of absorption spectra is more straight forward than in NIR (Figure 41). More light sources and detectors for the MIR range become commercially available, though comparably expensive, but being more recent technological developments, the commercial readiness and reliability of these instruments still needs to be proven.



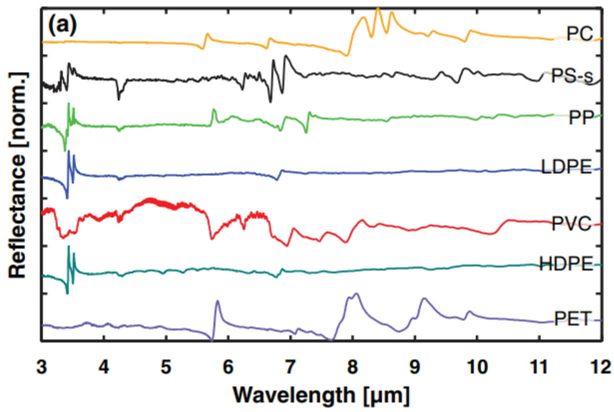


Figure 41. Reflectivity of several polymers in the NIR spectral region[38](left). Normalized reflectance spectra for several polymers in the MIR spectral range[39] (right).

4.2 FT-IR SPECTROSCOPY

Fourier - Transform Infrared (FT-IR) Spectroscopy is a variant of infrared absorption spectroscopy that utilises an interferometer and subsequent Fourier transform analysis (FT-IR) of the obtained data to derive the absorption spectrum. It analyses polymer absorption in the MIR spectral range and thus can be applied for all types of plastic including black plastic. Polymer identification is carried out by comparing measurement data against known spectral data available in the equipment database. The method is sensitive and yields distinctive spectra that in some cases also allow for the identification of different polymer grades and/or additives within a polymeric family (Figure 42). Since in most cases it requires sample preparation and small and steady samples to perform measurement, it can be seen as a laboratory-based reference technique.

[38] S. Zhu et al., Advanced Industrial and Engineering Polymer Research 2 (2019)

[39] A. Vazquez-Guardado et al., Applied Optics 54 (2015)

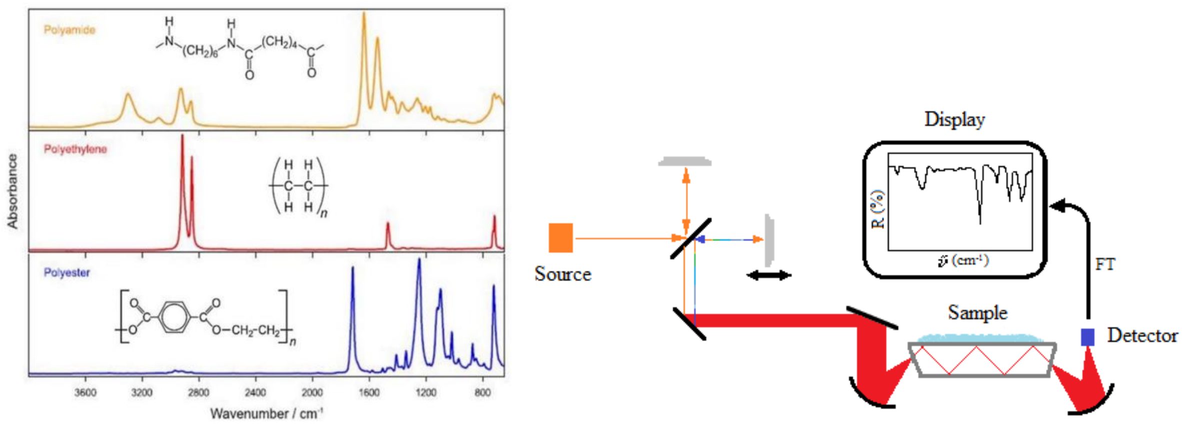


Figure 42. Fourier-transform infrared spectroscopy spectra of different polymers[40] (left). Schematic of Attenuated Total Reflection configuration spectrometer: ATR-FTIR (Wikimedia Commons) (right)

4.3 HYPERSPECTRAL IMAGING (HSI)

Hyperspectral imaging (HSI) is another special variant of absorption spectroscopy. It combines the power of digital imaging and spectroscopy since every pixel of the spatial image contains additional spectral information. The resulting hyperspectral image yields data in form of a so-called hypercube. The spectral information, i.e., the spectrally resolved reflection or absorption of the analysed sample, usually covers the visible (VIS) and/or NIR range (Figure 43. Recently also applications for the MIR spectral range have emerged using newly available light sources and detectors in this spectral range.

Different configurations of hyperspectral imaging systems exist, with the line scan or push broom method is the most used one for industrial applications, as it offers a good trade-off between spectral resolution and speed (Figure 43). While having the same advantages and disadvantages as other absorption-based techniques, its big plus is the combination of spatial and spectral information. This allows for quasi real-time identification and sorting. The method is used in the agricultural and food industries but also gained attention for use in the plastic recycling industry.

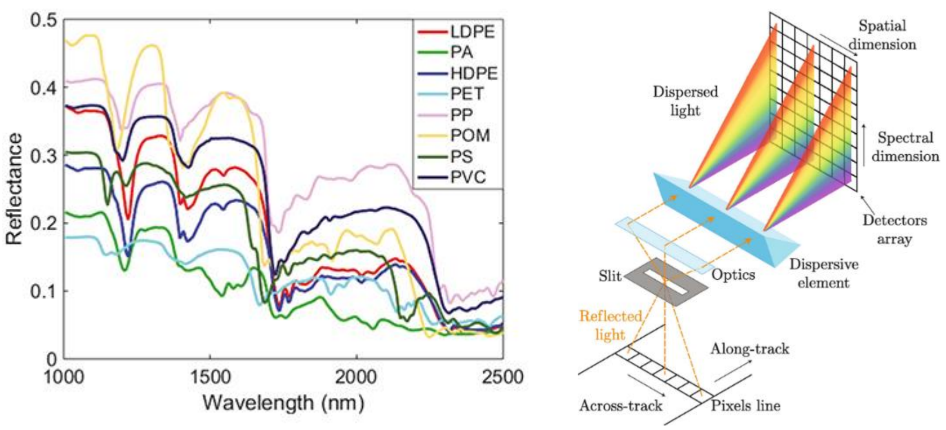


Figure 43. Average reflectance spectra captured by hyperspectral imaging system of the different classes of polymer waste samples[41] (left). Schematic of the line scan/ push broom configuration of a hyperspectral imaging system[42] (right).

[40] C. Araujo-Andrade et al., Waste Management & Research 39 (2021)
[41] S. Serranti,et al , "Characterization of post-consumer polyolefin wastes by hyperspectral imaging for quality control in recycling process, Waste Manage. 31, 11, 2217–2227 (2011).
[42] D. Marinelli et al., Encyclopedia of Mathematical Geosciences. Encyclopedia of Earth Sciences Series. Springer, Cham. (2021)

4.4 LASER INDUCED FLUORESCENCE (LIF)

In contrast to the methods described above, this technique analyses the emission spectra of polymers following photoexcitation. The spectral range of the fluorescence is usually in the VIS to NIR range. As in the case of absorption spectroscopy this method is fast, robust, and comparably simple. It is also quite sensitive when the analysis also includes the fluorescence decay. As excitation source for the LIF setup a laser with emission in the UV to blue spectral region, where polymer absorption is strong, is chosen. It is directed to the sample and the consequent fluorescence is collected and directed to a spectrometer. As detector unit a Si-based sensor (CCD) is used. The resulting spectra exhibit broad and overlapping features requiring for a more sophisticated analysis as in the case of the absorption spectra, as shown in Figure 44.

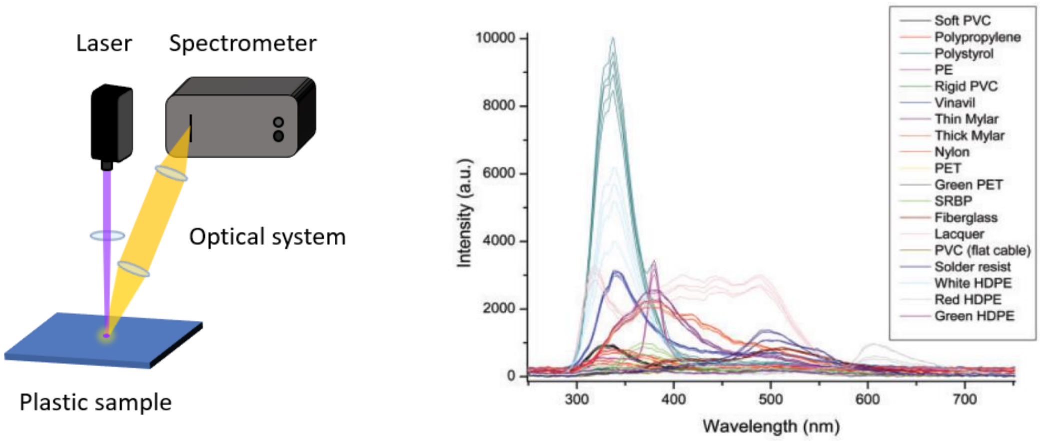


Figure 44. Schematic setup for LIF measurements using a laser and spectrometer (left). In case of LIF laser excitation is followed by fluorescence of the sample. Right) LIF spectra of various polymers[43] (right).

4.5 LASER INDUCED BREAKDOWN SPECTROSCOPY (LIBS)

LIBS (Laser Induced Breakdown Spectroscopy) is a technique based on the analysis of a laser-generated plasma and more specifically on the emission (in the near UV/VIS/IR range) of atoms/ions or molecular groups (elemental constituents) when they are vaporised from their original sample by a focused pulsed laser with sufficient fluence to vaporise part of the material under study. The setup is similar to LIF while for LIBS the laser generates a plasma which emission is detected (Figure 45).

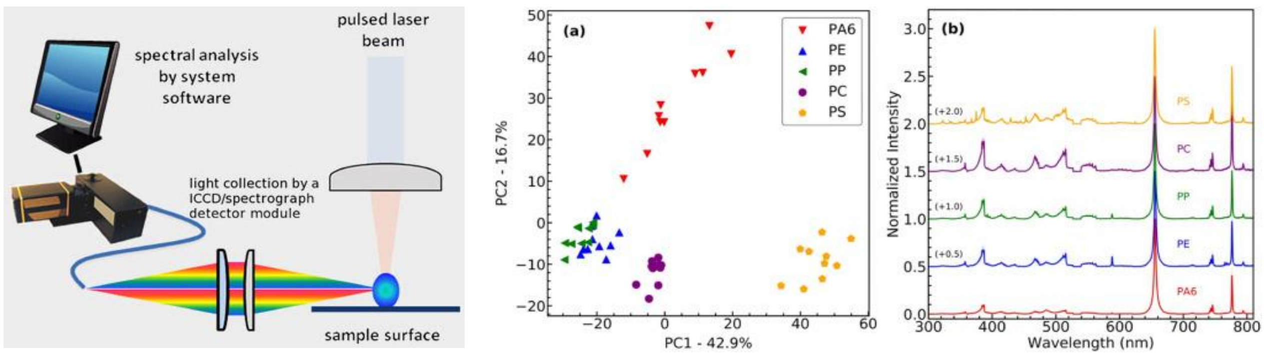


Figure 45. Emitted light collection by a set of optical lens and optical fiber (left). Principal Component Analysis Plastic type identification for PS, PC, PA6, PE, and PP, the plastic types clusters and the reference spectra of the plastic samples (right) .

LIBS spectral data from polymers provide elemental and molecular emissions and a classical spectral analysis based on element line identification is not sufficient to distinguish the different polymers.

[43] V. Spizzichino et al., Applied Spectroscopy 70 (2016)

However, in recent scientific studies[44, 45], LIBS has achieved a promising performance for polymer identification by using machine learning and chemometrics dedicated software. Similarly, there has been recent work showing potentials of detecting bromine and other legacy additives by this technique.

4.6 RAMAN SPECTROSCOPY (RS)

Raman spectroscopy utilises the inelastic scattering, called Raman scattering, of light by a sample. It is based on light interacting with virtual vibrational states which leads to low scattering cross-sections. Hence, the contribution of inelastically scattered light to the total signal is small and the latter is dominated by elastically scattered (Rayleigh scattering) light. Because of the interaction, the inelastically scattered light exhibits an increased (Stokes shift) or a decreased (Anti-Stokes shift) wavelength. The method is sensitive, also to the molecular structure, and yields distinctive spectra (Figure 46). Since the technique depends on the detection of low signals, a sophisticated setup is required and the samples to be analysed often must be prepared. Therefore, Raman spectroscopy is mainly used as reference setup in the laboratory. The setup consists in a laser is used to illuminate the sample and the scattered/reflected light is collected and directed to a spectrometer. To remove the elastically scattered signal filters must be used in the detection path and the optical system must be optimised to the transmittance of the inelastically scattered signal.

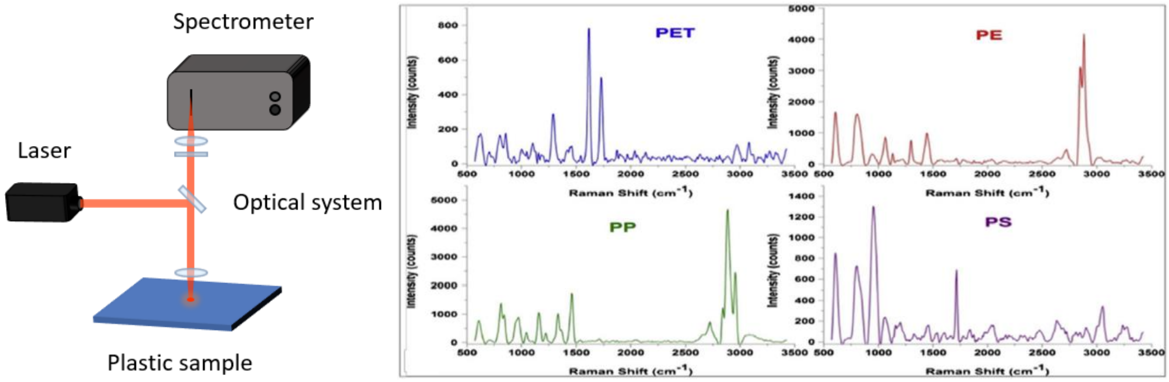


Figure 46. Schematic setup for Raman measurements. A laser is focused on the sample and the scattered light is collected by the optical system. Raman spectra of different polymers[46].

4.7 SUMMARY AND SELECTION OF THE ADAPTED TECHNOLOGY IN PRECYCLING

Table 9 summarises comparison of the presented spectroscopic methods which have been evaluated for plastic identification and classification in the context of the project.

[44] Zeng, Q. et al Trends in Analytical Chemistry, 140, 116280 (2021).
[45] Liu, K., et al. Trends in Analytical Chemistry, 110, 327-334 (2019).
[46] S. Brunner et al., Waste Management 38 (2015)

Table 9. Summary of the advantages and disadvantages of the described spectroscopy techniques for the sorting of PWS

Technology	Main advantages	Main disadvantages
NIR absorption	Fast and robust Applicable for industrial/in-line measurements Easily scalable	No black plastics No detection of additives Sophisticated data analysis
MIR absorption	Suitable for black plastics New light sources and detectors available	Commercial readiness not yet given. Sophisticated data analysis
FT-IR	Well established technique Sensitive with distinctive spectra	Sample preparation possibly required. No industrial / in-line measurements
Hyperspectral Imaging (HSI)	Fast and robust Spatial and spectral information Applicable for industrial/in-line measurements	Advanced data analysis /data processing pipelines needed. (Black plastics only in MIR range)
Laser-induced Fluorescence (LIF)	Fast and robust Applicable for industrial/in-line measurements Tracing in plastics demonstrated	Difficult to apply in contaminated materials
Laser-induced Breakdown Spectroscopy (LIBS)	Fast and robust Applicable for industrial/in-line measurements Can detect additives.	For additives identification, lower Limit of Detection (LoD) than lab techniques
Raman Spectroscopy	Sensitive with distinctive spectra Information on molecular structure	Sample auto-fluorescence Low signal and advance instrumentation system required. Often sample preparation

Considering PRecycling requirements: sorting and classification for recycling, detection and determination of additives, detection of harmful contaminants to be used for specific demonstrators, LIBS technique was selected and will be further developed by MIRTEC and AIMEN. This includes development of specific characterization protocols and data-based software for discrimination and identification of polymers and additives. These activities are undertaken in WP2, WP3 and WP4.

5. MATERIALS REQUIREMENTS, PROPERTIES AND BENCHMARKING

The technical, processing, quality and safety requirement of the demonstrators to be developed in the frame of the PRecycling project have been defined in order to take them into account when developing the recycled materials. The final characteristics of the recyclates will, then, guarantee the compliance of the final products.

Material development studies has been carried out according to available regulations' requirements. Key factors for injection moulding, spinning and 3D printing processes of recycled polymers have been defined (e.g., polymer properties, rheology, melt strength, filament diameter, printability of extruded filaments etc.). For home appliances, maximum recyclate content will be defined according to the mechanical and chemical safety requirements that is relevant to the presence of residual elements coming from additives (i.e. pigments, fillers); for toys according to processability requirements and toy safety standards; while for textile according to the process requirements (i.e. tensile strength requirements for woven or knitted textiles, amount of impurities of particles, etc.).

The following sections include the specific requirements for home appliances, toys and textiles, both, in general and addressed to the type of demonstrator expected to be developed in WP5. The benchmarking polymeric materials are also contemplated.

This chapter is outcome of the Task 1.3 and represent a verification of the **milestone MS2** entitled 'Materials requirements, properties & benchmarking'.

5.1 HOME APPLIANCES REQUIREMENTS

- *Definition of the product/demonstrator*

Within the scope of the PRecycling project, three kinds of demonstrators related to three different Home Appliances applications will be developed: i) washing machine pump filter which is mainly based on recycled PP+ chopped glass fibers (cGFs), ii) oven frame part, based on recycled PA66, and chopped glass fibers, and iii) EVA cover/inner liner of refrigerator based on recycled HIPS.

- *Proposed recyclates and benchmarking of materials*

The main types of recycled materials to be used for each type of home appliance demonstrators are the following:

- for the washing machine pump filter the used material is PP and contains 30 wt% of cGFs
- for the refrigerator inner line/EVA cover, the current used polymer is HIPS and
- for the oven parts is PA66 with 25 wt% of cGFs.

The selected waste streams will come from the home appliance wastes collection, sorted and classified by Coolrec, if they meet with required process parameters, mechanical-physical and other requirements included in the following paragraphs and in the Annex 1 of this Deliverable.

Benchmarking will be carried out on material level, where the chemical and mechanical properties of the used recyclates within the demonstrators will be compared with technical datasheets of current virgin PP and HIPS grades used by home appliances companies. Table 10 shows the proposed materials and their main properties as examples.

Table 10. Proposed recyclates and benchmarking of materials

Demonstrator	Proposed Recyclate	Benchmarking material	Properties of the benchmarking material
Washing machine pump filter	Recycled PP	Homo PP+30 wt% GF	High strength, water contact
Refrigerator inner line/EVA cover	Recycled HIPS extrusion/injection grade	HIPS extrusion/injection grade	Resistive to oil and C-pentane, food contact grade
Oven part	Recycled PA66	PA66+ 25wt% GF	High strength and thermal resistivity, V0 grade

- *Mechanical-physical requirements*

Table 11 collects the physical and mechanical requirements of all the three types of products should meet according to Arçelik acceptance limits.

Table 11. Mechanical-physical requirements of home appliance demonstrators according to Arçelik acceptance limits.

Demonstrator and proposed recyclate	Mechanical-physical requirements
Washing machine pump filter – Recycled PP-30 wt% GF	Density: Max. 1.1 g/cm3
	E modulus (ISO 527): Min. 5500 MPa
	Yield strength, MPa (ISO 527): Min. 70
	Elongation at Yield (ISO 527): Min. 3 %
	Izod Impact Strength Notched (ISO 180): Min. 8 kJ/m^2
	Flexural Modulus (ISO 178): Min. 4500 MPa
	Flexural Strength (ISO 178): Min. 100 MPa
Refrigerator inner line/EVA cover - Recycled HIPS	Density: 1.03-1.07 g/cm3
	E modulus (ISO 527): Min. 1400 MPa
	Izod Impact strength notched (ISO 180) Min. 5 kJ/m^2
	Flexural Modulus (ISO 178): Min. 1400 MPa
	Elongation at Break (ISO 527): Min. 40%
	Tensile strength at break (ISO 527): Min. 15 MPa
Oven part – Recycled PA66-25 wt% GF	Density: 1,58 g/cm3
	E modulus (ISO 527): 7700 MPa
	Tensile strength (ISO 527): 95 MPa
	Elongation at Break (ISO 527): 2%
	Izod Impact Strength Notched: (ISO 180): 6,2 kJ/m^2
	Flexural Modulus (ISO 178): 6500 MPa
	Flexural Strength (ISO 178): 145 MPa

- *Processing and other quality requirements*

Other requirements for the three home appliance demonstrators of the project are included in Scaling requirements.

- *Scaling requirements*

For the compounding of the materials and the injection moulding process, a minimum of 20 kg of recycled materials will be needed for oven and washing machine pump filter demonstrators.

Table 12. Processing and other requirements for home appliances demonstrators.

Demonstrator and proposed recyclate	Processing requirements	Others
Washing machine pump filter – Recycled PP	MFI (230C /2.16 kg): Min. 3,5 g/10 min	Aging procedure on coupons: • 0.7% Detergent, 95ºC, 13 days • 1.8% Bleach, 40C, 13 days • A maximum of 20% change in the mechanical properties is acceptable after aging procedure
	Moulding shrinkage: 0.1-0.5 % Process temperature: 200-260 C	Tests on the product: Certain types of tests like impermeability in different working temperatures and transportation tests are applied to the final product.
Refrigerator inner line/EVA cover-Recycled HIPS	MFI (200C/5kg): Inner liner: 2-5 g/10 min EVA cover: min. 4 g/10min Process temperature: 180-260 C Moulding shrinkage: 0.4-0.7 %	**Environmental Stress Crack Resistance (ESCR):** The tensile specimens are exposed to c-pentane and mold oil for a certain time. After that, the tensile test is performed and the change in the "elongation at break" is monitored. Based on the Arçelik method, this value shouldn't be changed more than 40%. **Heat Shock and Alcohol Test (on the cabinet):** Cabinets are exposed to the heat shock test for 3 days (at -30C for 12 hours, 50C for 12 hours), after test the cabinets shouldn't have any cracking, yellowing, deformation. The Alcohol test is performed to the cabinets after coming out from heat shock test. For 3 days every 24 hours %50 isopropyl alcohol is applied to the ref. at -30C and +50C. The cabinets are checked again to see whether any cracking is there, yellowing or deformation. **Oil Resistance Test (on the cabinet):** A certain amount of cooking oil is applied to the entire surface. The refrigerator is started to operate. The product shouldn't crack within a minimum 6 days from the beginning of the test.
Oven part – Recycled PA66	Process temperature: 270-290 C Moulding shrinkage: 0.35-0.6 %	Flammability rating: 0.75, 1, 3 mm: V0 Heat Deflection Temperature, HDT (ISO 75): 260 C at 0.45 MN/m2

In case of extrusion grade recycled HIPS which is used in inner liner of refrigerators, a minimum of 200 kg sample will be needed. If it is not feasible to provide such a high number of samples for co-extrusion and thermoforming of inner liner, EVA cover of refrigerator can be considered as another alternative part for the recycled HIPS. In the scenario, a minimum amount of 50 kg of injection grade HIPS would be enough for the injection of EVA cover.

5.2 TOYS APPLICATIONS

- *Safety / Standards*

In the European market, consumer products are subject to multiple safety requirements as a measure to protect the consumer and the environment. Compliance with these requirements is essential for its commercialization. In the case of toys, in addition to the generic requirements due to their status as consumer products, the specific requirements contained in **Directive 2009/48/EC on toy safety** are applicable (Toy Safety Directive – TSD). This Directive establishes, in addition to a general safety requirement, particular requirements for, mainly, the physical-mechanical, electrical, flammability and chemical properties of the toy. To demonstrate that the toy complies with these essential requirements, the harmonized European standards are used, specifically the different parts of the **EN-71 standard.**

- *Mechanical-physical requirements*

The EN 71-1:2014+A1:2018 standard addresses mechanical-physical, acoustic, and marking and labelling requirements. Within this standard, the requirements to be evaluated will focus on those that are critical, taking into account the characteristics of the demonstrators developed.

Table 13 collects some of the Physical and Mechanical properties that toys should meet according to the Toy Safety Directive of 2009/48/EC. Annex 2 of this Deliverable includes the complete set of requirements for the type of toys intended in the project (injection moulded toys).

Table 13. Physical and Mechanical properties according to the TSD of 2009/48/EC.

Annex II, point I (Physical and Mechanical properties) of 2009/48/EC TSD
Toys and their parts and, in the case of fixed toys, their anchorages, must have the requisite mechanical strength and, where appropriate, stability to withstand the stresses to which they are subjected during use without breaking or becoming liable to distortion at the risk of causing physical injury
Accessible edges, protrusions, cords, cables and fastenings on toys must be designed and manufactured in such a way that the risks of physical injury from contact with them are reduced as far as possible.
Toys must be designed and manufactured in such a way as not to present any risk or only the minimum risk inherent to their use which could be caused by the movement of their parts
Toys and their parts must not present a risk of strangulation
Toys and their parts must not present a risk of asphyxiation by closing off the flow of air as a result of airway obstruction external to the mouth and nose
Toys and their parts must be of such dimensions as to not present a risk of asphyxiation by closing off the flow of air as a result of internal airway obstruction by objects wedged in the mouth or pharynx or lodged over the entrance to the lower airways
Toys, which are clearly intended for use by children under 36 months, and their component parts and any of their detachable parts must be of such dimensions as to prevent their being swallowed or inhaled. This also applies to other toys which are intended to be put in the mouth, and to their component parts and any of their detachable parts

- *Chemical requirements*

Unlike the physical-mechanical requirements, the chemical requirements that ensure the safety of the toy are not conditioned by its design, shape or dimensions, but rather by the nature of the raw materials used in its manufacture and by the age of the user to whom it is intended. The requirements that raw materials must meet in order to be used in toys are set out in **Regulation (EC) No. 1907/2006 REACH and Directive 2009/48/EC,** mentioned above.

The following are the requirements that apply to the project recycled materials:

- Regulation (EC) No. 1907/2006 REACH - Know the presence of substances considered Substances of High Concern (SVHC).

- Comply with the restrictions established in Annex XVII of this regulation on the content of the substances indicated in Table 14.

Table 14 also collects some of the chemical requirements that toys should meet according to the Toy Safety Directive of 2009/48/EC. Annex 2 of this Deliverable includes the complete set of chemical requirements for the recycled materials to be suitable for use in toys, toy components or children's articles.

Table 14. Chemical properties according to the TSD of 2009/48/EC.

Annex II, point III (Chemical properties) of 2009/48/EC TSD
The exposition to chemical substances or mixtures do not cause risks of adverse effects on human health. Toys shall comply with the relevant Community legislation

Substances that are classified as CMR of category 1A, 1B or 2 under Regulation (EC) Nº 1272/2008 shall not be used in toys
Toys for children under 3 years or other toys intended to be placed in the mouth shall not contain nitrosamines and nitrosatable compounds
Prohibition of 55 allergenic fragrances
Specific migration limits for 19 elements
Specific requirements for toys intended for children under 3 and other toys intended to be put into the mouth:
1.- Maximum content of certain phosphate flame retardants: TCEP (CAS 115-96-8), TCPP CAS (13674-84-5) and TDCP (CAS 13674-87-8): 5 mg/kg
2.- Specific migration limit for BPA (CAS 80-05-7): 0,04 mg/l
3.- Specific migration limit for phenol (CAS 108-95-2): 5 mg/l in polymeric materials
4.- Specific migration limit for formaldehyde (CAS 50-00-0): 1,5 mg/l in polymeric materials
Other requirements are applicable depending on the materials in the toy (foams, liquids, etc)
REACH Regulation (EC) Nº 1907/2006. Annex XVII: relevant entries (for plastic materials):
1.- Entry 5: benzene (CAS 71-43-2): limit of contend of 5 mg/kg
2.- Entry 23 Cadmium (CAS 7440-43-9) and its compounds: limit of contend of 0,01 % by weight
3.- Entry 50 Accepted limit of Polycyclic Aromatic Hydrocarbons (PAH) in toys and childcare articles under REACH Regulation (EC) No 1907/2006: ≤ 0.5 mg/kg.
Benzo(a)pyrene (BaP) - CAS No. 50-32-8 Benzo(e)pyrene (BeP) - CAS No. 192-97-2 Benzo(a)anthracene (BeA) - CAS No. 56-55-3 Chrysene (CHR) - CAS No. 218-01-9 Benzo(b)fluoranthene (BbFA) - CAS No. 205-99-2 Benzo(j)fluoranthene (BjFA) - CAS No. 205-82-3 Benzo(k)fluoranthene (BkFA) - CAS No. 207-08-9 Dibenzol(a,h)anthracene (DBAhA) - CAS No. 53-70-3

5.2.1 3D printed toys

- *Definition of the product/demonstrator*

The objective is to develop toy product demo case(s) by introducing recycled plastics in 3D printing fabrication processes. Design-for-all/inclusive/universal design principles that account for ergonomics and/or disabilities as a parametric design system will be employed. Two indicative scenarios are analysed below:

A) Collaborative 3D Printed Fairy-tale Boards for (Non-) Visually Impaired Users

A collection of fairy-tale boards for collaborative storytelling between visually impaired and non-visually impaired users is expected (Figure 47). A universal design approach will be followed, through the implementation of high contrast colours and descriptions of elements in Braille tactile system. Users will be able to interactively play the fairy-tale by integrating the selected 3D printed elements on the board, or even modify/expand the story according to their preferences.

Figure 47. Indicative collaborative fairy-tale board designed for (non-) visually impaired users

B) <u>3D Printed Customisable Rackets</u>

Customisable rackets based on anatomical features and aesthetic preferences shall be created (Figure 48). In the design process the following will be considered:

(a) employment of Computational/Algorithmic Design to develop highly customisable rackets based on anatomical features and aesthetic preferences.

(b) Customisable and ergonomic handles.

(c) Consideration of dimensions, weight, and centre of mass for comfortable handling and optimisation of aerodynamic performance through CFD Analysis.

(d) Customisable surface design and aesthetic personalisation.

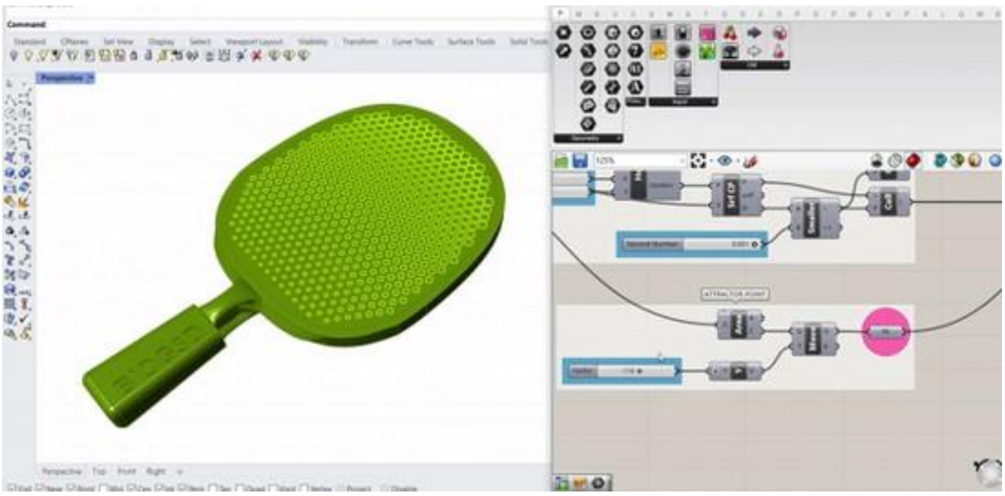


Figure 48. 3D printed racket with customisable aerodynamic features and/or customisable surface design

- *Proposed recyclates and benchmarking of materials*

The expected recycled materials for the demonstrators are PP, ABS, and/or HIPS. The decision will be based on the available amounts obtained within the consortium. Commercial recycled PP, ABS and HIPS will be employed as reference materials for the benchmarking. The main properties of the utilized materials, according to their Technical Datasheets, are presented in Table 15.

Table 15. Reference materials utilized for recycled PP, ABS and HIPS benchmarking

Material	Reference	Properties of the benchmarking material
Recycled PP	Fiberlogy R PP	Specific Density: 1.05 g/cm^3 (ISO 1183) Tensile Strength at Yield: 26 MPa (ISO 527) Tensile Strength at Break: 21 MPa (ISO 527) Tensile Modulus: 1100 MPa (ISO 527) Elongation at Yield: >30% (ISO 527) Elongation at Break: 250% (ISO 527) Flexural Strength: 18MPa (ISO 178) Flexural Modulus: 1200 MPa (ISO 178) Izod Impact Strength (Notched) at 23 °C : 20 kJ/m^2 (ISO 180) Heat Distortion Temperature at 0.45 MPa: 80 °C (ISO 75) Heat Distortion Temperature at 1.8 MPa: 65 °C (ISO 75) Vicat Softening Temperature: 135 °C (ISO 306) Melting Temperature Tm: 163 °C (DSC) Continuous Use Temperature (UL Yellow Card): 65 °C (UL 746)
Recycled ABS	ReForm™ - rTitan	Specific Gravity: 1.10 g/cc (ISO 1183) Melt Flow Rate (at 260 °C / 5 kg): 41 g/10min (ISO 1133) Tensile Strength at Yield (50 mm/min): 43.6 MPa (ISO 527) Tensile Modulus (1mm/min): 2030MPa (ISO 527) Elongation at Break (50 mm/min): 34% (ISO 527) Impact Strength (Charpy Notched) at 23 °C : 20 kJ/m^2 (ISO 179) Vicat Softening Temperature: 97 °C (ISO 306) Melting Temperature Tm: 235 ± 10 °C (ISO 294)
Recycled HIPS	Kimya HIPS-R	Specific Density: 1.03 g/cm^3 (ISO 1183-1) Melt Flow Index (at 200 °C / 5 kg): 4.7-7.1 g/10min (ISO 1133-1) Tensile Modulus: 1273 MPa (ISO 527-2/5A/50) Tensile Strength: 23.7MPa (ISO 527-2/5A/50) Tensile Strain at strength: 1.5% (ISO 527-2/5A/50) Tensile Stress at Break: 16.7 MPa (ISO 527-2/5A/50) Tensile strain at Breal (Type A): 11.5% (ISO 527-2/5A/50) Flexural Modulus: 1533 MPa (ISO 178) Charpy Impact Resistance: 7.3 kJ/m^2 (ISO 179-1/1eA) Shore Hardness: 76.6D (ISO 868)

- *Processing requirements*

The feedstock material shall be in the form of filament with a diameter 1.75±0.05mm. The aforementioned material shall be handled at temperatures ≤ 280 °C (i.e., max nozzle temperature), and demonstrate adhesive behaviour on a flat surface heated at ≤ 100 °C (i.e., print bed temperature). The processability of a thermoplastic filament as feedstock material for 3D printing depends on various factors such as the percentage and distribution of the remnants in the filament, the difference in the material properties (and, consequently, the printing behaviour), as well as the affinity of the polymers combined. When combining polymers with significant differences in the required printing parameters (namely extrusion temperature and print bed temperature), low quality parts, non-uniform flow or even nozzle clogging may occur. In general:

(a) the lower the percentage in remnants,
(b) the greater the compounding, and

(c) the greater the material affinity (especially crystallization and thermal properties),

the better the processability through FFF technology, and the lower the thermal degradation of the materials during FFF process will be. Finally, it should be noted that for each case of combined polymers, the accepted remnants percentage might differ.

- *Other quality requirements*

The base colour of the materials shall be light, white, or transparent for the addition of pigments.

- *Scaling requirements*

In 3D printing many parts can be simultaneously manufactured, as long as they do not exceed the available build volume. The in-house capabilities (i.e., MODIX Big40 V3) allow for a max build volume of L400 mm x W400 mm x H800 mm and a printing resolution of 0.2, 0.25, 0.3, 0.4, 0.6, or 0.8 mm. For each material25 kg will be required. The upscaling strategies will include the following steps:

(a) Thermal/speed towers and 2D matrix [i,j] tests for fine tuning of printing parameters (Figure 49).
(b) 3D torture tests for material benchmarking with detailed features on torture tests corresponding to end-product features (Figure 50).
(c) 3D simplified geometries in relation to end-products (Figure 51).

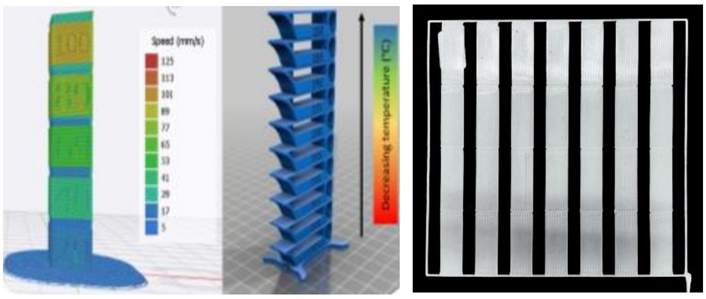


Figure 49. Thermal/speed towers (left), 2D matrix [i,j] tests for fine tuning of printing parameters (right)

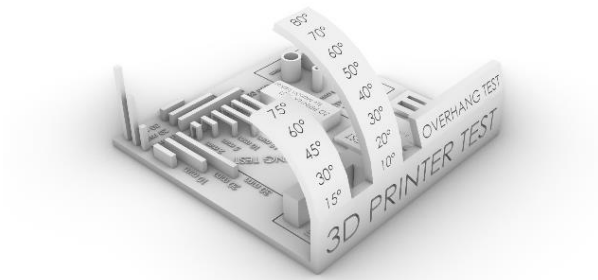


Figure 50. 2D matrix [i,j] tests for fine tuning of printing parameters

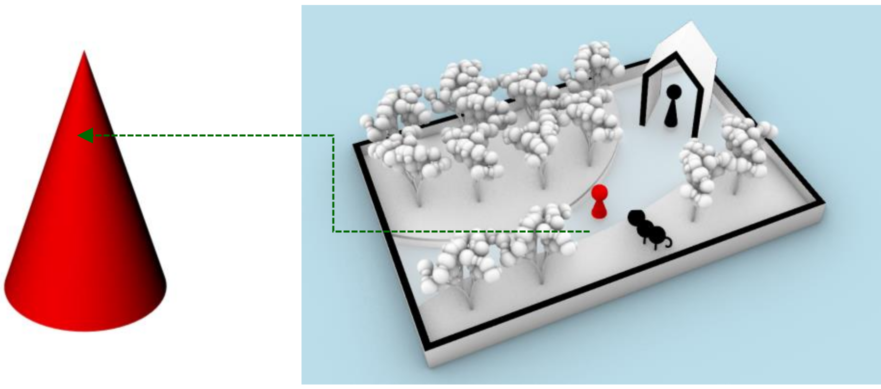


Figure 51. 3D simplified geometries in relation to end-products

5.2.2 Injection moulded toys

- *<u>Definition of the product/demonstrator</u>*

An injection moulded toy will be manufactured as demonstrators within the project by using the developed recycled materials, according to the available amount of material obtained after WP3 tasks. If the final amount is high a second type of injection moulded toy will be obtained.

AIJU has two toy injection moulds, a puzzle and a ship with moving parts (Figure 52). If needed, AIJU could also count on the collaboration of toy companies, if necessary, and as long as there is enough recycled material.

Figure 52. Toy demonstrators to be developed by injection moulding

- *<u>Proposed recyclates and benchmarking of materials</u>*

The main type of recycled materials to be used for the demonstrators will be PP. However also HIPS (or ABS) can be used, according to the available amount of recycled material obtained.

The selected waste streams come from the toy wastes collection made by AIJU. Also, the PP and HIPS (or ABS) from refrigerators from Arcelik or Coolrec can be used if they meet the chemical requirements included in the following sections and in the Annex 2 of this Deliverable.

Benchmarking will be carried out on material level, where the chemical and mechanical properties from the used recyclates of the demonstrators will be compared with technical datasheets of current virgin PP and HIPS grades used by toy companies. Table 16 shows some possible references of these materials and their main properties as examples.

Table 16. References of virgin HIPS and PP

Material	Reference	Properties
HIPS	EDISTIR® SR 550 POLYSTYRENE IMPACT 6540 STYRON™ 678E	Density: 1.04-1.05 g/cm³ Melt flow index: 11-12 g/10 min Young's Modulus: 1950-2000 MPa Tensile strength: 43 MPa Deformation at tensile strength: 2 % Deformation at break: 45-55 % Charpy Impact strength (notched): 8-45 kJ/m^2
PP Copolymer	Moplen EP548P Moplen EP340M	Density: 0.9 g/cm³ Melt flow index: 7-16 g/10 min Young's Modulus: 1500-1550 MPa Tensile strength: 28 MPa Deformation at tensile strength: 5-6 % Deformation at break: >50 % Charpy Impact strength (notched): 8-45 kJ/m^2

- *Processing requirements*

Considering that the materials will be provided as recyclate compound, the main processing requirement for the recyclates is the melt flow index (MFI): a range of 20-25 g/10 min for the manufacturing of big toys and 11-15 g/10 min for medium-small parts (possible other values).

- *Other requirements*

For the manufacturing of toys, the material must be able to be coloured to be attractive for children. Therefore, as far as possible base color of the material should be light, white or transparent.

- *Scaling requirements*

Within the PRecycling project, it will be important to find a waste stream of at least 10 kg to develop a demonstrator at pilot plant level in AIJU or at least 50 kg for an industrial demonstrator in collaboration with a toy company.

5.3 TEXTILE APPLICATIONS

- *Definition of the product/demonstrator*

Within this project, three kinds of demonstrators will be envisaged with 100% recycled polyester, i.e., garments, interior textiles and mattresses. The final demonstrator(s) will mainly depend on the polyester waste stream(s) available in the project. During recycling, degradation occurs, making it harder to reprocess the polyester, especially when low dpf is required as is the case for certain garments. Keeping this in mind, first focus will be given to the development of interior textiles like curtains as these can be made with higher dpf filaments.

- *Proposed recyclates and benchmarking of materials*

Since the aim of the project is to develop 100% circular polyester-based textiles, the polyester recyclates used within this project should also come from textiles and not from PET bottles or other PET waste streams. The current selected waste streams are cut-off textile wastes coming from a weaving factory and curtain waste streams.

Benchmarking will be done on different levels. The first benchmarking will be done on filament level, where the developed filaments from recyclates will be compared with filaments made with virgin PET grades. Benchmarking will be done using a virgin standard PET grade, both as filament and as demonstrator product.

- *Processing requirements*

Requirements for waste stream:

  - >99% purity
  - Easy to shred
  - High bulk density (easy to granulate materials)

Requirements for recycled pellets: thermal (Tm, Tc, Tg, Tdeg) and rheological (IV) properties similar to benchmark virgin PET.

- *Mechanical-physical requirements*

The mechanical-physical requirements largely depend on the end application. The most important properties for textile applications are:

  - Strength and abrasion: tear strength, tensile strength, seam strength, bursting strength, abrasion, and its effect on the strength
  - Visual appearance
  - Shape retention: shrinkage or elongation

- Colour
- Dry cleaning

Garments: Garments is still a very broad category that can be divided into several subcategories like trousers and shorts, skirts, jackets, swimwear etc., having their own specific requirements and thus, also different tests (Table 17). Standards used for garments will also depend on end user (e.g., children or adults). For protective clothing, it is difficult to have general criteria that a product must meet due to the large variety in products and end applications.

Table 17. Requirements needed for garments

	Strength	Abrasion	Appearance after wash	Colour fastness	Light fastness	Pilling	Appearance after dry cleaning	Parameters linked to claims	Protection against rain/water	Print durability	Seam slippage & SPI count
Trousers & short	X	X	X	X	X	X					
Skirts	X		X	X	X	X					
Jackets		X	X			X	X	X			
Coats/raincoats		X	X			X	X		X		
Knitwear	X		X	X		X	X			X	
Pyjamas and nightwear	X		X								
Shirts, dresses & blouses	X		X	X							
Lingerie & underwear			X	X (after washing & to perspiration)							
Swimwear				X (seawater & chlorinated water)							
Lining											X

An example of criteria for garments is shown in Figure 53 for a shirt made from a woven fabric.

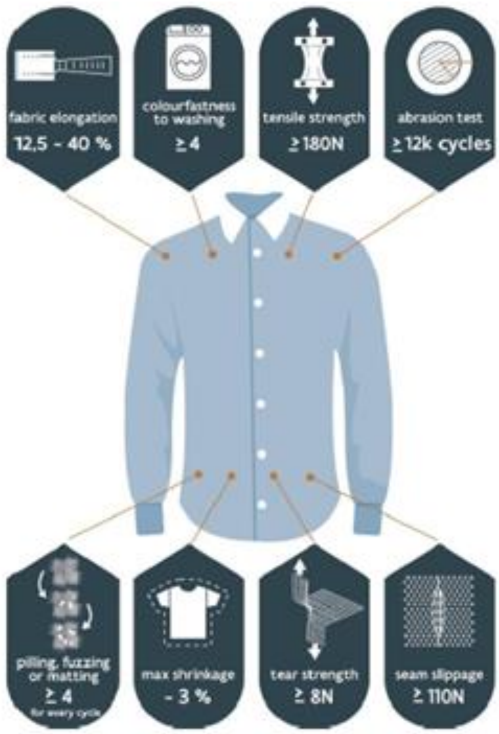


Figure 53. Criteria for shirt made from a woven fabric

Interior textiles - curtains: For curtains there are other requirements than garments since these need to withstand other environments, but the most important tests stay the same. As with garments, the requirements also depend on the kind of textile and the application. There are other requirements and standards for shower curtains than for household curtains. For the last one, there is also a subdivision made between knitted textiles and woven textiles.

The most important requirements for a woven curtain can be found in Table 18.

Table 18. Requirements needed for curtains

Test	Minimum requirements
Light fastness	5 – 6
Colour fastness after washing	4
Staining after washing	3-4
Shrinkage after washing	<3%
Colour fastness after dry cleaning	4
Staining after dry cleaning	3-4
Shrinkage after dry cleaning	<3%
Tear strength	>4.4N
Fire retardancy	M1-M2

- *Chemical requirements*

For textiles, there are two lists containing restricted substances. The most important one is REACH, since all products need to fulfil this legislation.

Beside REACH, there is also OEKO-TEX® Standard 100, which is a label for textiles tested for harmful substances. Depending on the product, the limits for these harmful substances are different. The four product classes are: product for babies (product class I), products with direct contact to skin (product class II), products without direct contact to skin (product class III) and decoration material (product class IV). In annex 4 of this Standard, the limit values of the product classes are fixed from a human ecological point of view. These limits are complemented with further and often stricter requirements that aim to bring an improved environmental performance during production. Within the certificate it is possible to use the term “recycled” in the product group description in case proof indicating the recycled origin of more than 20% is also submitted. These materials can only be certified for product classes II-IV, with an exception for recycled PET-bottles that can also be used in product class I.

- *Other quality requirements*

No other requirements.

- *Scaling requirements*

Within the PRecycling project, it will be important to find a waste stream of at least 50 kg to make a demonstrator.

Annex 2 of this Deliverable includes an excel file with all the collected requirements for the four types of demonstrators to be developed in PRecycling.

6. CONCLUSIONS

In the present report the inventory and registration/identification related information of the incoming plastic streams from different EU zones has been gathered. The incoming plastic streams (PWS) from different EU zones – 4 regions: plastics from WEEE in Western Europe (NL, BE, FR and DE) and East-South Europe (TR); and other plastic wastes in South-West Europe (ES) and South Europe (GR) have been identified. Furthermore, the current waste treatment processes of the PWS have been analysed, including the targeted value chains in the PRecycling that are toys waste, textiles waste, and home appliances waste. An inventory containing information about the type of collected product, volumes, polymer and/or additive/filler identification has been provided.

The identification of the most important waste streams at the European level has been focused on those applicable to the project, then, the possible wastes amount available from PSW *Electrical and electronics*, and *Household, leisure and sports*, has been considered. Therefore, the type of product/family of products collected, the total volume of these wastes and the types of polymers present in the wastes at European level have been estimated and included in an inventory table. The type of polymer has been estimated from the demand data in Europe by type of material for selected applications. These data can give an idea of the high growth potential of the recycling option compared to landfilling or incineration.

Furthermore, information on the first pre-selection of the adapted sensor-based technology among LIBS, FT-IR, MWIR and HIS based on the inventory, that will act as reference information for the next steps of the project is given. Considering PRecycling requirements, sorting and classification for recycling, detection and determination of additives, detection of harmful contaminants to be used for specific demonstrators, LIBS technique was selected and will be further developed by MIRTEC and AIMEN. This includes development of specific characterization protocols and data-based software for discrimination and identification of polymers and additives.

This report also contains the definition of technical characteristics for using recyclates to guarantee the compliance of the selected final demonstrators / products. Material development studies in the following activities of the project will be carried out according to available regulations' requirements. Key factors or the compliance of the final product (domestic appliances, toys, and textile applications) will be considered to define the maximum recycled content.

6.1 ACTION POINTS

Collection of toys in Greece (Athens) during the July.

6.2 FUTURE TASKS

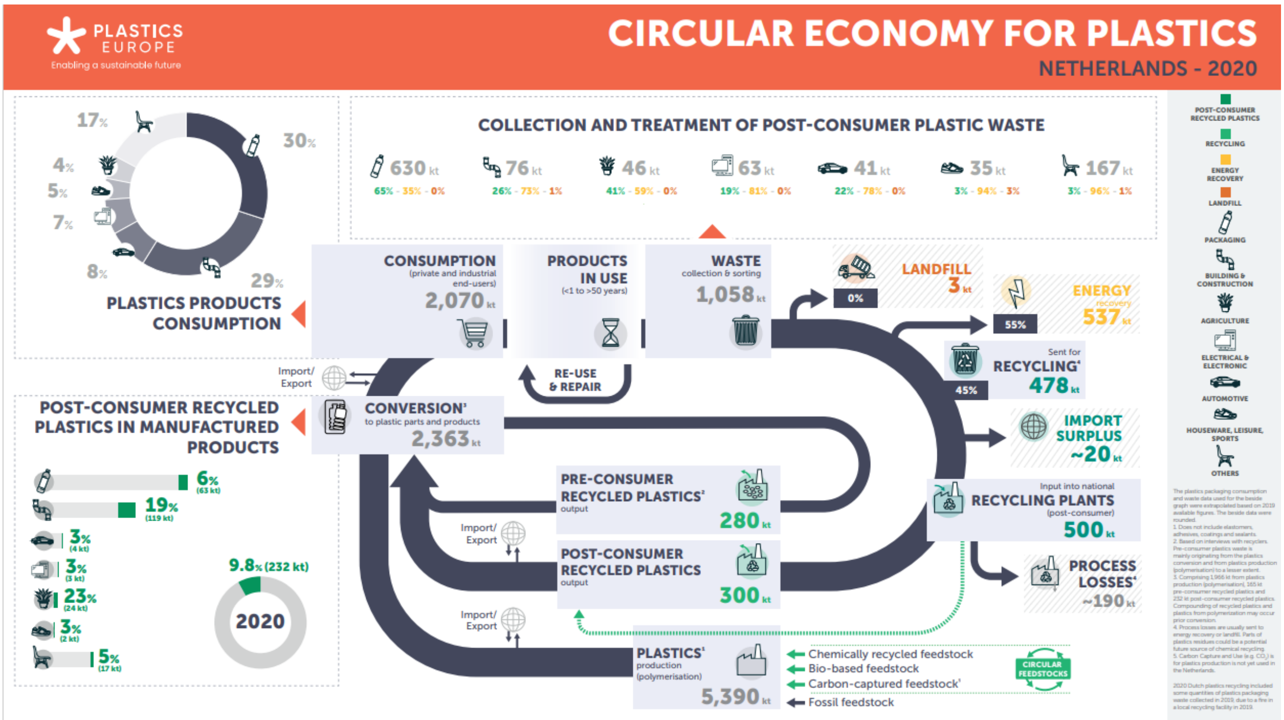
Toys delivery for sorting, conclusion on sampling methodology and continuation of detailed PWS characterizations.

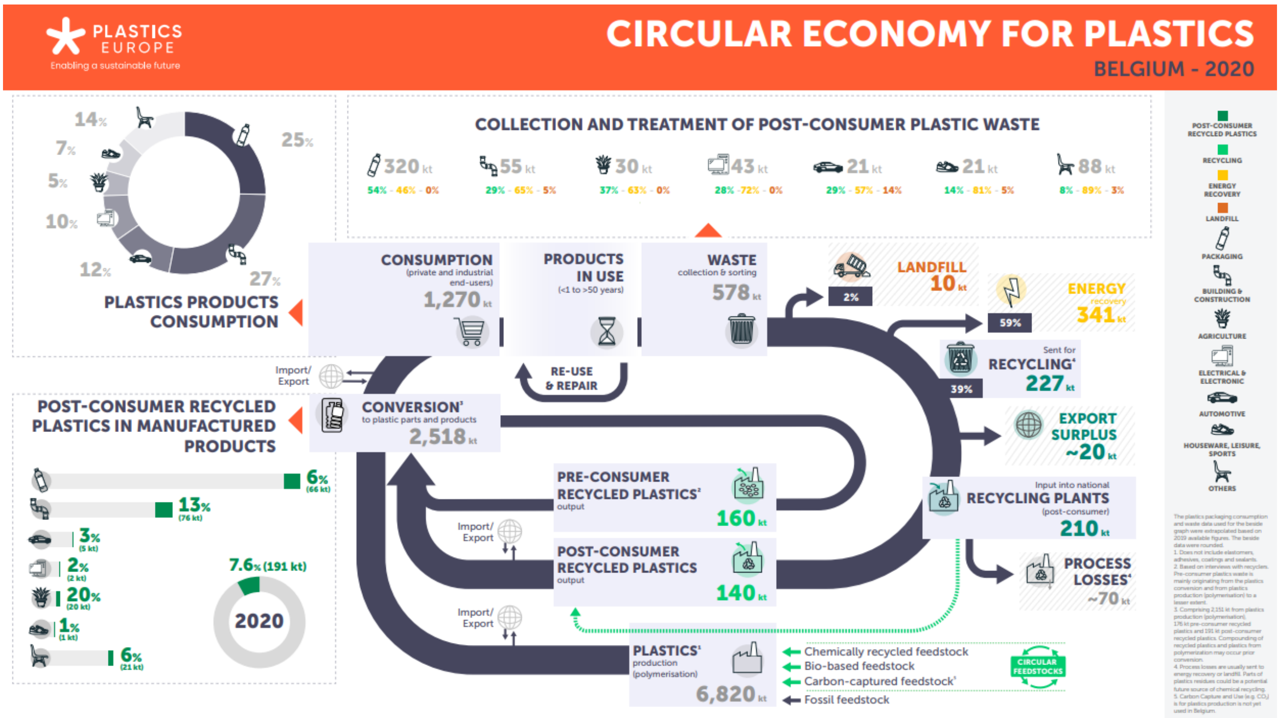
6.3 DEVIATIONS FROM DOA

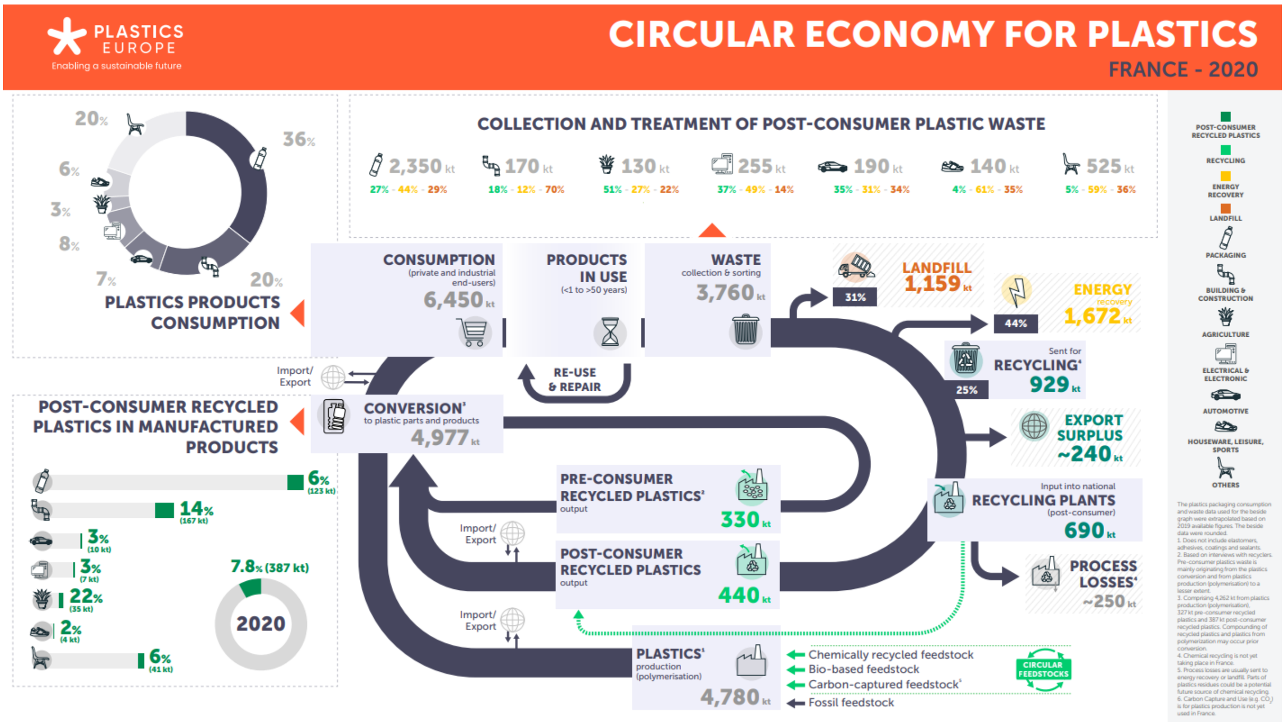
No major deviations occurred.

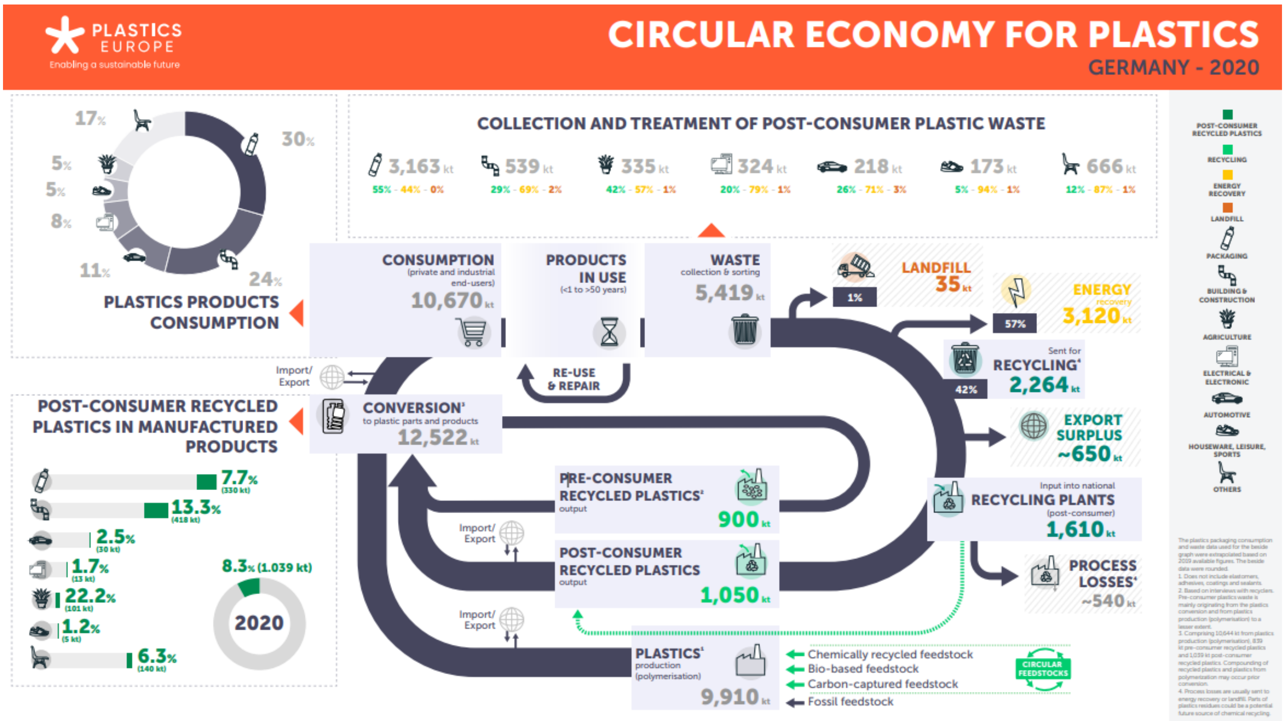
7. ANNEXES

7.1 ANNEX 1 - OVERVIEW OF THE CIRCULAR ECONOMY FOR PLASTICS PER COUNTRY

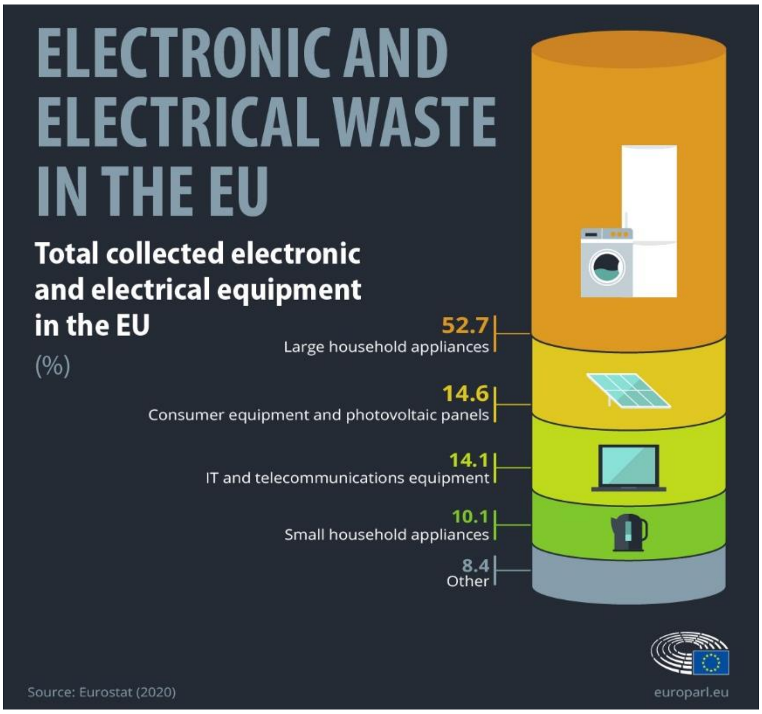


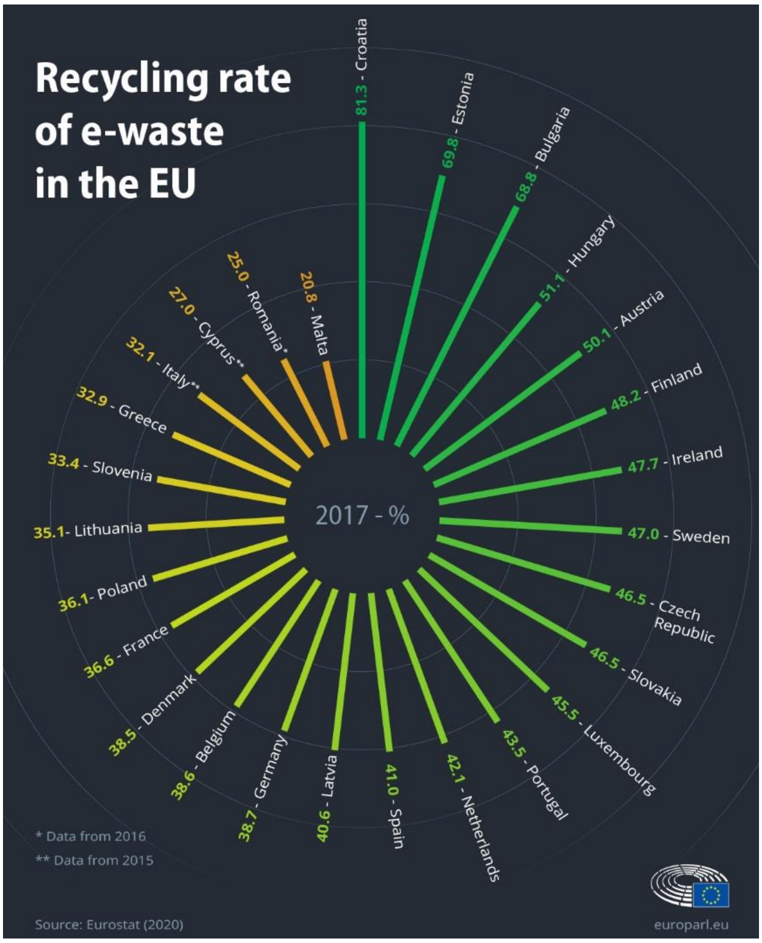



PLASTICS EUROPE
Enabling a sustainable future
CIRCULAR ECONOMY FOR PLASTICS
FRANCE - 2020
COLLECTION AND TREATMENT OF POST-CONSUMER PLASTIC WASTE
2,350 kt 27% - 44% - 29%
170 kt 18% - 12% - 70%
130 kt 51% - 27% - 22%
255 kt 37% - 49% - 14%
190 kt 35% - 31% - 34%
140 kt 4% - 61% - 35%
525 kt 5% - 59% - 36%
20% 36% 6% 3% 8% 7% 20%
PLASTICS PRODUCTS CONSUMPTION
CONSUMPTION (private and industrial end-users) 6,450 kt
PRODUCTS IN USE (<1 to >50 years)
WASTE collection & sorting 3,760 kt
LANDFILL 1,159 kt
31%
ENERGY recovery 1,672 kt
44%
Sent for RECYCLING 929 kt
25%
EXPORT SURPLUS ~240 kt
RECYCLING PLANTS Input into national (post-consumer) 690 kt
PROCESS LOSSES ~250 kt
RE-USE & REPAIR
Import/ Export
CONVERSION to plastic parts and products 4,977 kt
PRE-CONSUMER RECYCLED PLASTICS output 330 kt
POST-CONSUMER RECYCLED PLASTICS output 440 kt
PLASTICS production (polymerisation) 4,780 kt
Chemically recycled feedstock
Bio-based feedstock
Carbon-captured feedstock
Fossil feedstock
CIRCULAR FEEDSTOCKS
POST-CONSUMER RECYCLED PLASTICS IN MANUFACTURED PRODUCTS
6% (123 kt)
14% (167 kt)
3% (10 kt)
3% (7 kt)
22% (35 kt)
2% (4 kt)
6% (41 kt)
7.8% (387 kt)
2020
POST-CONSUMER RECYCLED PLASTICS
RECYCLING
ENERGY RECOVERY
LANDFILL
PACKAGING
BUILDING & CONSTRUCTION
AGRICULTURE
ELECTRICAL & ELECTRONIC
AUTOMOTIVE
HOUSEWARE, LEISURE, SPORTS
OTHERS


PLASTICS EUROPE
Enabling a sustainable future
CIRCULAR ECONOMY FOR PLASTICS
GERMANY - 2020
COLLECTION AND TREATMENT OF POST-CONSUMER PLASTIC WASTE
3,163 kt 55% - 44% - 0%
539 kt 29% - 69% - 2%
335 kt 42% - 57% - 1%
324 kt 20% - 79% - 1%
218 kt 26% - 71% - 3%
173 kt 5% - 94% - 1%
666 kt 12% - 87% - 1%
17% 30% 5% 5% 8% 11% 24%
PLASTICS PRODUCTS CONSUMPTION
CONSUMPTION (private and industrial end-users) 10,670 kt
PRODUCTS IN USE (<1 to >50 years)
WASTE collection & sorting 5,419 kt
LANDFILL 35 kt
1%
ENERGY recovery 3,120 kt
57%
Sent for RECYCLING 2,264 kt
42%
EXPORT SURPLUS ~650 kt
RECYCLING PLANTS Input into national (post-consumer) 1,610 kt
PROCESS LOSSES ~540 kt
RE-USE & REPAIR
Import/ Export
CONVERSION to plastic parts and products 12,522 kt
PRE-CONSUMER RECYCLED PLASTICS output 900 kt
POST-CONSUMER RECYCLED PLASTICS output 1,050 kt
PLASTICS production (polymerisation) 9,910 kt
Chemically recycled feedstock
Bio-based feedstock
Carbon-captured feedstock
Fossil feedstock
CIRCULAR FEEDSTOCKS
POST-CONSUMER RECYCLED PLASTICS IN MANUFACTURED PRODUCTS
7.7% (330 kt)
13.3% (418 kt)
2.5% (30 kt)
1.7% (13 kt)
22.2% (101 kt)
1.2% (5 kt)
6.3% (140 kt)
8.3% (1.039 kt)
2020
POST-CONSUMER RECYCLED PLASTICS
RECYCLING
ENERGY RECOVERY
LANDFILL
PACKAGING
BUILDING & CONSTRUCTION
AGRICULTURE
ELECTRICAL & ELECTRONIC
AUTOMOTIVE
HOUSEWARE, LEISURE, SPORTS
OTHERS

7.2 ANNEX 2 - E-WASTE IN THE EU: FACTS AND FIGURES





7.3 ANNEX 3 - EXCEL TABLE OF REQUIREMENTS

7.3.1 Application: Home appliances (ARÇELİK)

Requirements				
Definition of the product/demonstrator	**Proposed recyclates and benchmarking of materials**	**Processing requirements**	**Mechanical-physical requirements (Arçelik acceptance limit)**	**Others**
Washing machine pump filter	Proposed Recyclate	MFI (230C /2.16 kg)	Density (g/cm3)	Aging procedure on coupons
	Recycled PP	Min. 3,5	Max. 1.1	-0.7% Detergent, 95C, 13 days -1.8% Bleach, 40C, 13 days 'TOYS'!D1
	Benchmarking	Molding shrinkage (%)	E modulus, MPa (ISO 527)	
	Homo PP+30 wt% GF	0.1-0.5	Min. 5500	
			Yield strength, MPa (ISO 527)	Tests on the product
			Min. 70	Certain types of tests like impermeability in different working temperatures and transportation tests are applied to the final product.
			Elongation at Yield, % (ISO 527)	
			Min. 3	
			Izod Impact Strength Notched, kJ/m2 (ISO 180)	
			Min. 8	
			Flexural Modulus, MPa (ISO 178)	
			Min. 4500	
			Flexural Strength, MPa (ISO 178)	
			Min. 100	
Refrigerator inner line	Proposed Recyclate	MFI (200C/5kg)	Density (g/cm3)	Environmental Stress Crack Resistance (ESCR)
	EXT Recycled HIPS** **For trial tests we will need a minimum of 500 kg raw material. If it is not feasible to provide large amounts of the material, we can change the selected part to another one which is EVA COVER of refrigerator. For the EVA COVER we would need around 200 kg raw material for trial tests. EVA COVER is made from HIPS INJECTION garde not EXT.	2-5	1.03-1.07	The tensile specimens are exposed to c-pentane and mold oil for a certain time. After that, the tensile test is performed and the change in the "elongation at break" is monitored. Based on the Arçelik method, this value shouldn't be changed more than 40%. 
	Benchmarking		E modulus, MPa (ISO 527)	
	EXT HIPS		Min. 1400	
			Izod Impact strength notched, kJ/m2 (ISO 180)	
			Min. 5	
			Flexural Modulus, MPa (ISO 178)	
			Min. 1400	
			Elongation at Break, % (ISO 527)	Heat Shock and Alcohol Test (on the cabinet)
			Min. 40	Cabinets are exposed to the heat shock test for 3 days (at -30C for 12 hours, 50C for 12 hours), after test the cabinets shouldn't have any cracking, yellowing, deformtion. The Alcohol test is performed to the cabinets after coming out from heat shock test. For three days every 24 hours %50 isopropyl alcohol is applied to the ref. at -30C and +50C. The cabinets are checked again to see whether is there any cracking, yellowing or deformation.
			Tensile strength at break, MPa (ISO 527)	
			Min. 15	
				Oil Resistance Test (on the cabinet)
				A certain amount of cooking oil is applied to the entire surface. The refrigerator is started to operate . The product shouldn't crack within a minimum 6 days from the begining of the test.
Oven part	Proposed Recyclate		Density (g/cm3)	Flammability rating
	Recycled PA66		1.58	0.75, 1, 3 mm: V0
	Benchmarking		E modulus, MPa (ISO 527)	
	PA66+ 25wt% GF V0-black		7700	
			Tensile strength, MPa (ISO 527)	Heat Deflection Temperature, HDT (ISO 75)
			95	260 C at 0.45 MN/m2
			Elongation at Break, % (ISO 527)	
			2	
			Izod Impact Strength Notched, kJ/m2 (ISO 180)	
			6.2	
			Flexural Modulus, MPa (ISO 178)	
			6500	
			Flexural Strength, MPa (ISO 178)	
			145	

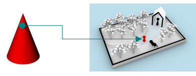
7.3.2 Application: Toys (AIJU)

Requirements			
Physical and Mechanical requirements	Standard	Chemical requirements	**Safety / Standards / Risk assessment**
Annex II, point I (Physical and Mechanical properties) of 2009/48/EC TSD	**Mechanical-physical requirements - based on EU (EN 71-1:2014+A1:2018)**	Annex II, point III (Chemical properties) of 2009/48/EC TSD	
Toys and their parts and, in the case of fixed toys, eir anchorages, must have the requisite mechanical strength and, where appropriate, stability to withstand the stresses to which they are subjected during use withoutbreaking or becoming liable to distortion at the risk of causing physical injury	4.15.1.3 Strength: specific requeriment for toy scooters.Not applicable to the toy demonstrators.	The exposition to chemical substances or mixtures do not cause risks of adverse effects on human health. Toys shall comply with the relevant Community legislation	Revision of MSD
	4.15.1.4 Stability: specific requeriment for toys inteded to bear the mass of a child.Not applicable to the toy demonstrators.	Substances that are classified as CMR of category 1A, 1B or 2 under Regulation (EC) Nº 1272/2008 shall not be used in toys	
	4.15.3 Rocking horses and similar toys: specific requirement for toys inteded to rocking horses and toys inteded to bear the mass of a child.Not applicable to the toy demonstrators.	Toys for children under 3 years or other toys intended to be placed in the mouth shall not contain nitrosamines and nitrosatable compounds	EN 71-12
	4.15.4 Toys not propolled by a child: specific requeriment for toys designed to bear the mass of a child.Not applicable to the toy demonstrators.	Prohibition of 55 allergenic fragrances	Revision of MSD
	4.15.5.3 Strength: specific requeriment for toy scooters.Not applicable to the toy demonstrators.	Specific migration limits for 19 elements	EN 71-3
	4.15.5.4 Adjustable and folding steering tubes: specific requeriment for toy scooters.Not applicable to the toy demonstrators.	**Specific requirements for toys intended for children under 3 and other toys intended to be put into the mouth:**	EN 71-X, Y, Z. Standards currently under development
	4.16 Heavy inmmobile toys: specific requirement for inmobile toys with a mass of 4,5 kg or more.Not applicable to the toy demonstrators.	1.- Maximun contend of certain phosphate flame retardants: TCEP (CAS 115-96-8), TCPP CAS (13674-84-5) and TDCP (CAS 13674-87-8): 5 mg/kg	
Accessible edges, protrusions, cords, cables and fastenings on toys must be designed and manufactured in such a way that the risks of physical injury from contact with them are reduced as far as possible.	4.5 Glass: the toy demonstrators do not include glass material.Not applicable to the toy demonstrators.	2.- Specific migration limit for BPA (CAS 80-05-7): 0,04 mg/l	
	4.7 Edges: No hazardous sharp edges (test 8.11 Sharpness of edges).	3.- Specifi migration limit for phenol (CAS 108-95-2): 5 mg/l in polymeric materials	
	4.8 Points and metallic wires: No hazardous sharp points (test 8.12 Sharpness of points).	4.- Specific migration limit for formaldehyde (CAS 50-00-0): 1,5 mg/l in polymeric materials	
	4.9 Protruding parts: tubes and rigid components in form of prejection which constitute hazard shall be protected.	Other requirements are applicable depending on the materials in the toy (foams, liquids, etc)	
	4.10.2 Driving mechanisms: the toy demonstrator will not include driving mechanisms.Not applicable to the toy demonstrators.	**REACH Regulation (EC) Nº 1907/2006. Annex XVII: relevant entries (for plastic materials):**	
	4.14.2 Mask and helmets: specific requirement for masks or helmets.Not applicable to the toy demonstrators.	1.- Entry 5: benzene (CAS 71-43-2): limit of contend of 5 mg/kg	Internal methods. Can be based on EN standards
	4.15.1.3 Strength: specific requiriment for toy scooters.Not applicable to the toy demonstrators.	2.- Entry 23 Cadmium (CAS 7440-43-9) and its compounds: limit of contend of 0,01 % by wheight	Internal methods. Can be based on EN standards
	4.15.5.7 Protruding parts: specific requirement for toy scooters.Not applicable to the toy demonstrators.	3.- Entry 50 Accepted limit of Polycyclic Aromatic Hydrocarbons (PAH) in toys and childcare articles under REACH Regulation (EC) No 1907/2006: ≤ 0.5 mg/kg.	Specific methods, based on German standard AfPS
	4.17 Protectile toys: specific requirement for proyectile toys.Not applicable to the toy demonstrators.	Benzo(a)pyrene (BaP) - CAS No. 50-32-8	
	5.1 General requeriments:Toys intended for children under 36 months and their removable components shall not be small part. Toys intended intended for children under 36 months shall not contain accessible hazardous sharp edges or accessible hazardous sharp points, (test 8.11 Sharpness of edges and test 8.12 Sharpness of points).The toy shall be tested according: 8.3 (torque test), 8.4.2.1 (tension test), 8.5 (drop test), 8.7 (impact test), 8.8 (compression test).	Benzo(e)pyrene (BeP) - CAS No. 192-97-2	
	5.2 Soft-filled toys and soft-filled parts of a toy: specific specific requirement for toys filled with soft materials.Not applicable to the toy demonstrators.	Benzo(a)anthracene (BeA) - CAS No. 56-55-3	
	5.4 Cords, chains and electrical cables in toys: n the case of toys intended for children under 36 months, cords, chains and electrical cables in toys must have a maximum length determined according to their position and the age for which the toy is intended.	Chrysene (CHR) - CAS No. 218-01-9	
	5.7 Glass and porcelain:the toy demonstrator will not include glass and/or porcelain material.Not applicable to the toy demonstrators.	Benzo(b)fluoranthene (BbFA) - CAS No. 205-99-2	
Toys must be designed and manufactured in such a way as not to present any risk or only the minimum risk inherent to their use which could be caused by the movement of their parts.	4.10 Parts moving against each other: the toy demonstrator will not include folding and sliding mechanisms, driving mechanisms, hinges or springs.Not applicable to the toy demonstrators.	Benzo(j)fluoranthene (BjFA) - CAS No. 205-82-3	
	4.15.1.3 Strength: specific requiriment for toy scooters.Not applicable to the toy demonstrators.	Benzo(k)fluoranthene (BkFA) - CAS No. 207-08-9	
	4.15.1.6 Transmission and wheel arrangement: the toy demonstrator will not include transmission /wheel arragement.Not applicable to the toy demonstrators.	Dibenzol(a,h)anthracene (DBAhA) - CAS No. 53-70-3	
	4.15.5.4 Adjustable and folding steering tubes.Not applicable to the toy demonstrators.	4.- Entry 50 and 51: Accepted limit of phthalates in the polymers under REACH Regulation (EC) No 1907/2006: ≤ 0.1 % by weight (sum or individual)	Internal methods. Can be based on CPSC or ISO
Toys and their parts must not present a risk of strangulation	4.24 Yo-yo balls.Not applicable to the toy demonstrators.	Bis (2-ethylhexyl) phthalate - DEHP	
	5.4 Cords, chains and electrical cables in toys: toys intended for children under 36 months, cords, chains and electrical cables in toys must have a maximum length determined according to their position and the age for which the toy is intended.	Dibutyl phthalate - DBP	
	5.14 Straps inteded to be worn fully or partially around the neck.Not applicable to the toy demonstrators.	Benzyl butyl phthalate - BBP	
Toys and their parts must not present a risk of asphyxiation by closing off the flow of air as a result of airway obstruction external to the mouth and nose	4.3 Flexible plastic sheeting: if the toy demonstrator includes plastic decals with an area greater than 100mm x 100mm will have an average thickness of 0,038 mm or more.	Di-isodecyl phthalate - DIDP	
	4.4 Toy bags.Not applicable to the toy demonstrators.	Di-n-octyl phthalate - DNOP/DnO	
	4.14 Enclosures: the toy demostrator will have a small sized hence this requirement is not aplicable.	Diisononyl phthalate - DINP	
	5.3 Plastic sheeting:if the toy demonstrator includes plastic decals with an area greater than 100mm x 100mm will have an average thickness of 0,038 mm or more.	Diisobutyl phthalate - DIBP	
	5.12 Hemispheric-shaped toys: cup-shaped toys, bowl-shaped toys and one half of egg-shaped having a nearly round, oval or elliptical opening with an specific dimensions and intended for children under 3 years should have opening or ribs as the standard states.		

Physical and Mechanical requirements	Standard
Toys and their parts must be of such dimensions as to not present a risk of asphyxiation by closing off the flow of air as a result of internal airway obstruction by objects wedged in the mouth or pharynx or lodged over the entrance to the lower airways.	4.6 Expanding materials: the toy demonstrators do not include glass material.Not applicable to the toy demonstrators.
	4.12 Ballons: the toy demonstrators do not include latex/rubber latex material.Not applicable to the toy demonstrators.
	4.17 Protecitle toys: specific requirement for proyectile toys. Not applicable to the toy demonstrators.
	4.22 Small balls: any ball that passes enterily through template E (according test 8.32) is considered a small ball.If the toy is intended for children over 3 years of age and includes a small ball, it must include a warning
	4.25 Toys attached to food: the toy demonstrator will not be attached to food. Not applicable to the toy demonstrators.
	5.1 General requeriments:Toys intended for children under 36 months and their removable components shall not be small part. Toys and removable components of toys shall fit enterely in the small parts cylinder (test 8.2 small parts cylinder).The toy shall be tested according: 8.3 (torque test), 8.4.2.1 (tension test), 8.5 (drop test), 8.7 (impact test), 8.8 (compression test).
	5.2 Soft-filled toys and soft-filled parts of a toy: specific specific requirement for toys filled with soft materials.Not applicable to the toy demonstrators.
	5.8 Shape and size of certain toys:toys having a mass of 0.5 kg or less intended for children who are too young o sit up unaided shall not protrude past the base of templates A and B (test 8.16 geometric shape of certain toys)
	5.10 Small balls:any ball that passes enterily through template E (according test 8.32) is considered a small ball.Toys intebnded for children under 3 years should nor include a small ball.
	5.11 Play figures: the rounded end of play figures for children under 36 months with a tapered neck attached to a cylindrical shape without appendages and an overall length not exceeding 64mm shall not protrude the base of template B (test 8.33 test for play figures).
	5.13 Suction cups:the toy demonstrators do not include suction cups.Not applicable to the toy demonstrators.
Toys, which are clearly intended for use by children under 36 months, and their component parts and any of their detachable parts must be of such dimensions as to prevent their being swallowed or inhaled. This also applies to other toys which are intended to be put in the mouth, and to their component parts and any of their detachable parts	4.6 Expanding materials: the toy demonstrators do not include expanding material.Not applicable to the toy demonstrators.
	4.11 Mouth-actuated toys and other toys intende to be put in the mouth:as a general requirement should not contain or generate a small part (test 8.2 small parts cylinder, test 8.3 torque test, 8.4tension test, 8.17 durability of mounth-actuated toys).
	4.12 Ballons: the toy demonstrators do not include latex/rubber latex material.Not applicable to the toy demonstrators.
	4.17 Protecitle toys: specific requirement for proyectile toys.Not applicable to the toy demonstrators.
	4.18 Aquatic toys and inflatable toys: specific requeriment for aquatic toys and inflatable toys.Not applicable to the toy demonstrators.
	4.23 Magnets: the toy should not contain dangerous magnets which are small parts and have a manetic flux index greater than 50 kG^2mm^2.
	4.25 Toys attached to food: the toy demonstrator will not be attached to food.Not applicable to the toy demonstrators.
	5.1 General requeriments:Toys intended for children under 36 months and their removable components shall not be small part. Toys and removable components of toys shall fit enterely in the small parts cylinder (test 8.2 small parts cylinder).The toy shall be tested according: 8.3 (torque test), 8.4.2.1 (tension test), 8.5 (drop test), 8.7 (impact test), 8.8 (compression test)
	5.2 Soft-filled toys and soft-filled parts of a toy: specific specific requirement for toys filled with soft materials.Not applicable to the toy demonstrators.
	5.9 Toys comprising monofilament fibres: specific specific requirement for toys with monofilament fibres.Not applicable to the toy demonstrators.
The packaging in which toys are contained for retail sale must not present a risk of strangulation or asphyxiation caused by airway obstruction external to the mouth and nose	6 Packaging.Not applicable to the toy demonstrators.
Toys contained within food or co-mingled with food must have their own packaging. This packaging, as it is supplied, must be of such dimensions as to prevent its being swallowed and/or inhaled.	6 Packaging.Not applicable to the toy demonstrators.
	4.25 Toys attached to food: the toy demonstrator will not be attached to food.Not applicable to the toy demonstrators.
Toy packaging, as referred to in points (e) and (f), which is spherical, egg-shaped or ellipsoidal, and any detachable parts of this or of cylindrical toy packaging with rounded ends, must be of such dimensions as to prevent it from causing airway obstruction by being wedged in the mouth or pharynx or lodged over the entrance to the lower airways	6 Packaging..Not applicable to the toy demonstrators.
Toys firmly attached to a food product at the moment of consumption, in such a way that the food product needs to be consumed in order to get direct access to the toy, shall be prohibited. Parts of toys otherwise directly attached to a food product shall fulfil the requirements set out in points (c) and (d).	4.25 Toys attached to food: the toy demonstrator will not be attached to food.Not applicable to the toy demonstrators.
Aquatic toys must be designed and manufactured so as to reduce as far as possible, taking into account the recommended use of the toy, any risk of loss of buoyancy of the toy and loss of support afforded to the child	4.18 Aquatic toys and inflatable toys: specific requeriment for aquatic toys and inflatable toys.Not applicable to the toy demonstrators.
Toys which it is possible to get inside and which thereby constitute an enclosed space for occupants must have a means of exit which the intended user can open easily from the inside.	4.14.1 Toys which a child can enter: specific requeriment for toys which a child can enter.Not applicable to the toy demonstrators.
Toys conferring mobility on their users must, as far as possible, incorporate a braking system which is suited to the type of toy and is commensurate with the kinetic energy generated by it. Such a system must be easy for the user to operate without risk of ejection or physical injury for the user or for third parties. The maximum design speed of electrically driven ride-on toys must be limited so as to minimise the risk of injury	4.15.1.5 Braking: specific requirement for toys with brakes. Not applicable to the toy demonstrators.
	4.15.1.8 Electrically-driven ride-on toys: specific requirement for driven-toys. Not applicable to the toy demonstrators.
	4.15.2.3 Braking requirements: specific requirement for driven-toys. Not applicable to the toy demonstrators.
	5.6 Speed limitation of electrically-driven ride-on toys: Not applicable to the toy demonstrators.
The form and composition of projectiles and the kinetic energy they may generate when fired from a toy designed for that purpose must be such that, taking into account the nature of the toy, there is no risk of physical injury to the user or to third partie	4.17 Protecitle toys: specific requirement for proyectile toys.Not applicable to the toy demonstrators.
Toys must be manufactured so as to ensure that: (a) the maximum and minimum temperature of any accessible surfaces does not cause injury when touched; and (b) liquids and gases contained within the toy do not reach temperatures or pressures which are such that their escape from the toy, other than for reasons essential to the proper functioning of the toy, might cause burns,scalds or other physical injury	4.19 Percusion caps specifically designed for use in toys and toys using percussion caps. Specific requirement for percursion caps.Not applicable to the toy demonstrators.
	4.21 Toys containing a non-electrical heat source. The toy demonstrators do not contain a non-electrical heat source.Not applicable to the toy demonstrators.
Toys which are designed to emit a sound shall be designed and manufactured in such a way in terms of the maximum values for impulse noise and continuous noise that the sound from them is not able to impair children's hearing.	4.20 Acoustics:sound pressure level limit must be complied with depending on the type of toy and its category of exposure the category of the toy

General requirements	
Torque test:	Ultimate Strength:
0.34 Nm	20-85 Mpa
Tension test:	Tensile Elongation at Failure:
Accessible dimension ≤ 6 mm: 50 N	
Accessible dimension > 6 mm: 90 N	8-25 % (TPU 350 %)
Protective components: 60 N	Coefficient of Thermal Expansion:
Seams: 70 N	
Compression test:	30.5-150 µm/(m °C)
110 N	Density:
Drop test:	0.9-1.25 g/cm^3
850 mm x 5 times	Glass Transition Temperature:
Tip over test (for large and bulky toys):	
3 times	60-147 °C
Impact test:	Melting Temperature:
1 kg from height 100 mm	150-270 °C
Soaking test (for glued wooden toys and glued plastic decals):	Maximum Service Temperature:
At 20° C for 4 min x 4 times	130-250°C

7.3.3 Application: 3D printed Toys (BIOG3D)

Definition of the product/demonstrator	Proposed recyclates and benchmarking of materials	Processing requirements	Scaling requirements
A) Collaborative 3D Printed Fairytale Boards for (Non-) Visually Impaired Users	Proposed recyclates: PP, ABS, (HIPS)	Max filament diameter: 1.75±0.05mm 1.75±0.05mm	Max build volume (W×D×H): 400 x 400 x 800 mm
A collection of fairytale boards for collaborative storytelling between visually impaired and non-visually impaired users. A universal design approach will be followed, through the implementation of high contrast colours and descriptions of elements in Braille tactile system. Users will be able to interactively play the fairytale by integrating the selected 3D printed emelents on the board, or even modify/expand the story according to their preference.	Processability assessment: A) 2D matrix [i,j] tests for fine tuning of printing parameters	Max nozzle temperature: 280°C	Accepted nozzle diameters: 0.2, 0.25, 0.3, 0.4, 0.6, 0.8 mm
		Max build plate temperature: 100°C	Upscaling: In Additive Manufacturing (AM) many parts can be simultaneously manufactured, as long as they do not exceed the available build volume.
	B) 3D torture tests for material benchmarking with detailed features corresponding to end-product features		
			
	C) 3D simplified geometries in relation to end-products		
			
B) 3D Printed Customisable Rackets	Benchmarking of materials:		
Customisable rackets based on anatomical features and aesthetic preferences. In the design process the following will be considered: (a) customisable and ergonomic handles, (b) consideration of dimensions, weight, and center of mass for comfortable handling and optimisation of aerodynamic performance, (c) customisable surface design and aesthetic personalisation.	ASTM D695-15 - Standard Test Method for **Compressive Properties** of Rigid Plastics		
	ISO 527-2:2012 Plastics - Determination of **Tensile Properties** - Part 2: Test Conditions for Moulding and Extrusion Plastics		
An injection moulded toy will be manufactured as demonstrators within the project by using the developed recycled materials, according to the available amount of material obtained after WP3 tasks. If the final amount is high a second type of injection moulded toy will be obtained. AIJU has two toy injection moulds, a puzzle and a ship with moving parts. We can also count on the collaboration of toy companies, if necessary, and as long as there is enough recycled material.	Proposed recyclates:	MFI (ISO 1133): 20-25 g/10 min – big toys 11-15 g/10 min – medium-small parts (possible other values, ckeck before)	Within the PRecycling project, it will be important to find a waste stream of at least 10 kg to develop a demonstrator at pilot plant level in AIJU or at least 50 kg for an industrial demonstrator in collaboration with a toy company
 	PP, HIPS (or ABS)		
	Benchmarking of materials:		
	HIPS (i.e. EDISTIR® SR 550; POLYSTYRENE IMPACT 6540; STYRON™ 678E)		
	Density: 1.04-1.05 g/cm³ Melt flow index: 11-12 g/10 min Young's Modulus: 1950-2000 MPa Tensile strength: 43 MPa Deformation at tensile strength: 2 % Deformation at break: 45-55 % Charpy Impact strength (notched): 8-45 kJ/m2		
	PP copolymer (i.e. Moplen EP548P; Moplen EP340M)		
	Density: 0.9 g/cm³ Melt flow index: 7-16 g/10 min Young's Modulus: 1500-1550 MPa Tensile strength: 28 MPa Deformation at tensile strength: 5-6 % Deformation at break: >50 % Charpy Impact strength (notched): 8-45 kJ/m2		

7.3.4 Application: Textiles (Centexbel)

Requirements					
Definition of the product/demonstrator	Proposed recyclates and benchmarking of materials	Processing requirements	Mechanical-physical requirements	Chemical requirements	Other quality requirements
Curtains	Proposed recyclates	Intrinsic viscosity	washing/dry-cleaning	Oekotex Standard 100 - annex 4 - category IV (decoration	(5-6)
	Polyester	0.63 - 0.84	Titer of multifilaments = 167 dtex	material) - selection of certain SoC:	M1-M2)
	Benchmarking	Temperature stability	Tear strength >=4.4N	Formaldehyde < 300mg/kg	washing > =4
	Virgin PET grades for filament extrusion	Tdeg >> Tm (at least 80°C gap)		Sb (antimony) - no limiting value	cleaning >=4
	Tests: DSC (ISO 11357), TGA (ISO 11358), Intrinsic viscosity (ISO 1628 - 5), Ash content (ISO 3451)	Ash content		Cleavable carcinogenic arylamines < 20 mg/kg Cleavable aniline < 50 mg/kg Colourants with more than 0.1% Michler's Ketone/Base <	Colour fastness to staining >= 3
		<1%		REACH (EC 1907/2006)	
		Moisture content			
		<100ppm			
Garment - T-shirt	Proposed recyclates	Intrinsic viscosity	Fabric elongation: 12.5-40%	Oekotex Standard 100 - annex 4 - category II (in direct contact with skin) - selection of certain SoC:	Colour fastness to washing > =4
	Polyester	0.63 - 0.84	Tensile strength >=180N	Formaldehyde < 75mg/kg Sb (antimony) - 30 mg/kg	Colour fastness to acidic perspiration = 3-4
	Benchmarking	Temperature stability	Abrasion test >=12k cycles	Cleavable carcinogenic arylamines < 20 mg/kg Cleavable aniline < 50 mg/kg	alkaline perspiration = 3-4
	Virgin PET grades for filament extrusion	Tdeg >> Tm (at least 80°C gap)	Pilling >=4 for every cycle	REACH (EC 1907/2006)	Colour fastness to rubbing = 4
	Tests: DSC (ISO 11357), TGA (ISO 11358), Intrinsic viscosity (ISO 1628 - 5), Ash content (ISO 3451)	Ash content	Shrinkage <3%		Light fastness >=4
		<1%	Tear strength >= 8N		
		Moisture content	Seam slippage >= 110N		
		<50ppm			