Politecnico di Milano
Scuola di Design
MSc. Design and Engineering
Academic Year: 2019-2020

A Design Scheme for Collecting and Sorting Flexible Plastic Packaging Waste for Recycling in Italy

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ABSTRACT

The main scope of the thesis is to develop a product/service for the collection of post-consumer flexible plastic packaging. The research encompasses the study of the whole process, from the service-system definition to the design brief definition and first proposals of a reverse vending machine. The project aims to facilitate recyclability of plastic packaging films by adapting and developing a deposit-refund system. The activity of the stakeholders in this system is strictly analyzed and defined. This deposit-refund model is adapted to a case study for Italy by creating an economical cost analysis of a four year period. The design roles are further defined in order to create a fully functional system, focalizing on the role of a product designer and the brief to create a reverse vending machine.

SOMMARIO

Lo scopo principale della tesi è di sviluppare un prodotto/servizio per la raccolta di imballi di plastica flessibile post consumo. La ricerca comprende lo studio dell'intero processo dalla definizione del service-system alla definizione del design brief e di una prima proposta di raccolgliatore-compattatore. Il progetto, mira a facilitare la riciclabilita' dei film in plastica adattando e sviluppando un sistema di deposito-ricompensa (deposit-refund). L'attivita' delle parti interessate (gli stakeholders) in questo sistema, e' completamente analizzata e definita. Il modello di deposito-ricompensa (deposit-refund), e' stato adattato per un caso studio in Italia, creando un'analisi economica di un periodo di quattro anni. Le fasi progettuali sono ulteriormente definite al fine di creare un sistema completamente funzionale, focalizzandosi sul ruolo del product designer del brief per la creazione di un reverse vending machine.

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INTRODUCTION

What is waste? Why does it need to be recovered? Which are the plans for waste management? How much are we in control?

These were the main questions that lead to the environmental concerns. Nowadays, the biggest role is played by plastics which are taking over the world, both waters and terrain. The optimal way to approach and manage this material is to create a true circular economy, which would only be the first step to create a complete functioning waste management model. One of the scopes of this thesis is to raise the awareness that, through circular economy, we can create value out of plastic waste.

During my internship in Ferrero (May 2019 - November 2019), I had the opportunity to design packaging using many types of plastics in many packaging forms. This lead me to realize that, technically, any material can be recycled. The real issue is how the packaging is designed and collected. Packaging is a great way to prevent big quantities of waste, but if it is not thought out well where it ends up after consumer use, it can also become the greatest reason of waste. In 2020, the circular economy for many types of plastic packaging exists, but not for all of them. Whether it exists or not is not only dependent on polymer type, but also on the final form it takes. There are functional systems for PET bottle collection, recognition and a market to sell the material, whereas almost no collection, recognition or market exists for post-consumer flexible plastic packaging.

In this thesis, I will introduce the current technologies and constraints for recycling plastics, focalizing on flexible plastic packaging films. The main intention of the thesis is to create a solution for collecting and sorting post-consumer flexible packaging by proposing a new design project for a reverse vending machine through adapting the deposit refund system, which is typically used for PET bottle collection.

CHAPTER 1

Recycling and Circular Economy of Plastics

Figure 1

1.1 Recovery of Waste

Where does waste come from?

Waste is human generated. It is described as an unwanted residue perceived to be of negative value, therefore the first human instinct is to dispose of it. Even though consumers are disgusted by waste, they rarely realize that they are active contributors to pollution through waste. In the consumers' mind, It is almost as if the waste vanished as soon as it is being disposed of. It is a relatively new misperception where the responsibility of the generated waste is automatically transferred to "waste management practitioners". Based on a report called "Attitudes of Europeans towards waste management and resource efficiency" written in 2013 by the European Commission, 87% of the people surveyed think that their country generates too much waste, but only a minority, 43% believes their own household does the same thing.

In a city, waste is managed by the municipalities. It is brought to sorting facilities, differentiated through labor or automated recognition systems and sent to the next plant to either be recovered to have full, acceptable or downgraded versions of the original material, or transformed in a way to recover energy from it (waste to energy). In the European Union, although the municipal waste represents only approximately 7% to 10% of the total waste generated, it is the most complex waste stream to manage.

Waste collection schemes play a great role in recovering materials, and are essential to the waste streams' material composition. Efficient collection schemes, where the waste is correctly sorted by the consumer (waste owner), help solve litter issues. These schemes maximize recovery of the valuable material, in this case the recyclable waste, by ensuring that this material does not end up in a landfill.

What happens when waste is mismanaged?

Pollution can be defined as the introduction into the natural environment by humans of substances, materials or energy that cause hazards to human health, harm to living resources and ecological systems, damage to structures and amenities or that interfere with the legitimate uses of the environment. It is implicit in the definition that pollution only describes situations where unwanted effects occur (Royal Commission on Environmental Pollution, 1984).

An estimated 8 million tonnes of plastic leaks into the ocean each year (UNEP, 2019). What does this mean for the environment? How does it effect us?

Plastic is making its way into our oceans. In a research made in 2017 by Dr. Christian Schmidt, it was shown that between 88% to 94% of the total plastic load in the seas are caused by ten major rivers, by mismanaged plastic waste. Some of these plastic waste sink in the ocean water, but more than half of this plastic floats due to being less dense. Due to the water currents and gyre, all the waste is

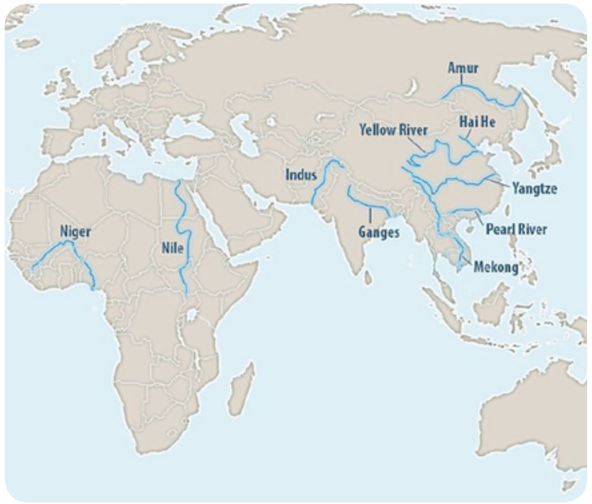


Figure 2: 10 major rivers that carry plastic waste to the oceans.

being concentrated into five locations in the oceans, the biggest one being called “The Great Pacific Garbage Patch”. It has an estimated surface of 1.6 million square kilometers equivalent to three times the size of France. (The Ocean Cleanup, 2020). It is estimated that 80% of all the garbage patches consist of plastic waste (European Commission, 2011a, European Commission, 2013). The sizes of these patches in our oceans are growing rapidly over the years. By 2050 it is estimated that there will be more plastic than fish in our oceans, if leakage of the plastic is not prevented in the next few years.

The marine litter, created on the sea floor, accumulating on shorelines and the surface, harms marine species. Because of it, by now, out of all 800 known marine species 15 of them are endangered.

Microplastics are defined as plastic debris particles smaller than 5 mm (GESAMP, 2015). They are in our clothes, food, water and cosmetics, and can be divided into primary and secondary microplastics. Primary microplastics include microbeads, nurdles (plastic pellets) and fibers, which are manufactured from industrial applications or caused by domestic applications. As they are too small to be filtered out by waste treatment plants, they are designed to wash down the drain, traveling through rivers and making their way into our food chain through fish consumption. Secondary microplastics are formed because of larger plastics breaking down due to ageing. As they are exposed to high levels of UV radiation, they become brittle. They are not only eaten by fish, but also by amphibians, insects, larvae, seabirds and other marine life, physically harming them. These small particles attract waterborne toxins and bacteria, which stick on the surfaces of microplastics. The health implications of microplastics on humans are not yet fully known.

Figure 3

Another threat to our health, always linked to waste in the plastic group, is plastic bags. They pose a health risk in residential areas by blocking sewage systems. Especially in developing countries, this blockage might cause serious diseases such as malaria, by creating breeding grounds for mosquitoes and other pests.

Not all trash is safe after being disposed. Aside from creating pollution, the hazardous waste (for example, medical waste or electronic waste which contains mercury, arsenic, PVC, solvents, lead, acids etc.) can raise both health and environmental problems. Uncontrolled toxic substances in waste that is disposed incorrectly will reach into soil and underground water, and contaminate them for years. Even if the waste is disposed in a landfill, liquids that are formed in the waste being called a leachate, are highly toxic and must be treated as waste water.

These are only some of the examples illustrating the importance of careful treatment of waste. We should realize that the generated waste is not something that must be disposed of, but that it can also become something rewarding for the economy, our environment and our health. There are three main methods of treating the waste: Material recovery, energy recovery and landfilling. Material recovery is the optimal solution to waste management, which creates a circular economy by reusing the material recovered from the waste. Energy recovery is using the waste as a fuel in order to generate energy, when it is not possible to recover the material with its original characteristics. Landfilling is not a form of waste recovery, but only a way to manage it by preventing it to be in contact with air, soil or water. Recovery of waste plays an important role in preventing the emission of greenhouse gasses and in promoting sustainability.

The main objective of waste management relies on the basic principle of a circular economy, which works for a sustainable future. Although the circular economy relies on waste and recyclable materials, the first step for sustainability is always a reduction of waste and responsible consumerism, where the 4R principle initiates the steps of a proper waste management: Reduction - Reuse - Recycling and Recovery (landfilling being the last resort).

1.1.1 Material Recovery (Recycling)

Most items are made from finite material resources which are not renewable. Just as the resources are not renewable, after we use the material, the waste doesn't vanish either. Therefore, it is important to understand that reusing the same material that came from a finite resource, in other words, recycling, is essential for our nature, planet and for our future. *"Recycling is not a goal in itself, but rather an essential tool to better manage natural resources."* (Worrell et al, 2014)

Resource recovery can be achieved by mechanical, thermal, chemical or biological processing of the waste to recover the materials in a certain form and with the correct specifications so that these materials are suitable for sale and reuse. It can also become the production of secondary materials for reuse (Alter, 1983).

Material recovery promotes many positive outcomes for our environment, health and economy. It is the most valued option out of three possible solutions to waste management. Recycling has a major contribution to the circular economy, by transforming and re-using a material that has already been processed in new products. In other words, less industrially reusable materials will be incinerated or wind up in landfills. Using recycled materials prevents the need of additional production of virgin materials, which leads to saving up on production and energy costs. It also reduces greenhouse gas emissions that result from extracting and mining virgin materials. Hence, more natural resources and energy is conserved because the recycled material has already been refined and processed, meaning that manufacturing the same material a second time is much cleaner and less energy intensive. As an example, recycling aluminum cans use 95%, recycling steel takes 75% and recycling plastics require 66% less energy than producing virgin materials.

1.1.2 Energy Recovery

Energy recovery is mostly associated with incineration of waste, although there are many emerging technologies such as combustion plants, waste incineration plants, cement and lime producing plants, anaerobic digestion plants (mostly used for agricultural waste), hydrothermal carbonization (HTC) and Dendro Liquid Energy (DLE).

Energy recovery is the second option for waste management. It is only preferred when the material cannot be recycled because either it is contaminated or lost in different material streams in the material recovery facilities (for the municipal solid waste). Some of these materials that can end up in waste-to-energy facilities are: Sponges, gift wrappings, toothbrushes, old shoes, greasy food packaging, vacuum cleaner bags etc. and some sanitary products that can't be recycled due to hygienic reasons. Additionally some recycled material residue, such as waste plastic that has degraded due to repetitive recycling and ageing of the material, can be treated in energy recovery facilities.

In a report published in 2019 by the ZeroWaste Association, some questions were risen about waste-to-energy solutions. Incinerating waste brought up some environmental concerns, mostly regarding the contribution of incinerators to greenhouse gas emissions and weighing the CO_2 emissions against the comparatively very small amount of energy that can be recovered from the waste. Due to it being a simple and easy-to-implement solution as against recycling, it raised some additional concerns that most of the recyclable materials were instead being burned or used as a fuel. Therefore, waste-to-energy must only be a viable option when waste incineration and co-incineration operations have a high level of energy recovery, or if the waste can also be reprocessed into materials to be used as solid, liquid or gaseous fuels.

There are some materials which cannot be used as solid recovered fuel, such as PVC, as well as inert elements like stones or glass particles, which must be excluded from the waste-to-energy material streams. As an example, PVC is a type of plastic which takes so much energy to be incinerated that it emits overmuch carbon dioxide. In this case it is safer to hold on to it or landfill it.

It should be noted that energy recovered by waste-plastics and other high calorific input materials, meet up to 10% of the energy demand of some European countries. Solid recovered fuel is now used in thermal plants and mostly in cement and lime kilns, reducing virgin fossil fuel consumption. If waste-to-energy plants such as "combined heat and power recovery (CHP) plants" meet the latest modern technologies, they can become a valuable, sustainable and efficient tool for a more environmentally responsible future.

1.1.3 Landfilling

Landfills are the most widespread solid waste management process, and currently they are quickly running out of space, requiring either alternative disposal methods or new landfills, and nobody wants a landfill, waste disposal, or treatment facility in their "backyard". Although landfills have limited immediate environmental harm, considering longterm risks, it will result in contamination of soils and groundwater, while the breakdown of plastics can produce persistent organic pollutants.

Figure 4

Landfill is the disposal of trash by dumping the waste into extremely large holes in the ground. In a municipal solid waste landfill, the ground is covered by a layer of clay and flexible plastic which has a thickness around 1 cm. There are pipes around the landfill, which collect and transport the contaminated fluid caused by the waste, which must be treated as waste-water, as it can be toxic and harmful.

Landfilling adds to the greenhouse gases being released into the atmosphere. Landfills are not designed to break down the waste but only to store it. Inevitably, the waste in the landfills will eventually start decomposing and produce methane, which is a more potent greenhouse gas than carbon dioxide. In some more advanced landfills, these gasses can be captured and used for electricity/heat generation or biofuel production, which however require the installation of an additional "landfill gas capture and energetic utilization system" (ZeroWasteEurope, 2019).

1.2 Plastics - Overview

The term plastic is used to describe petrochemicals (fossil feedstocks derived from crude oil) or biomass. Other raw materials used to produce plastics are natural products such as cellulose, coal and natural gasses. Crude oil goes through a polymerization or poly-condensation process in order to form plastic. Around 4% of the world's oil resource and gas production, both being non-renewable resources, are used for the production of plastic materials. Another 3 to 4% is consumed in order to provide energy for its manufacture. (Hopewell et al. 2009)

There is a large variety of plastics, with different characteristics suitable for many types of fields of application. Although plastics were only discovered in the 1950's, it has become indispensable in our daily lives. The demand for plastics has been raising exponentially in the recent years. In 2018, the global production of plastics reached 359 million metric tons, with 62 million metric tons being produced in Europe alone. China is one of the largest producers of plastics in the world, and is responsible for 30% of the world's plastic production. (PlasticsEurope Market Research Group (PEMRG) and Conversio Market & Strategy GmbH)

There are two main categories of plastics:
Thermosets and thermoplastics.

Thermosets, chemically change when they are heated and molded creating a three dimensional network, which prevents them from being re-melted. It is an irreversible polymerization process, therefore they cannot be mechanically recycled. Through technological developments, they might be chemically recycled or used as a solid fuel. Some common thermosets are polyurethane (PUR), epoxy resins, acrylic resins, silicone and vinyl ester.

Thermoplastics, are a family of polymers that can be re-heated and molded many times. The main difference that sets them apart from thermosets are that the molding process is reversible, hence thermoplastics can be mechanically or chemically recycled. Some common thermoplastics are: Polyethylene terephthalate (PET), polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), polycarbonate (PC), which are mainly used in packaging sector, and others such as, ABS, SAN, Polyamides (PA), Polymethyl methacrylate (PMMA), EVOH, Thermoplastic elastomers (TPE).

1.2.1 How did plastics enter our daily lives?

Plastics bring easy solutions to many industrial and daily needs. They are easily moldable, therefore versatile, durable, lightweight, some can be transparent, some are excellent for being in contact with food, all of which creates many opportunities to apply them in different fields. Some fields that plastics are commonly used in include building and construction, transport, electronics, agriculture, healthcare, sports, textile, energy and packaging.

Thermoplastics entered industrial production in the 20th century allowing the creation of many superior alternatives to everyday objects. Being a relatively cheap and easily moldable material, a new generation of objects was born, which can be called the "single use plastics" or "disposable plastics".

Product	Material	Plastic Substitution
Thermos	Aluminum	PET Bottle
Bottle	Glass	
Bag	Kraft paper	LLDPE Bag
Cutlery	Metal	Plastic cutlery
Plate	Ceramic	Plastic plate
Bags for cement	Burlap (Cloth)	PP+HDPE sack
Diapers	Cloth	Unwoven plastic
New generation of items		
Plastic straws	Plastic stemmed cotton buds	Plastic toothbrushes

Figure 5: PlasticsEurope and CitiBank Research Group

There has been a global shift from reusable plastics to the single-use (disposable plastics) in the last 60 years. In the short history of industrial plastic manufacture (especially thermoplastics) plastic materials in the municipal waste raised from less than 1% in 1960s to more than 10% already in 2005 (2015 data, production, use and fate of all plastics ever made), with packaging being the largest sector of worldwide plastic demand (Geyer et al. 2017).

1.2.2 Plastics in Packaging

“Packaging is a fundamental element of the product that the consumer buys and consumes. In addition to be the main means of communication to the customer, it plays the primary functions of containing and protecting the food in a cost-effective way along the entire supply chain, to which it must not in any way give substances in quantities that endanger human health or lead to an unacceptable change in the composition of the food products or a deterioration of their organoleptic characteristics.“

Direzione Packaging Unit (DPU), Ferrero Spa)

Packaging is often perceived as a medium of advertisement, an additional expendable material that has no greater value other than for marketing reasons. The true primary reason for the existence of any packaging of goods is to protect. This protection is mainly against breakage of fragile products (mainly during transportation), against food waste and/or theft.

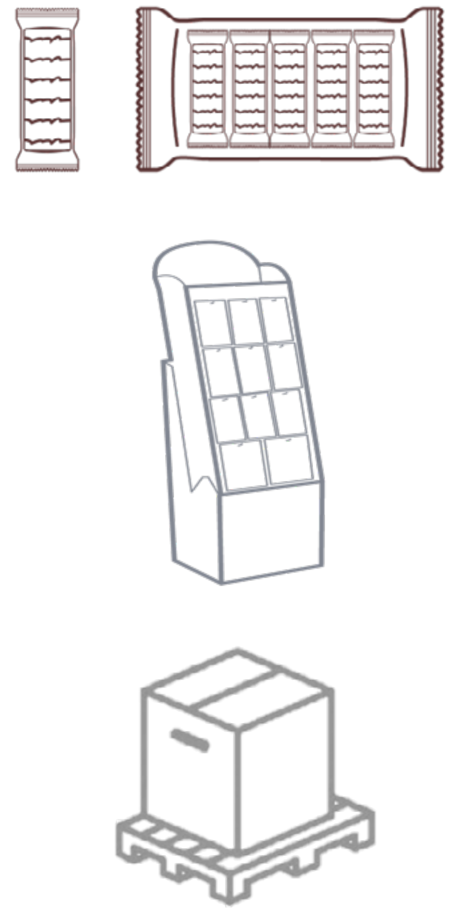
One of the biggest contributors to the greenhouse gas emissions is wasted food. With agriculture being taken into account, around 15% of greenhouse gas emissions are a direct cause of food production, process and transportation. Globally, an estimated 1.3 billion tonnes of food is wasted each year (FAO, Food and Agriculture Organization of the United Nations, 2011), which is equivalent to one third of the world’s food production.

Plastics are a commonly used material in packaging, due to their high protection barrier against UV radiation, odors, oxygen, humidity and bacteria, further preventing food waste.

According to a report of 2018 made by PlasticsEurope, packaging occupies 39,9% of all plastic demand (a total of 51.2 million tons) in Europe (EU28 + NO/CH).

Levels of packaging

Packaging can be divided into three subcategories based on the contact level with the main product that it contains.



Primary packaging, is the packaging that is directly in contact with the product.

Secondary packaging, is the packaging that has an indirect contact with the product. It usually holds together individual units that contain the goods, mostly for logistical and branding purposes. It typically groups two or more pieces of primary packaging, as with its main purpose being communication and protection of the goods.

Tertiary packaging, is the packaging level that is rarely seen by the consumer. It facilitates transportation and handling of a series of units of secondary packaging in order to group everything into unit loads during transit.

Figure 6

1.2.3 Thermoplastic Polymers in Packaging

Plastics are classified according to an identification system. This system is primarily used for recycling purposes, as well as for encoding the most common polymers. They are used in many industrial sectors such as packaging, textile, industrial, machinery, consumer and institutional products, building and construction, electronics and others. In the next page, these polymers are listed with their main properties which render them suitable for the designated industrial field, as well as the main applications of each polymer.

Identification Code	Type	Properties	Applications
1 PET	**Polyethylene Terephthalate**	Shock Resistant Good Mechanical properties Transparent Colorless	Beverage Bottles Trays Containers Flexible Packaging
2 HDPE	**High Density Polyethylene**	High Mechanical Resistance Good rigidity Barrier to humidity and chemical agents Opaque Odorless Non-toxic	Rigid Packaging sector: Food Detergents Chemicals Other fields: Crates, caps, drums, technical items, toys
3 PVC	**Polyvinyl Chloride**	Good wear Chemical, fire and deterioration resistance	Cosmetics packaging Construction components (floorings, coatings, pipes, window frames)
4 LDPE	**Low Density Polyethylene**	Light, transparent, ductile and flexible Good chemical resistance to acids and bases excellent electrical insulation High impermeability to water	Flexible Packaging (Films, bags) Agriculture (sheets) Cable coatings
5 PP	**Polypropylene**	Good thermal resistance High rigidity Water vapor impermeability (not to gasses).	Household items Toys Packaging (Trays, rigid bottles and flexible films)
6 PS	**Polystyrene**	Light Rigid Lumiosity Transparent Excellent resistance to external agents Sensitive to impacts	Packaging sector Disposable tableware Office items Single use containers and displays. Expanded polystyrene (**EPS**) used in protective and shock proof packaging (crates), insulating sound absorbing products in construction sector.
7 OTHER	Other thermoplastics. They have various properties and application fields. Some examples are: **Polymethylmethacrylate (PMMA)**, **Polycarbonate (PC)**, **Polyurethane (PUR)**, **Polyamide (PA)**, **Some Biopolymers**		

Figure 7: CONAI, Guidelines to facilitate the recycling of plastic packaging

It is reported in 2019 by PlasticsEurope that in 2018, packaging occupied 39,9% of all plastic industry in Europe.

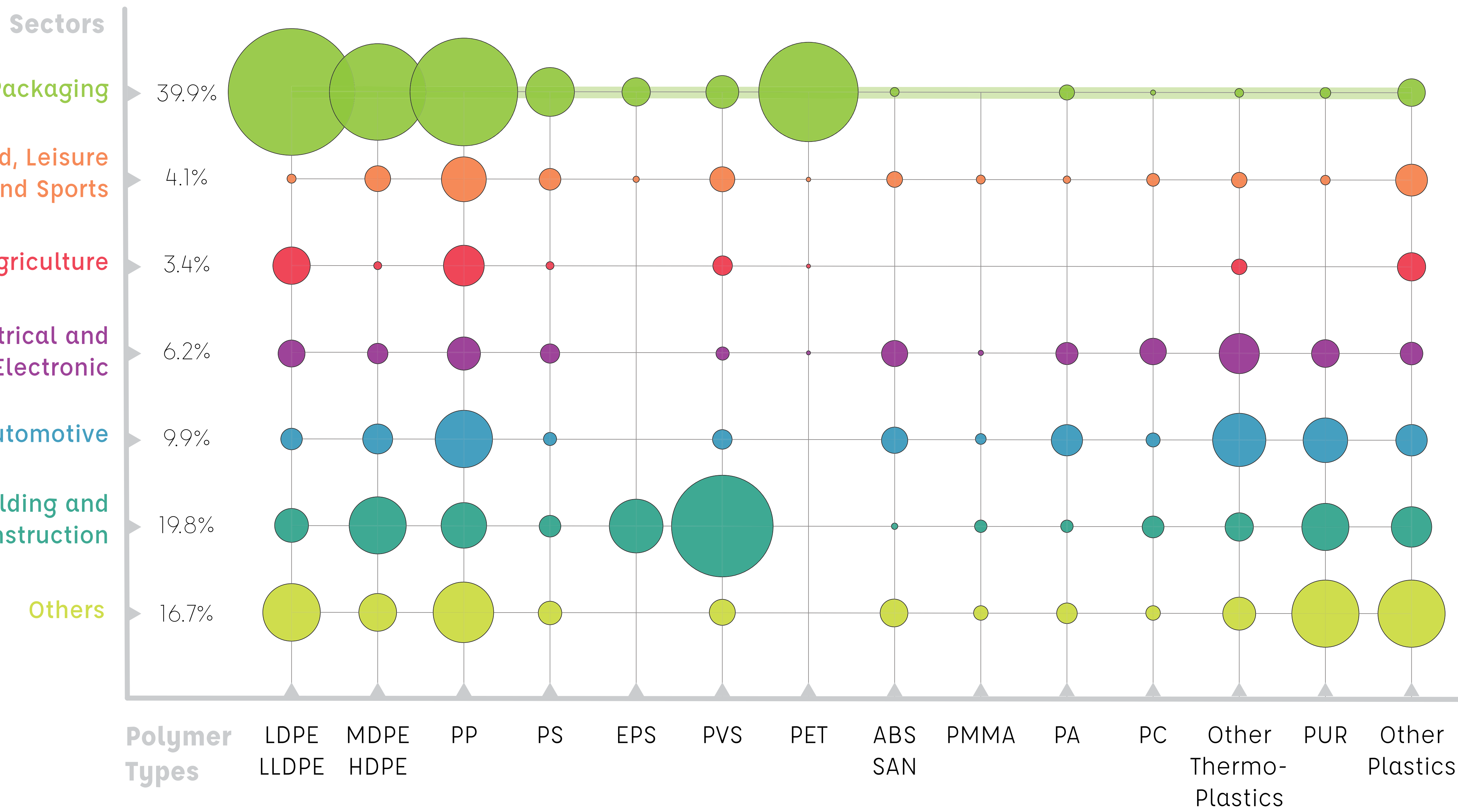


Figure 8: PlasticsEurope, 2019 Factsheet

1.3 Recyclability of Plastics

Every type of plastic has distinct properties which differentiates them from each other, even though they are all part of the same material family. As mentioned earlier, plastics are labeled with seven identification codes, which classify both the resin type and recycling purposes:

Identification Code	Type	Recyclability
1 PET	Polyethylene Terephthalate	(r-PET) **Easily sorted and recycled.** Qualities similar to virgin PET.
2 HDPE	High Density Polyethylene	**High degree of recyclability.** Often residues deriving from pigments and additives"
3 PVC	Polyvinyl Chloride	Recycled **only** in **construction** industry
4 LDPE	Low Density Polyethylene	Maintains mechanical properties. Loss of transparency. **Difficulty** of recycling of **flexible packaging** to **possible multilayer structures** with other polymers or metallized layers.
5 PP	Polypropylene	Maintains physical characteristics of the virgin material. **Recyclability linked to possible multilayer structure** in packaging (flexible films)
6 PS	Polystyrene	**Difficult to recycle** due to low impact resistance (Easily fragments into small pieces which are difficult to recycle) **EPS** packaging is usually used in meat and creamy product cases which are often contaminated, therefore difficult to recycle.
7 OTHER	Mixed resin types	Generally is not recognized and sorted. Depends on management of municipal collection systems.

Figure 9: CONAI, Guidelines to facilitate the recycling of plastic packaging

All these polymers have different densities, mechanical and chemical properties. In municipal waste collection schemes, plastics are collected as if they are one single material, despite these distinct characteristics. In order for them to be correctly recycled, they need to be re-sorted by their form (whether they are rigid or flexible plastics), by their densities, and through recognition systems into their appropriate resin group. They need to be cleaned, in some cases granulated, re-sorted and finally extruded to be used as recycled and re-converted materials.

Plastics can be recycled a limited amount of times. For example, a plastic bottle typically can be recycled up to 10 times. The polymer chain shortens every time the material is recycled, which causes a downgrade of the quality of the resin. After it reaches the end of its life cycle, ideally, it can be burned to produce energy or after a certain treatment, it can be used as a solid fuel along with other non-recyclable materials (Waste to energy).

All thermoplastics are technically recyclable. There are certain factors that prevent them from being recycled today. To list some of these factors:

- The thermoplastic might be coupled or sandwiched with other materials, altering physically its structure. Adding additives or ink also effects the recyclability of a material. Today, in most cases it is not feasible or economically not viable to separate these layers.

- The sector and specific application that the thermoplastic is used in strongly affects the outcome of the recycled material. If the material is highly contaminated (for example, contaminated with food) after consumer use, it might not be feasible eliminating the contamination or cleaning the material completely.

- Collection and transportation of the waste material affects the recyclability of the polymer. As listed before, materials such as polystyrene (PS) can become very brittle during transportation, and might fragment into many tiny pieces which would not be feasible to correctly separate it from other plastics. The collection method itself also affects the outcome, as mixed waste collection systems could cause additional contamination to the material.

In some cases, even if it is technically feasible to recycle all the thermoplastic materials, it would not be economically viable, as it directly affects the sale prices of the recycled end-material. In an industrially automated system; sorting, washing and recycling must be done efficiently enough so that the market value of the recycled material can remain comparable to the virgin material.

1.3.1 Recycle rates of plastics

Plastic production, converter demand and recycle rates are based on the most recent available data, which was documented in 2018. In this section, all the data will be compared, starting globally in a more general matter, then focussing on Europe and Italy in a more detailed manner, as a case study.

Global

World plastic production has reached 359 million tonnes in 2018 (PlasticsEurope, Facts 2019).

According to 2015 data, only around 9% of the plastic waste was recycled while 12% was incinerated and 79% was accumulated in landfills or was being littered. 42% of plastic production was converted into packaging, which makes approximately 141 million tonnes (Geyer et al. 2017).

In a study conducted by the Citibank research group, in 2018, it is estimated that approximately 150 million tonnes of plastic packaging waste is produced per year. While the packaging sector is dominated by flexible and rigid plastics, only 14% of plastic packaging waste is recycled globally.

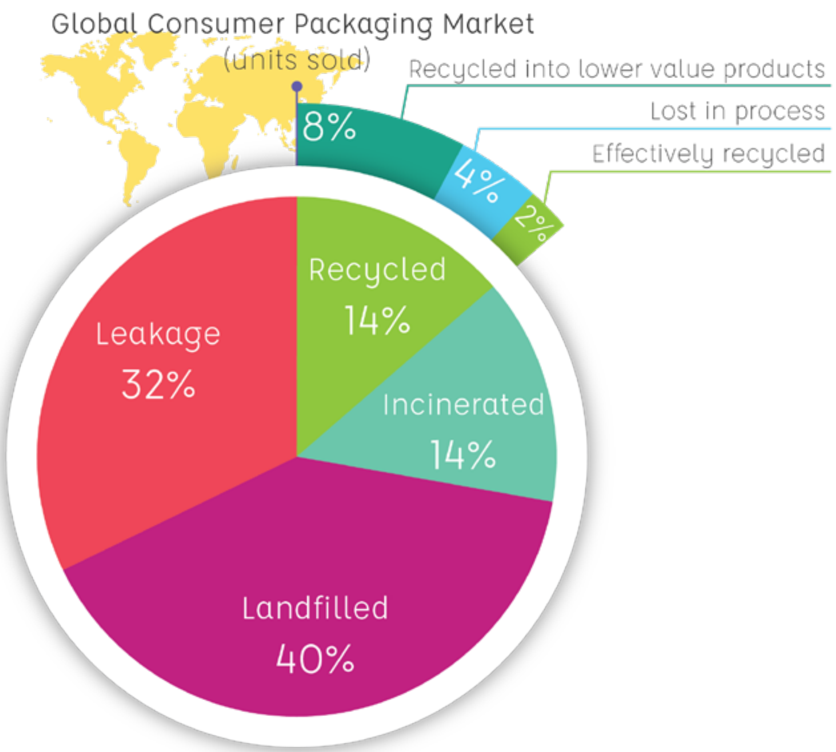


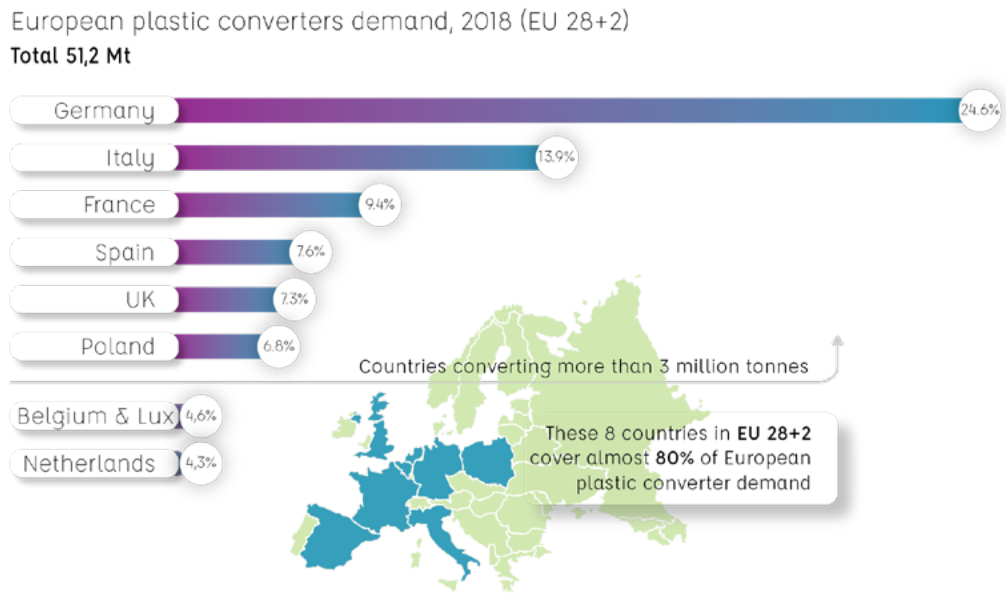
Figure 10: CityBank Researh Group

Europe

In 2018, the plastic production in Europe has reached 61.8 million tonnes, while plastic converter demand is around 52,4 million tonnes (PlasticsEurope, Facts 2019). Plastic converting is intended as the production of items and objects made of plastic material.

Just like in a global scale, Europe's plastic production and converter demand is also dominated by the packaging sector, accounting for 39,9%. The most commonly used polymers in packaging are low density polyethylene, polyethylene terephthalate, polypropylene and high density polyethylene.

In Europe (EU 28+2), almost 80% of total plastic converter demand is covered by eight countries, where six of them has a converter demand more than 3 million tonnes.



Figire 11: PlasticEurope (2019)

In the 30 European Countries listed below, the average recycle rate of plastic packaging is 42%. It should be pointed out that, complementary to mechanical recycling, Germany and Italy are the only two countries in 2018 that also performed chemical recycling.

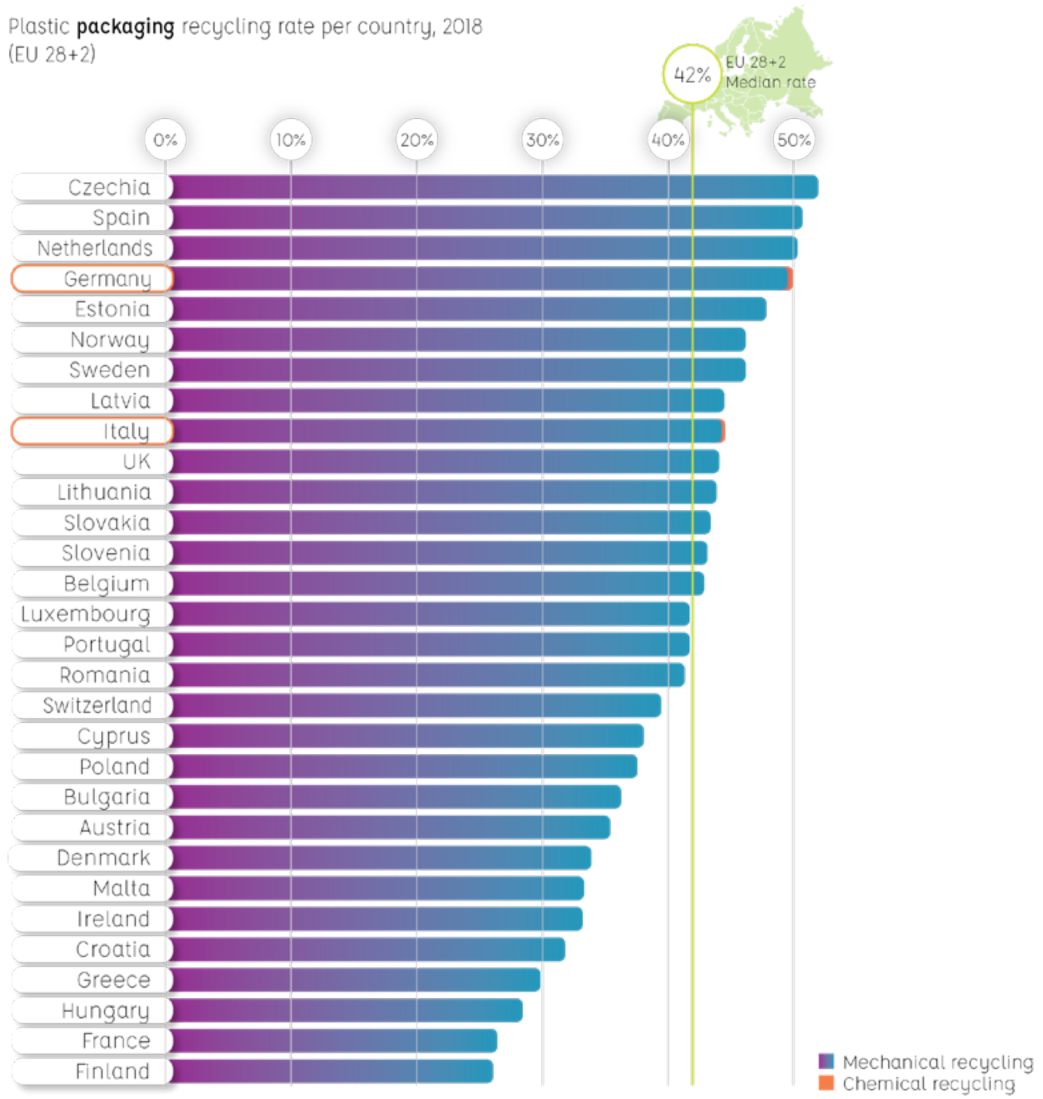


Figure 12: PlasticEurope (2019)

Italy

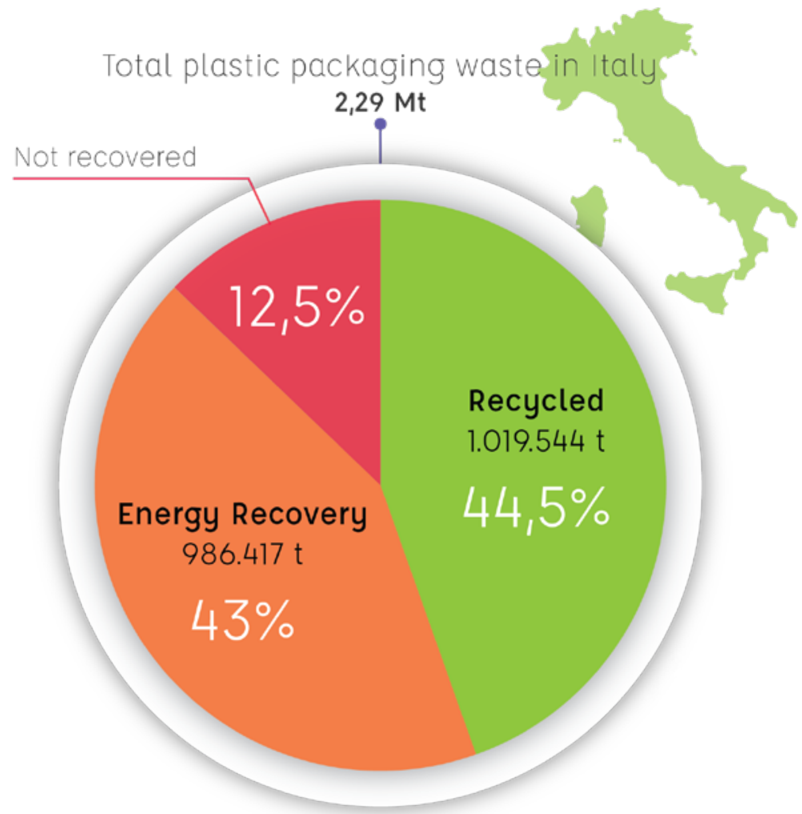


Figure 13: Corepla (2018)

Italy's plastic converter demand is 13,9% of EU 28+2, which is approximately 7,8 million tonnes of plastic. Of this total amount, 2.292.000 tonnes of plastic packaging was released for consumption in 2018.

Italian municipal waste collection and recycling system is managed by two different entities. One of them consists of independent recyclers, approved by the municipalities and the Italian government, with the other entity being a consortium called CONAI which is divided in seven segments that manage different municipal waste streams based on packaging (from households). COREPLA is the consortium under CONAI that manages municipal plastic packaging waste.

51% of the municipal plastic packaging collection in Italy is managed by the Corepla consortium, while 49% is managed by the independent operators. Corepla contributed in the collection of 1.219.571 tonnes of plastic. 110.823 tonnes of this waste was a part of an external fraction. 27.366 tonnes of plastic waste arrived from other collection platforms. Overall, 643.544 tonnes of plastic packaging waste was recycled by Corepla, while 383.057 tonnes were sent to energy recovery and 89.421 tonnes of plastic packaging ended up in landfills.

In 2018, a total of 1.019.544 tonnes of plastic packaging waste was recycled. As Corepla, contributed with 643.544 tonnes of recycled packaging, the consortial fraction of recyclers manages up to 63% of total packaging waste recycling in Italy.

1.3.2 Technologies for identifying, sorting and recycling plastics

There are three possible routes for recycling plastics: Primary recycling (reuse of the material in its original form), mechanical and chemical recycling. In all cases, the recycling process starts from the collection of waste.

In Europe, many of the plastic waste from households is collected through kerbside collection schemes. These schemes can be differentiated into co-mingled fractions, source separation and bring system. An alternative to these systems are deposit-return schemes, which can be found in ten European countries (2020).

In a co-mingled waste fraction, which is a kerbside collection scheme, materials such as plastics, paper/cardboard, metal and glass are collected in a single bag/bin and sorted into different material streams in material recovery facilities.

Source separation is a multi-stream kerbside collection where the waste material is already sorted in households according to the municipality's indications and collected separately or within a multi-compartment vehicle.
Kerbside collection schemes have a low level of material contamination and 40% to 60% recycling target.

Figure 14

Bring systems are usually implemented where the housing density is very high or very low, where kerbside collection would not be feasible. In a bring system, the household waste is brought to a central collection point. These systems have high level of contamination from 10% to 30% with a low recycling target 10% to 15%.

Alternatively, deposit-return schemes are implemented for certain packaging formats such as aluminum cans, glass bottles and PET plastic bottles. They have an extremely low contamination level and very high recycling rates (the median rate in Europe is 92% in 2020).

Sorting

The sorting of household plastic waste can be done either manually or automatically. This process is highly dependent on the type of waste stream as well as on other factors such as: performance (outcome of the desired business case), reliability (performance under specific conditions over a period of time), costs (income and payback time), maintenance requirements (maintaining and care of the machinery), environment, health and safety aspects (impact to the surroundings and employees), risks (possible external factors that might influence the technical and financial outcome) etc.

The sorting process goes as following:

1. Weighing, checking and registering the waste
2. Removal of possible contaminants
3. Classification of waste by shape, size and density
4. Manual, optical, magnetic and induction sorting
5. Removal of contaminants from sorted batches
6. Bulking material for facilitating transportation
7. Storage (Until the material is transported to material recovery facilities)

Automated sorting systems based on the size of the waste:

Trommel Screen, a rotating cylinder which are placed at a certain angle, allows waste of a given size to fall through.

Disk screens, are a bed of vertical screens that allow transportation of larger items while dropping the smaller waste through the gaps.

Oscillating screens, are a vibrating declined beds that allows smaller waste to pass through while transporting the larger formats to the end.

Automated sorting systems based on the weight and density of the waste:

Air separation, is usually where the light waste is blown away or sucked in by suction hoods directly from a conveyor belt. Systems such as zig-zag classifier, rotary air classifier and cross-current air classifier blow away horizontally or capture the light-weight waste through air streams, allowing the heavier waste to drop through the conveyor belt. Mainly these systems are used to separate rigid (3D) from flexible (2D) plastic waste.

Ballistic separation, is a system of steeply inclined perforated plates which vibrate in different sequences collecting heavy fractions in the bottom while light items are lifted by cams.

Optical sorting sensors are commonly combined with other separation technologies. Near-infrared sensors (NIR) are commonly used for identifying plastic types such as PET, HDPE, PVC, PP and PS. Visual spectrometry (VIS) is used to sort materials based on their color.

Mechanical Recycling

After the primary sorting stage, the recyclable materials are brought to material recovery facilities. In this stage, there is mostly a single waste stream.

In mechanical recycling or secondary recycling, thermoplastic materials are remelted and reprocessed into new products. During this process the structure of the polymer is not chemically changed. This process consists of grinding, washing, separating, drying, re-granulating and compounding the sorted waste.

In some cases dry separation methods are preferred for pre-identifying polymers. This separation method consists of a near infrared recognition (NIR). In a consumer based plastic waste stream, which mostly consists of packaging materials, NIR technologies can be coupled with air separation methods. It is a positive/negative selection technique which, for example, can be used to detect rigid packaging, and separate PET bottles from HDPE containers. In positive selection the packaging is blown up to the next conveyor and in negative selection the packaging is dropped to be sorted with a second type of polymers. Further on a visual spectrometry (VIS) can also be used to color sort the polymers.

Mechanical recycling processes start by grinding the polymers which creates flakes of the material. This process can also be called chipping where polymers are ground into a pre-determined grill size. This phase is a preparation for the next step which facilitates separating polymers by density. Near infrared recognition can also be utilized in sorting polymer flakes.

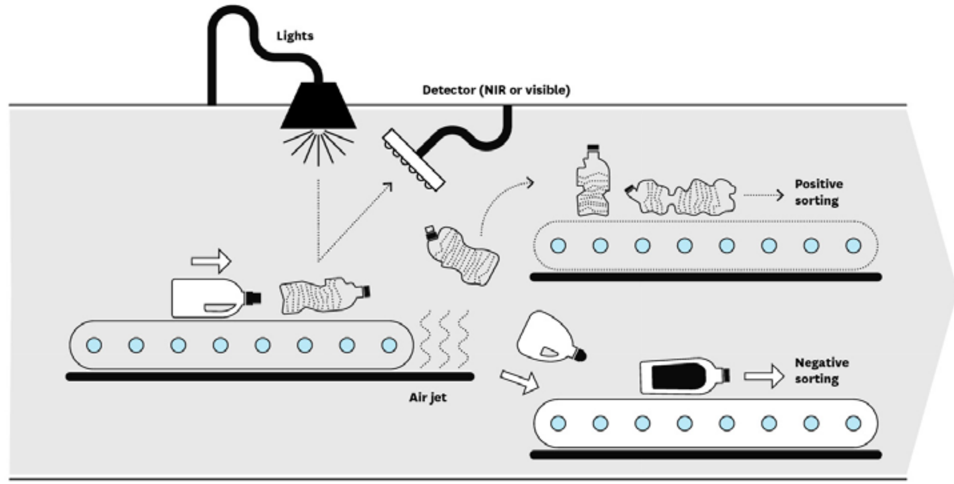


Figure 15: CONAI, Progettare riciclo

Polymer flakes are then washed at elevated temperatures, in a chemical solution which is alkaline or cationic detergent mixed in water.

Wet separation methods are usually based on the density of the material. The main examples would be the sink-float density separation which is based on centrifugal force or gravity; or methods such as layering by hydro-jigs mostly used for polyolefins.

Later on, the separated polymers are re-granulated and made into pellets through an extrusion process, ready to sold and molded into new products.

Chemical Recycling

Chemical or feedstock recycling is an area in plastic recovery, which has not been fully developed. There are several definitions and means to recycle chemically a plastic material but what they have in common is that they all alter the polymeric structure of the plastic material, chemically. This process theoretically gives an option for creating a true circular economy, as no plastic waste would have to be incinerated or landfilled. All plastic materials can be transformed into feedstock to create chemicals, diverse products, or primarily to be re-worked into plastics which would be on the same quality level of virgin materials. It is an option to recycle plastics that currently have no recycling solutions. Although chemical recycling is a more sustainable option than energy recovery or landfilling, it will only ever become a complementary model to mechanical recycling. The main reason to that is, after a plastic is chemically recycled, it must go through all the refining, polymerization and formulation processes, which would require a further energy consumption compared to mechanical recycling. Yet, chemical recycling needs to be improved in technology and meet necessary regulatory requirements in order to reach market maturity.

Chemical recycling can be divided into three categories: Solvent-based purification, depolymerization and feedstock recycling.

All these three procedures brings the polymer to a different level of pre-processed state.

Feedstock recycling, uses thermal cracking or pyrolysis which renders the end-material to have similar qualities as a virgin material after refining and petrochemical technologies are applied. It creates endless possibilities to recycling plastics, but at the energy-intensive cost of re-processing the material into a new polymer.

Depolymerization, breaks down the material to its monomer molecules or shorter fragment of polymers. In order to re-create plastic material, these monomers must go through a polymerization process to create polymer chains again. These polymer chains are then formulated back into plastic, and are further processed afterwards into their final form to be used in various sectors and applications.

Solvent-based purification, is a process where the plastic material returns to its precipitated polymer state before the plastic is formulated. This state is obtained by making the plastic material dissolve in a solvent, to separate the polymers from any contaminants and additives.

Chemical recycling is not expected to be a fully developed material recovery option before 2025.

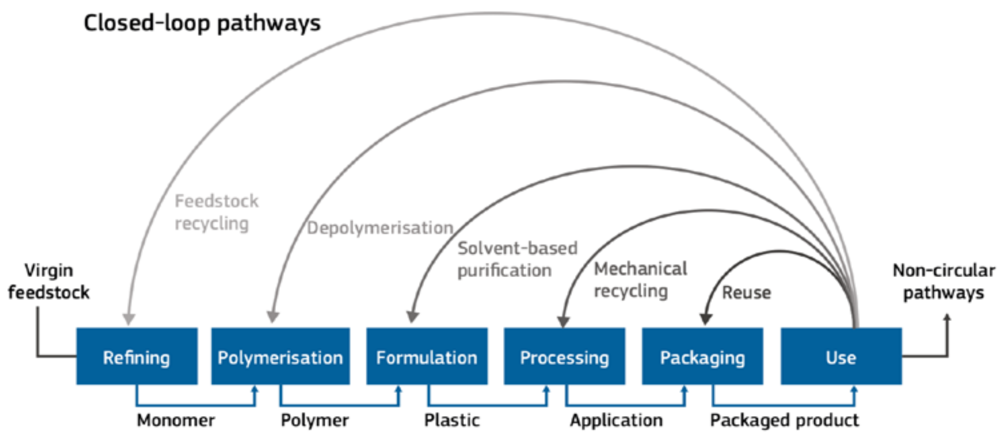


Figure 16: European Commission, 2019
A Circular Economy for Plastics

1.4 Circular economy

Circular economy is a term, which promotes a system based on production and consumption, with minimal losses of materials and energy. One of the biggest pioneers of this movement is the Ellen Macarthur Foundation believing that design is one of the most crucial stages where around 80% of the environmental impacts are determined.

The Ellen MacArthur Foundation defines circular economy as a system that is based on the principles of designing out waste and pollution, keeping products and materials in use, and regenerating natural systems.

Our resources on earth are finite and we are using them to create an extraordinary amount of products and tools at affordable prices. Everything around the world is easily accessible. We use, consume and throw these products away as waste as we no longer need them. However, when we throw them away it's not only the consumed product that we throw away, but along with that product all the resources that were consumed in order to create it are thrown away as well. This system is called a linear economy.

Ellen MacArthur foundation formulated three principles to achieve a circular economy which promotes the value of the materials, products and resources as well as the design systems created in order to produce these products.

1. Design out waste and pollution:

This principle is based on the fact that every product and every process that is used to create that product is designed specifically. Waste and pollution generated by these processes and products therefore a part of this design system. Therefore, by correcting "design flaws" waste and pollution will cease to exist.

2. Keep products and materials in use:

In order to create a circular economy; reusing, repairing and remanufacturing are essential to make long lasting products. However products such as food and packaging don't work with the same principle. It is a challenging, yet an important task to keep them away from landfills and recover them as valuable materials.

3. Regenerate natural systems:

As there is no concept of "waste" in nature, we shouldn't generate any waste either but improve our environment by returning nutrients to soil and other ecosystems. It is possible to enhance the existing natural resources.

A circular economy wouldn't only benefit the environment, by cutting greenhouse gas emissions but it would benefit the financial side of the economy for households and businesses. As an example, a better product design would help save from 77€ to 120 € for every tonne of plastic waste collected by making plastics recycling easier allowing the waste materials to find their way back to the market (EU Commission Factsheet, 2019).

1.6 Future targets for recycling in Europe

The European plastics industry set some targets for the future, in order to create a more sustainable system and an economy. They are not easy targets to reach but are necessary for creating a circular economy and environmentally friendly future.

(2025) Zero plastics to landfill

As mentioned before, landfilling is considered as the last resort for waste management. It has many environmental downsides, such as waste decomposing within time and producing methane, which could contribute and have a more devastating impact than any other greenhouse gas emission, or contaminants within the waste making their way into soil and water. Landfilling also occupies large area, which is especially problematic as many countries are facing an issue by running out of this space. Finding a suitable area for landfilling is also a challenge because naturally no one in the residential areas want garbage in their "backyard".

Beyond these challenges, landfilling is basically digging waste underground, never to be recovered. It is one way to avoid a problem and a responsibility but also means neglecting circular economy.

Plastics are produced from non-renewable resources, but once they become a part of a circular economy, they can become a valuable resource. Plastics ending up in landfills is a waste of this resource, which could have been used to prevent greenhouse gas emissions by mining and producing more virgin materials. Waste-plastic can also be used as a solid fuel as a waste-to-energy resource, as it has a high calorific value. Plastics ending up in landfills would contribute majorly in preventing greenhouse gas emissions. It is the first step to be taken for a functioning circular economy and a sustainable future.

Many countries (AT, BE, DK, EE, FI, FR, HU, IE, IT, LT, LU, NL, PL, RO, SE, SL, SK, UK) in the European Union as well as Norway and Switzerland have already adopted a landfilling ban in 2017, proving that "Zero plastics to landfill by 2025" is an ambitious yet achievable target.

(2030) All plastics should be recyclable

Another commitment made regarding Europe is creating a true, functioning circular economy for plastics, in other words, all products made of plastics must be reusable, recyclable or compostable.

Some targets are set through this new initiative, where according to the new European Union directive 2018/852, by 2025 50% of all plastic packaging material must be recycled. By 2030 this target is raised up to 55% (PlasticsEurope, 2019)

The Association of Plastic Recyclers (APR) defines a recyclable product as:

- At least 60% of consumers or communities have access to a collection system that accepts the item.
- The item is most likely sorted correctly into a market-ready bale of a particular plastic meeting industry standard specifications, through commonly used material recovery systems, including single-stream and dual stream material recovery facilities' systems that handle deposit system containers, grocery rigid plastic and film collection systems.
- The item can be further processed through a typical recycling process cost effectively into a post consumer plastic feedstock suitable for use in identifiable new products.

CHAPTER 2

Flexible Films in Packaging

Figure 17

2.1 Flexible Packaging

Plastic packaging can be divided into two groups based on its form: 3D and 2D packaging. 3D packaging can be named also as rigid packaging where the form is a 3D structure with higher material thickness in comparison to 2D packaging. While 2D packaging is what can also be called as flexible packaging, and is prefered for its lightness due to lower thickness range of the material. The form of the packaging is strictly correlated with the product that it envelopes, as after taking out the product that it contains, flexible packaging becomes flat. There are different use cases for these two types of packaging forms, mainly depending on the kind of protection and support that the packaging must give to the product.

The global packaging market is currently shifting towards deploying increasing amounts of flexible packaging due to many benefits such as economical, environmental and most importantly performance mainly regaarding its barrier purposes for food (alimentary) products.

In plastic flexible packaging, the main polymer group used, are the polyolefins which are crystalline thermoplastics for their translucency (generated by the regular arrangement of the molecules). They also have a higher mechanical impact resistance compared to other formats/materials. Some examples are, Low-Density Polyethylene (LDPE), Linear-Low-Density Polyethylene (LLDPE), Mid-Density Polyethylene (MDPE), High-Density Polyethylene (HDPE) and Polypropylene (PP).

Flexible films are mainly used in food packaging (such as wrappers and packets) or cling film. Further applications include tertiary packaging types, such as stretch and shrink film, film on reel, heavy duty bags, refuse sacks, pouches and carrier bags.

2.1.1 Advantages of flexible packaging

Barrier

Globally, there has been a shift in the packaging sector to flexible packaging in the recent years, mostly due to the advancements in barrier properties that flexible films can provide. Better the protection of the product, in this case food, the longer will be the shelf-life, therefore food waste will be prevented. It is declared by the United Nations in 2019 that food waste has the biggest environmental impact. All the energy that goes into producing the food is wasted and moreover the formation of methane has the biggest impact of greenhouse gas emissions. It has been declared that 1/3 of the global food production of food goes to waste every year. Therefore it is important to point out the benefits of flexible packaging.

Flexible packaging can have a structure of multiple materials, allowing a combination of excellent mechanical and chemical properties, in other words, creating an efficient barrier for the product, and prolonging its shelf life. Some of the barrier properties that is provided by flexible packaging are:

- Oxygen ingress
- Humidity
- Carbon dioxide (for modified atmosphere packaging)
- Light (UV barrier)
- Loss of flavor, nutrients, and oils from the product to the package or to external environment
- Loss of aromas from the product
- Infestation
- Barrier against external chemicals
- Protection from temperature changes

Lightweight

Due to its weight, flexible packaging has both environmental and economical benefits during transportation. Unlike rigid plastics, flexible packaging is light, and has a low packaging/product ratio. Maximizing packaging efficiency, and having a lightweight packaging, greatly improves space while transportation. For example, a rigid plastic container with a lid might have up to 5:1, while a flexible “brick pack” can have up to 29:1 product-packaging ratio (Flexible Packaging Europe, 2011, “The Perfect Fit”). Therefore, a flexible packaging doesn’t only decrease the weight but also the volume that must transported. More products can be fitted into a truck, decreasing the amount of travels and the consumed fuel. This leads up to a decrease in both financial costs and the environmental impact by greenhouse gas emissions.

Flexible packaging, due to its lightweight properties, uses far less resources in comparison to other packaging formats, hence has a lower environmental footprint.

Transparency

The translucency of the material also helps the consumers to evaluate the product that the packaging contains. It makes it easier for any breakages to be seen.

2.1.2 Structure

Flexible packaging films can have various layered structures. They can be made of one single layer with a single material or can be coated (monolayer, mono-material film), they can be made of several layers of the same material (multilayer, mono-material film) or they can be made of several layers of different materials (multilayer, multi-material film). Different layers serves various functions such as structural, sealant, barrier and tie-layer adhesive. The structural layer of the flexible film can be coupled not only with other polymers but with other material families as well, for example with a metallized layer (generally aluminum). A multi-material film can be up to 250 microns thick. For a combination of layers, each layer usually can be made with a thickness of 13 up to 75 microns.

The most diffused resin that is used in flexible packaging is low density polyethylene. Other resins can be used as structural layers as well, mostly of the polyolefins type.

Different structure combinations, give the flexible packaging different mechanical and barrier properties. As an example, polyethylene gives the packaging its bulk and structural integrity. For additional toughness it can be coupled with more polyethylene or PET layers. Polyethylene can also be used as a sealant layer, although ethylene vinyl acetate (EVA) is preferable due to its lower melting point. In food packaging, metallized layers are usually combined with other structural layers for its optimal barrier properties against oxygen, gas and water vapor ingress, as well as for the protection of aroma and flavor of the product.

Commonly used resins in Flexible Packaging

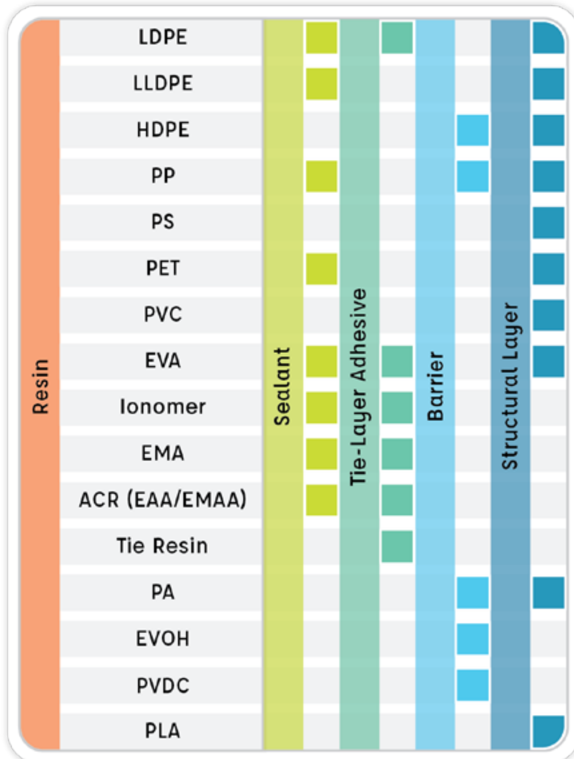


Figure 18: Morris B. A. (2017)

2.1.3 Post consumer flexible packaging

Flexible films occupy a large fraction of all plastic waste generated. According to the data taken from PlasticsEurope, in 2018, LDPE which is one of the largest fractions of plastic film material amounted to 17.5% of all plastic converted demand in Europe. Adding PP and HDPE to this fraction, polyolefins make up to almost 50% of the entire plastic demand.

LDPE film is not only used in packaging but also in many other sectors. Some of these main sectors are building and construction, automative, electrical and electronic, agriculture, household, leisure and sports, packaging and others. Calculating the data taken from diverse sources (Plastics Europe, FPA and Recycling of Flexible Packaging), LDPE packaging accounts for 73,87% of the whole LDPE industry.

Taking into consideration the end-users of the main sectors of LDPE industry, the market can be divided into two parts; business to business (B2B) and business to consumer (B2C).

In the REFLEX project made by the consortium CEFLEX (A circular economy for flexible packaging), the amount of flexible packaging formats and different combinations of materials were analyzed in a batch of 143kg of film waste in UK.

According to the project, it is established that the major part of the post-consumer flexible packaging waste has a mono-material structure. In the European Union, approximately 3 million tonnes of flexible packaging is mono-material polyethylene, polypropylene or has a mixed PE/PP structure (Niaounakis, 2020). This indicates that most consumer flexible packaging is already designed as **“recycle-ready” packaging**.

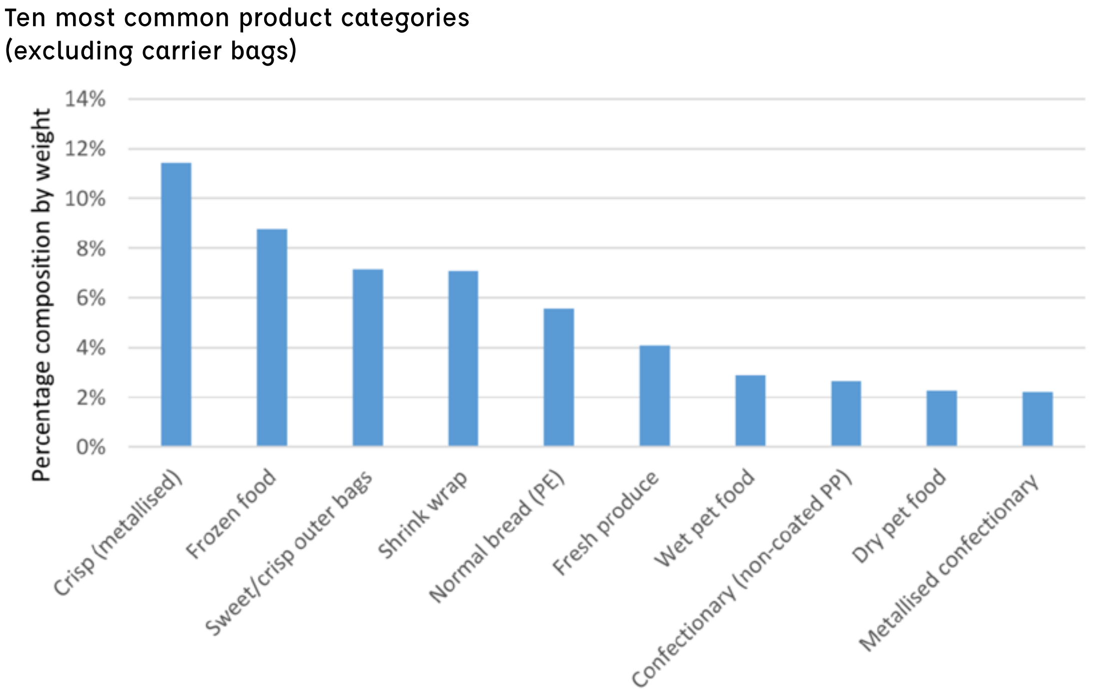


Figure 19: REFLEX Project

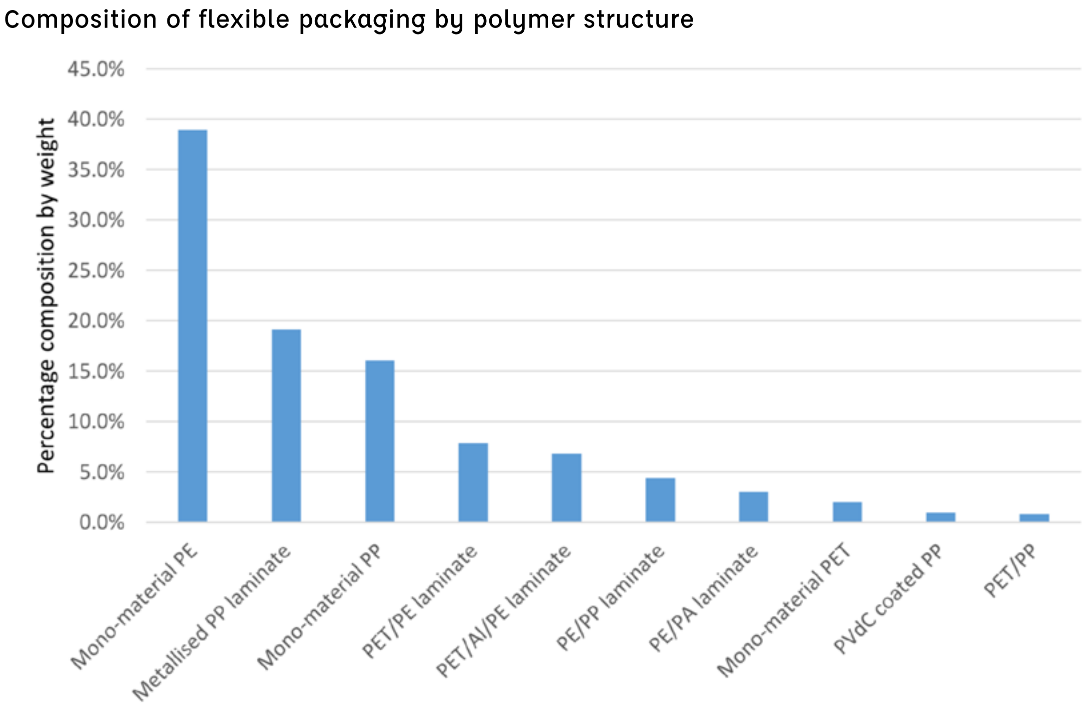


Figure 20: REFLEX Project

2.2 Constraints of recyclability of flexible packaging

Flexible films have several constraints, which make them more of difficult to recycle. The biggest challenge is the structure of the flexible films, that a multilayer film can be made of up to 9 layers, in addition to ink and additives. A multilayer film doesn't always contain one single material from a single family of polymers, but can be a mesh of plastic, paper and even metallic layers, most likely aluminum. Some barrier layers, if under a certain threshold doesn't effect the recyclability of the flexible packaging. For example, EVOH, if used under or equal to 5% in total weight of the film, and is combined with a structural layer of polyolefinic (PE/PP) resin can still be considered "recycle-ready", according to RecyClass. Even though, during the sorting process in the material recovery facilities, it is extremely difficult to identify, if the film consists of many materials or a single material and correctly send it to the correct batch. Therefore, even if the film has a mono-material structure, it is most likely to be sent off to energy recovery or landfilling.

A second constraint of the flexible films in the recovery facilities are that they get caught up in the machinery and entangle, blocking the mechanism. This prevents other materials to be recycled as well, creating a time loss, hence an economical loss for the material recovery facilities (MRFs). Therefore, for the MRFs it is more profitable to disregard the flexible films with the current technologies. In some cases, the flexible films are analyzed only if they have a dimension superior to an A3 sized paper.

Mechanical and chemical recycling of the flexible films are possible, although require specialized treatments. New technologies are necessary for a more efficient recovery for the flexible plastics. In 2019, several companies emerged that were capable of recycling flexible packaging, but the processes used are new and mostly still being in the development stage. Being relatively new, these methods can only recycle materials efficiently under a certain quantitative threshold.

2.3 End market for flexible films (State in 2020)

The flexible packaging market has the largest share in the packaging sector. In 2018, globally this packaging format made up to 33% of all packaging. It is estimated that global market for flexible packaging will have an average annual growth rate of 4% each year from 2019 until 2024. Starting from 2019 the market volume of flexible packaging will grow from 29.9 million tonnes to 36.4 million tonnes in 2024.

Currently, the market for recycled flexible packaging material is almost non-existent. Recycled PET used in bottles and soft-drink containers is currently dominating the recycled plastic packaging market.

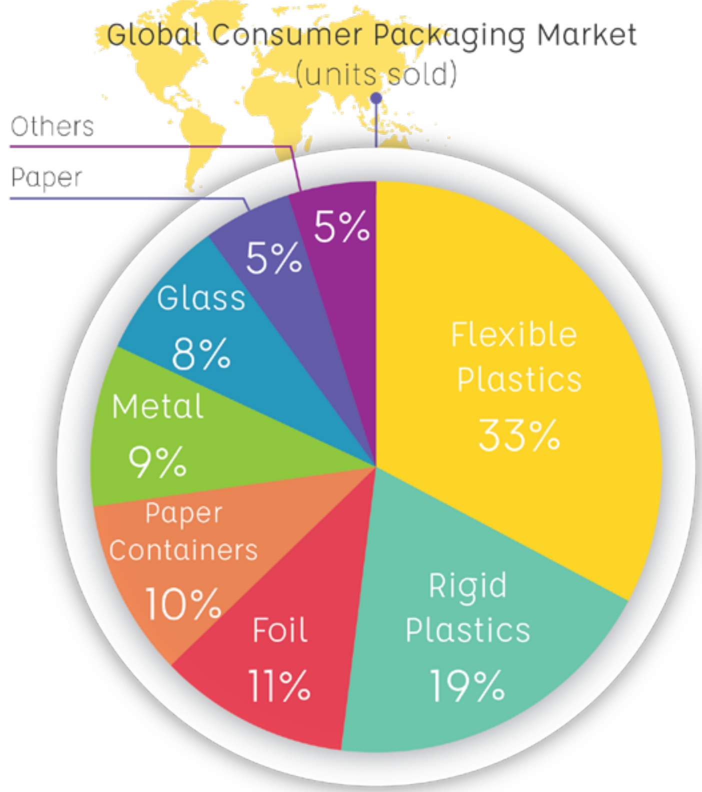


Figure 21: Citybank Research Group

Mostly, flexible films are recycled from B2B sources, such as films from agricultural or industrial applications, and not of those from packaging. Possible high levels of contamination, from municipal collection of waste streams, lowers the quality of the recycled material. Recycling films from B2B sources is more convenient for plastic converters from end market, due to larger and cleaner films. In fact, in Europe only 31% of all LDPE is being recycled and 87% of the recycled films in Europe is arriving from B2B fraction of waste streams.

Most of the packaging produced is for cases that require contact for food. Due to safety regulations, currently it is not possible to use recycled flexible films to reproduce food packaging. This is one of the major issues why there is not a large end-market demand for recycled materials from flexible films (FIACE). As such, it is indicated that flexible packaging is bound the be recycled in an open-loop recycling process. **Open loop recycling** signifies that the material recycled from a product is not shaped into the original product, but instead is used to produce a completely different product or can even be used in a different industrial sector. In contrast, **closed-loop recycling** instead is when the recycled material is used to produce the original product. The new product can be a mixture of recycled and virgin materials or can be made out of completely recycled materials. One of the main and most widespread examples for closed-loop recycling for plastics is the PET bottles.

It is important to point out that overcoming the constraints of recycling the flexible packaging is not nearly enough to create a circular economy for this material. Creating a higher value for the recycled material, as well as a growing end market are crucial components of a working circular economy.

As the flexible packaging market has been exponentially growing (currently polyolefins taking up to 50% of all plastic packaging), and as European recycling targets for plastic packaging for 2030 is 55%, it is clear that there will inevitable be a growing end market for recycled flexible packaging.

2.4 Advancements on recyclability of flexible films and multilayer materials

There are several evaluations of existing systems, that are being modified and adapted to mechanical recycling as a complementary option for post-consumer flexible packaging. These technologies are not yet fully developed in an industrial scale but they are a leap forward to create value out of waste packaging films.

Saperatec
Chemical solvents to separate the layers of multi-material packaging

Saperatec, modified a solution that was initially developed for rigid packaging solutions. This development is being extended further to flexible packaging. Through a chemical liquid solution the layers of the multilayer packaging are separated using a low-energy mechanical method.

APK AG
Newcycling - Dissolving the polymer flakes in a solvent (Chemical recycling)

Newcycling is a solvent-based chemical recycling technology that enables multi-layer packaging to be recycled back to its original polymer state. APK is able to create LDPE re-granulates that have similar properties to a virgin polymer.

Enval
Microwave induced Pyrolysis (Chemical recycling)

Enval's recycling method is focused on recovering aluminum laminates sandwiched between plastic layers. Shredded multilayer material is mixed with carbon. Through microwave oyrolysis, the plastic layers are degraded to a mixture of hydrocarbons,

while aluminum layers remain undamaged. From this process aluminum, oils (which derived from the degraded plastics) and gas are obtained. While gas can be used to generate electricity, the oils can be used as fuel or feedstock.

2.5 Recycle rates of flexible packaging

2.5.1 Europe

Globally, a true circular economy for flexible packaging doesn't yet exist. While flexible films used in sectors other than packaging are mostly being recycled, while the films in packaging industry are being discarded due to many constraints and lack of technological improvements in material recovery facilities.

LDPE Packaging Recycling Rates in Europe
(2018 data)

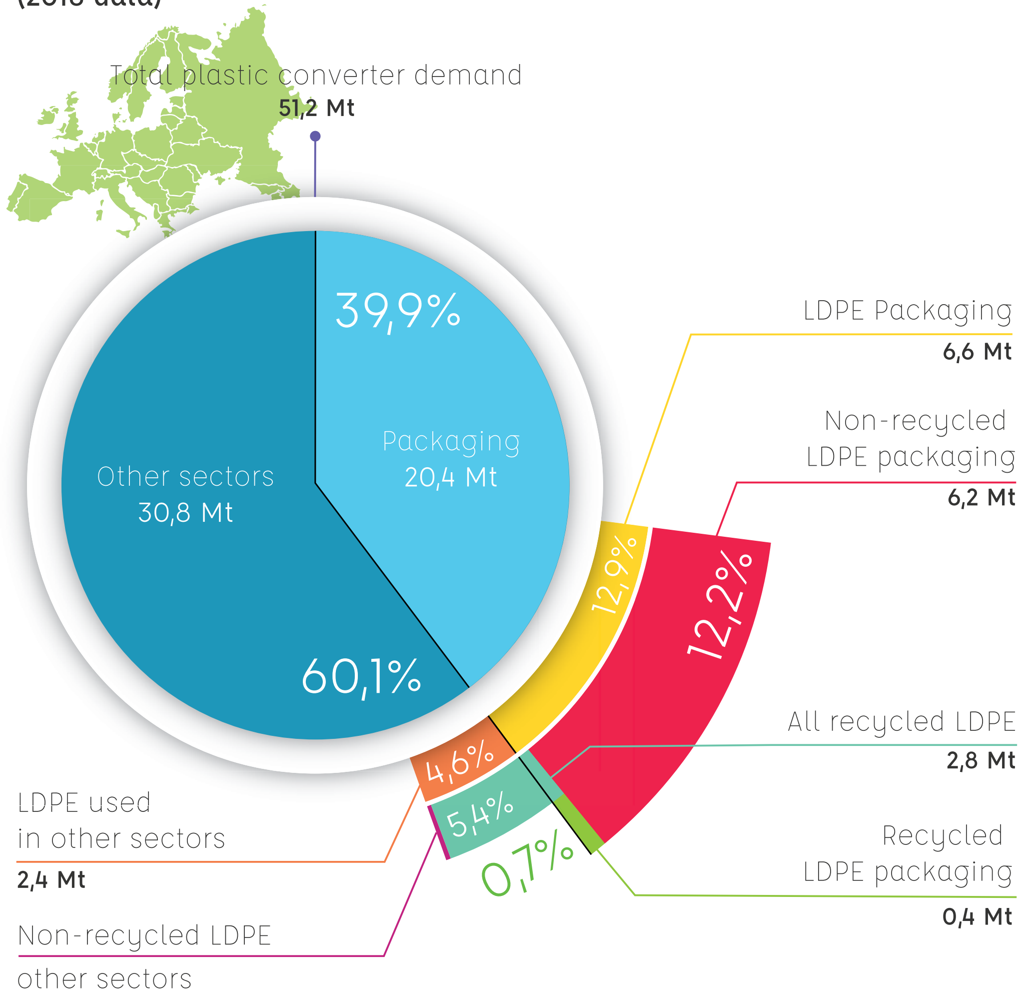


Figure 22: Chart created based on the data from FPA, PlasticsEurope and Niaounakis (2020)

The chart below, is plotted according to 2018 data. It shows the amount of production in packaging sector and recycle rates of the most common polymer resin used in flexible packaging, which is low density polyethylene (LDPE).

According to the chart, 6.2 million tonnes of LDPE flexible packaging is not recycled, therefore either sent directly to energy recovery or to landfills.

Many global associations formed in order to create value out of flexible packaging waste. In Europe, this movement is lead by the CEFLEX initiative. CEFLEX is a consortium, joined by many stakeholders from the plastic industry, consisting of material producers, film producers, brand-owners, retailers, collectors, sorters, recyclers, suppliers and end users.

2.5.2 Italy

In Italy, post-consumer flexible packaging has a fixed recycling stream, as well as some undergoing experimental streams, made by the consortium CorePla under CONAI.

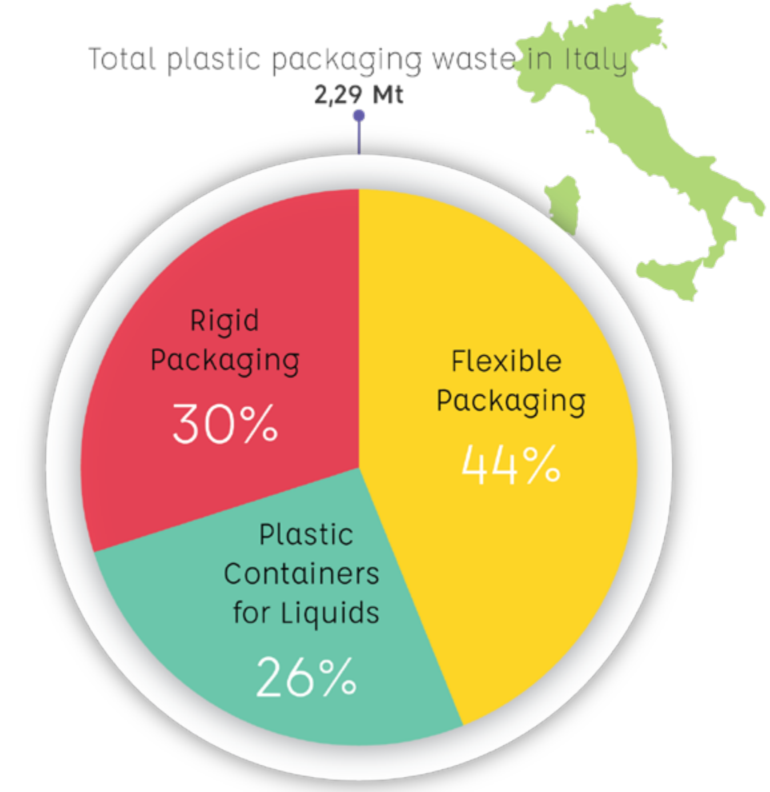
Fixed streams are:

- Colored films of any dimension (FIL/C)
- Transparent films of dimensions bigger than an A3 paper. The main reason to this is that there is not enough primary flexible transparent packaging that is worth creating a waste stream for.

Currently undergoing experimental streams are:

- Transparent, colored, opaque films smaller than an A3 measurement which are mixed, mono-material or multi-material flexible packaging (up to 7% other materials and 3,5% metallized layers are accepted). (SELE FIL/S)
- Transparent, colored, opaque films smaller than an A3 measurement which are mixed, mono-material or multi-material flexible packaging (up to 5,5% other materials and 2% metallized layers are accepted). (SELE FIL/S)

In Italy, 44% of all packaging is flexible films, while 70% of all flexible packaging is in the primary and 7% is in the secondary packaging category. Carrier bags are not considered as flexible packaging, as through a legislation in 2011, all shoppers are made of biopolymers (3% of all plastic packaging in Italy).



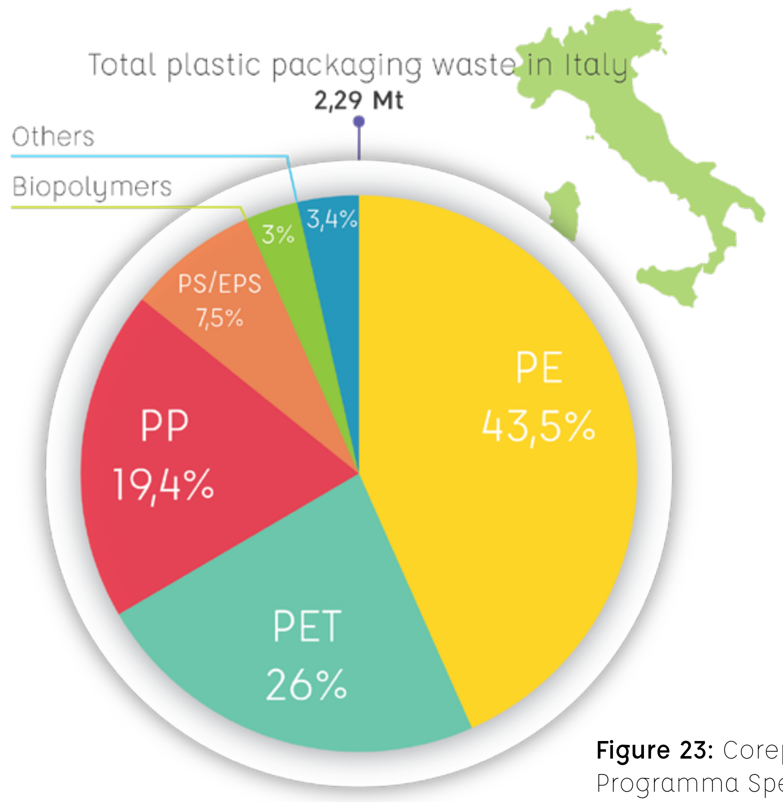


Figure 23: Corepla, Programma Specifico di Prevenzione 2019-2023

PRODOTTO	2016	2017	2018	var. % 18/17
PET	211.472	235.257	244.809	4,1%
HDPE	65.312	68.472	69.967	2,2%
FILM	60.698	71.502	84.608	18,3%
FILS & IPP	65.985	59.130	72.062	21,9%
IMBALLAGGI MISTI	116.897	120.090	140.183	16,7%
SRA	7.968	7.774	4.549	-41,5%
TOTALE	**528.331**	**562.224**	**616.178**	**9,6%**

Figure 24: Corepla, Programma Specifico di Prevenzione 2019-2023

One of the most prevalent resins in plastic packaging in Italy is polyethylene (PE), 43,5%, followed by PET and PP.

Corepla recycled a total of 643.544 tonnes of municipal plastic packaging in the year of 2018, of which 27.366 tonnes arrived from commercial and industrial waste streams. 14% of all plastic packaging recycled by Corepla are films, which is equivalent to 84.608 tonnes of flexible packaging.

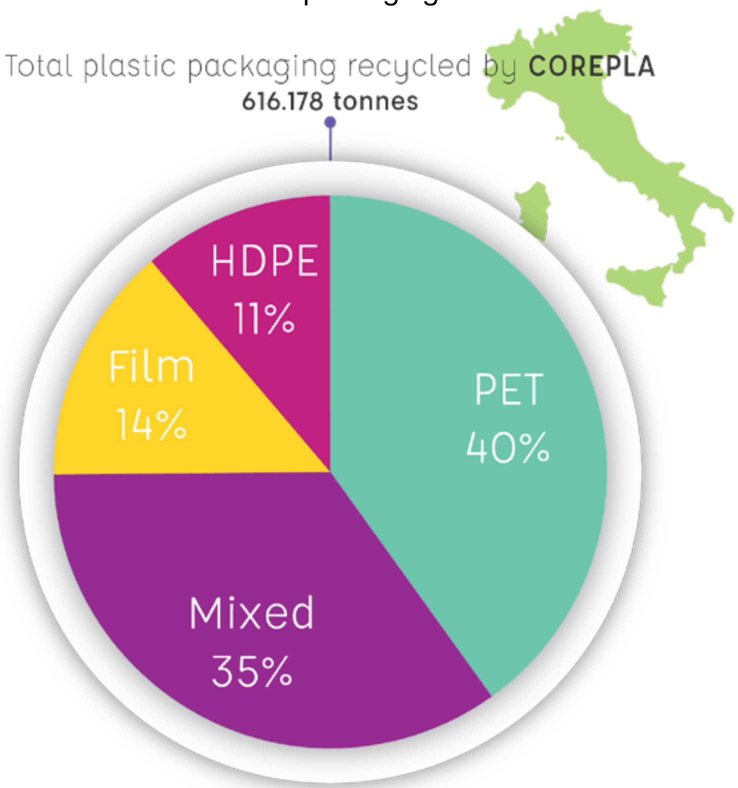


Figure 25: Corepla, Relazione sulla gestione 2018

These batches of waste streams for flexible packaging are not further sorted into polymer resin types and are all mixed batches, therefore have a low sales value.

Films coming from any sectors other than packaging have a higher recycle value (because the recycling of post-consumer packaging is mostly focused on recovery of PET and HDPE containers). Therefore, it has been a challenge for CorePla to valorize flexible packaging arriving from municipality waste streams. In fact, in the past years, sales of post-consumer plastic packaging even had negative values. In 2018, a batch of flexible packaging had a value of 2 euros per tonne of waste material. The marketable value of post-consumer flexible films has dropped drastically due to China-ban. These film batches don't have a constant buyer, and the material is sold every three months through auctions.

In Italy, it is calculated that of 2,29 million tonnes of post-consumer plastic packaging, 1,0 million tonne is of flexible films. Corepla manages 51% of the municipal plastic waste collection, and 63% of the recycling of all packaging in Italy. In 2018, Corepla recycled 84.608 tonnes of post-consumer flexible films. Assuming that Corepla have received at least 51% of all post-consumer flexible films, it is estimated that

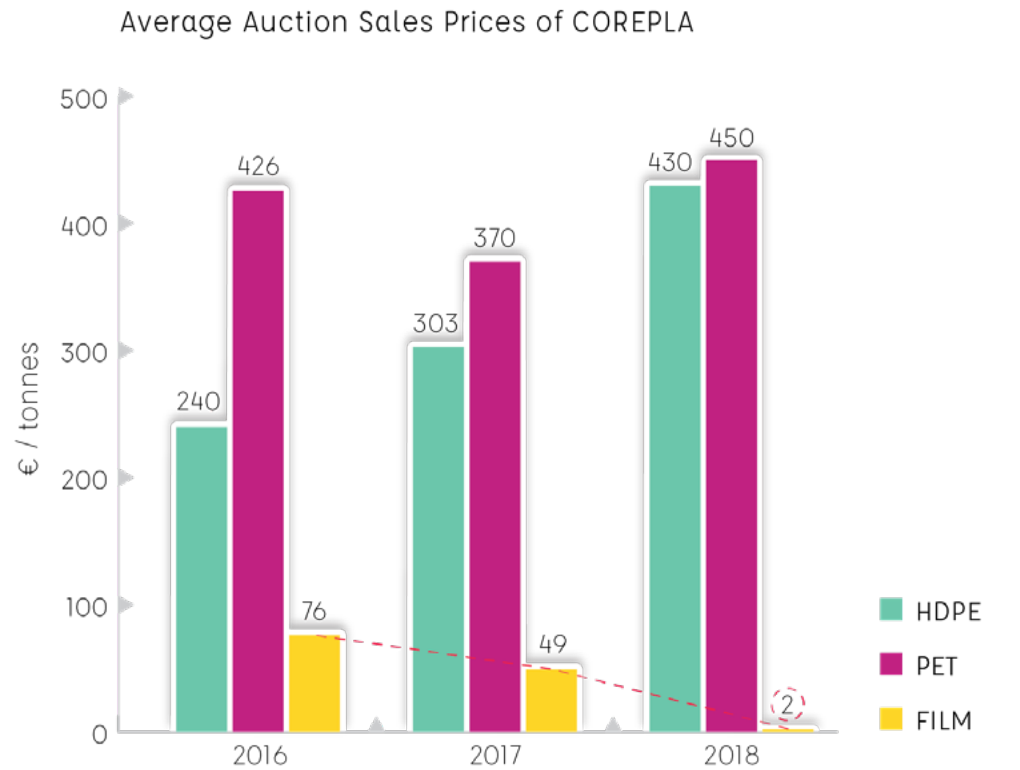


Figure 26: Corepla, Relazione sulla gestione 2018

approximately 450.000 tonnes of post-consumer films were not recycled, therefore were either sent to energy recovery or were landfilled. Further estimations were made for independent recyclers. In conclusion, it is estimated that **in Italy at least 870.000 tonnes of post-consumer flexible films are currently not being recycled.**

Flexible Packaging Recycling Rates in Italy (2018 data)

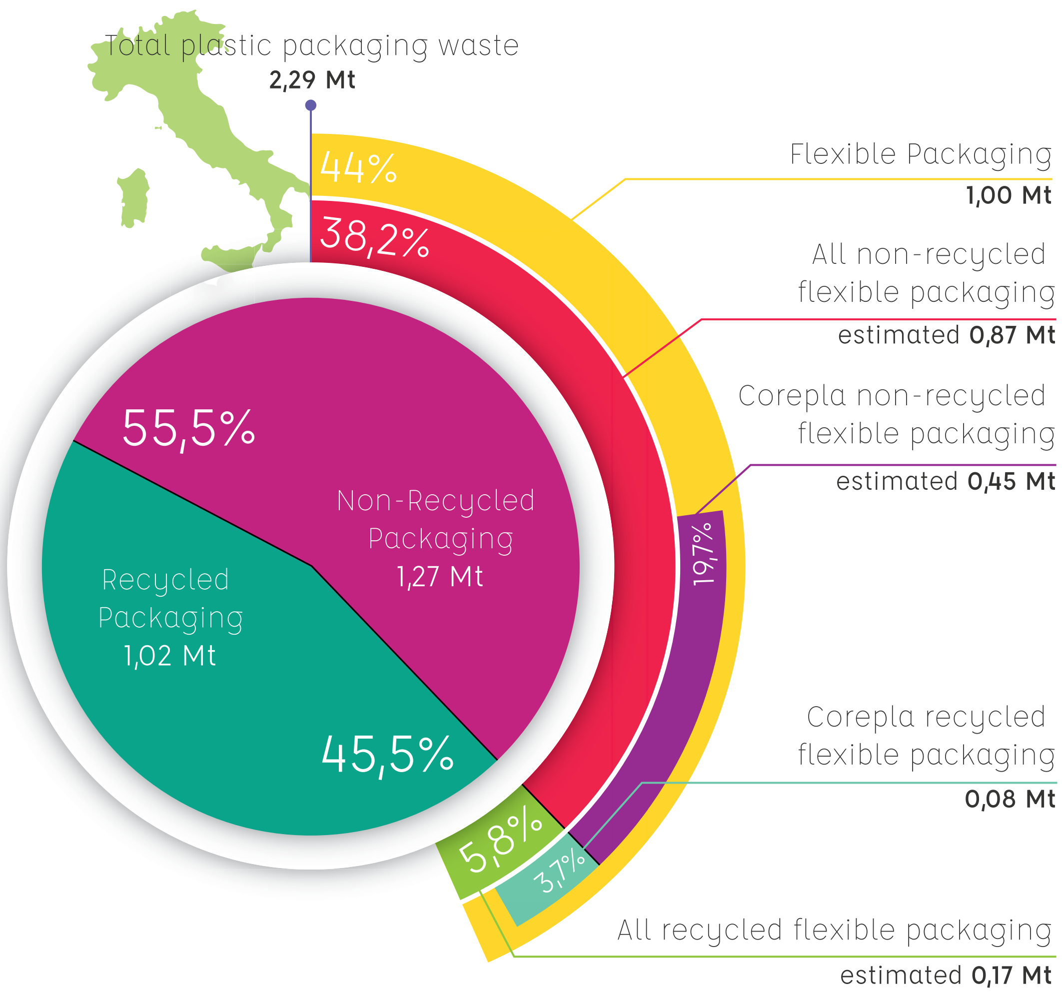


Figure 27: CorePla and PlasticsEurope

CHAPTER 3

Drop-off Collection Schemes

Figure 28

3.1 Consumer drop-off systems

Municipal waste recovery starts from the collection of the waste. Municipal post-consumer waste mostly consists of packaging materials. In this matter, consumers play a big role in the collection of the material. The responsibility of creating a circular economy starts from them. Therefore, creating an awareness in the consumer towards "waste" actually being a valuable material is under the responsibility of all the stakeholders in this sector.

The collection and transportation of the municipal waste contributes to the emission of greenhouse gasses. It is not only the volume of the collected waste stream that plays a great role, but also the weight of the material that is being delivered during the transportation phase, from households to the pre-treatment, sorting or material recovery facilities. Therefore consumer-level sorting is the first phase of municipal waste recovery. For example, any material in the plastic stream that still contains a considerable amount of food residues contributes to the corruption of the material recovery system. Most of the organizations buy and re-sell the waste material which is to be recycled, based on the weight of the waste. Any non recyclable material or material that doesn't belong in the dedicated waste stream (for instance, food remaining in a plastic container), which was pre-sorted by the consumers, has a negative effect on the circular economy.

There is another option to collection of the waste by the municipalities, which relies on the consumers: The consumer drop-off systems (also called bring systems) (section 1.3.2). The drop-off systems are dedicated to a single type of waste material or a packaging format. Its true purpose is to collect the certain type of recyclable material with a minimum amount of contamination level. This leads to a higher quality of recycled material to be sold in the end-market.

There are two types of waste drop-off systems. The main mechanism that accepts the waste from the consumer can either be manual or automated. Usually, these systems are implemented in retailers such as supermarket chains or buildings that are accessible by the public. In a manual system, typically, the material is accepted by an employee working in the retailers', while in an automated system the material is accepted by a reverse vending machine. It is optional to have a rewarding system for the consumer that brings the material.

Currently, bring systems around the world are mostly dedicated to collecting beverage bottles made of PET and glass; either of which can be refillable or non refillable, aluminum cans and empty batteries. The costs of implementing these systems are theoretically meant to be balanced out by the material revenues (revenues gained by re-selling the recyclable materials to re-converters).

Voluntary systems

A voluntary drop-off system can be managed by any company, such as brand-owners, non-profit organizations, retailers or others. There are several advantages to voluntary bring systems that are voluntary but it should be pointed out that they are not profitable systems.

As an example, a study was conducted in the United Kingdom by ERM in 2008, analyzing the advantages of such a system. Tesco, a supermarket chain in UK, placed 85 reverse vending machines (of Tomra) inside of their stores. It was a voluntary scheme created in order to encourage the recycling of packaging. However, it was reported by Tomra that the initial outlay, in addition to the cost of the reverse vending machines as well as the operating costs, were not balanced by the material revenues. Therefore, the main incentive was only to have good publicity, along with customer and staff satisfaction derived from the promotion of recycling. The customers received loyalty points by returning the empty packaging.

Mandatory systems

Mandatory systems are usually managed by governments, which are accepted through legislations, nationwide. They are implemented through a national deposit scheme, where acceptable waste materials have an additional cost paid by the consumers. The consumers reacquire the deposit value once they return the packaging or the recyclable waste material to the designated machines or retailers. The main motive to add this deposit value is to have a more controlled system, and to avoid market distortions: In a system without a mandatory deposit value, participating brand-owners would have a different price range for their product when compared to non-participating brand-owners. Therefore, it was agreed by the stakeholders that id a national deposit scheme were to be introduced, it would need to be mandatory (ERM, 2008). These deposit schemes currently are mostly implemented for beverage containers (PET or glass bottles, cans).

3.2 Deposit Refund Schemes for beverage containers in Europe

Mandatory drop-off systems can also be called as deposit-refund or deposit-return schemes (DRS). In Europe, there are ten countries that implemented deposit refund schemes nationwide, specifically for beverage containers. They have a very high success rate for collecting and recycling the packaging.

Jurisdiction	Data Year	Refund		Total Return Rate
		Local Currency	Euro and USD Equivalent	
Croatia	2016	0.5 HRK	€0.066 USD$0.07	Up to 87%
Denmark	2016	1-3 DKK	€0.13- €0.4 USD$0.15-$0.45	89%
Estonia	2017	€0.10	(USD$0.11)	82.7%
Finland	2016	€0.10-€0.40	USD$0.11- $0.45	92%
Germany	2015	€0.25	USD$0.28	98.4%
Iceland	2014	15 ISK	€0.11 USD$0.12	90%
Lithuania	2017	€0.10	USD$0.11	91.9%[ii]
Netherlands	2016	€0.25	USD$0.28	95%
Norway	2016	1-2.5 NOK	€0.13- €0.32 USD$0.12-$0.30	91.7%
Sweden	2016	1-2 SEK	€0.11-€0.22 USD$0.12-$0.24	84.9%[iii]

Figure 29: Reloop 2018

3.2.1 System

All deposit-refund systems (DRS) in Europe all work according to the same principles. As Norway is one of the leading countries in plastic packaging recycling, their deposit refund system will be used to explain the system.

The system is initially implemented through the introduction of high levels of taxes which ought to be paid by the brand-owners for the packaging that is sold in the market. There are two levels of taxes which must be paid by the brand-owners:

1. Base tax
Base tax is an initial tax that must be paid by brand-owners for every unit of single-use beverage packaging placed on the market.

2. Environmental tax
Environmental tax is a variable tax that is dependent on the recycling rate of bottles and cans in Norway. If the recycling rate is less than 25%, brand-owners must pay the full amount of the tax. Up to 95% of recycling rate, the tax rate proportionally goes down. Over 95% of recycling rate of beverage containers within' Norway, brand-owners will be exempt from the environmental tax.

There are additional costs for the system:

Handling fee:
The amount paid to retailers to compensate for the service costs of taking back post-consumer packaging.

Producer fee:
An amount paid by brand-owners for every unit of packaging placed on the market. This fee is calculated taking into account the economic balance of the deposit-refund system. Deposit refund systems are usually based on a non-profit scheme. Producer fee is an additional fee in case the material revenue and unredeemed deposits are not enough to balance the economic costs.

In Germany, the system works in a different manner, but with the same principles. There is no clearing system (a 3rd party that operates the system). The deposit refund system is operated by the producers and retailers. Furthermore, there are no handling fees, as the collected waste material (packaging) is owned by the retailers. Retailers make up for their service costs by receiving the material revenue.

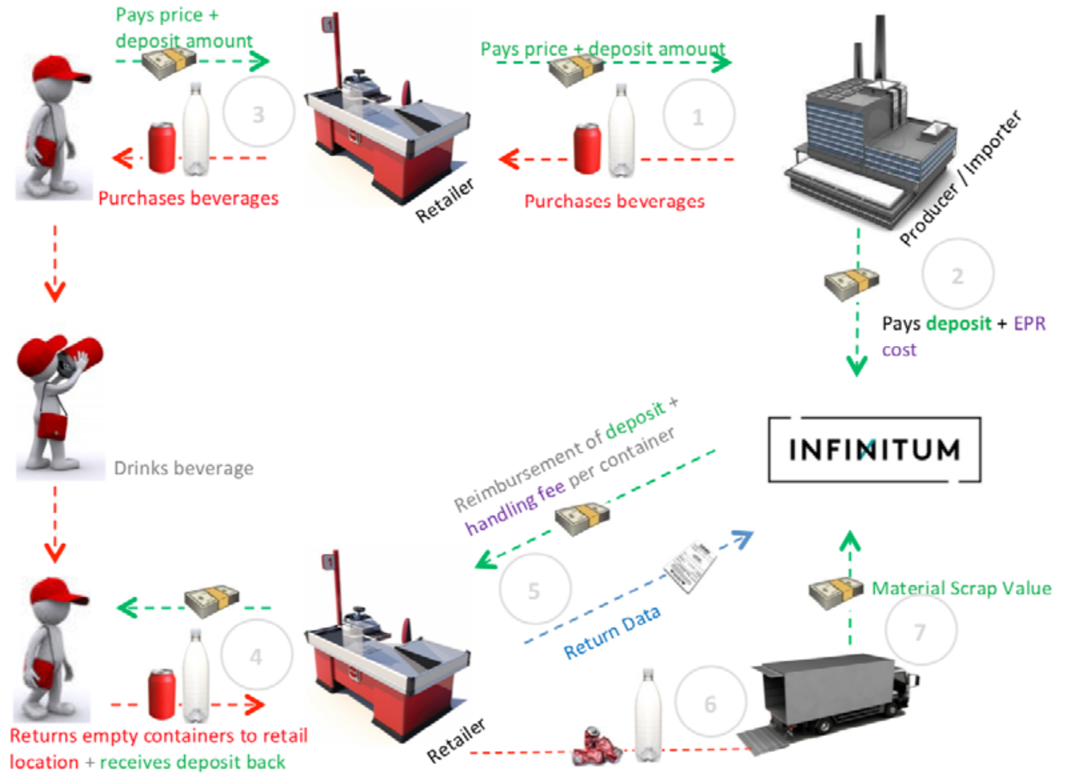


Figure 30: Reloop 2018

The deposit-refund system is initiated by the introduction of the deposit value by the brand-owner.

1. Retailer purchases the product with the deposit value from the brand-owner.
2. Brand-owner pays the deposit value and the producer fee to the clearing system (the system operator).
3. Consumer purchases the product and pays the deposit value.
4. Consumer returns the packaging to the retailer and receives the deposit value.
5. Clearing system receives the “return data” of the packaging from the retailer and reimburses the deposit value to the retailer as well as the handling fee.
6. Clearing system arranges the transportation of the waste from the retailer to the material recovery facility.
7. Clearing system receives the material scrap value (material revenue).

All the packaging that can be accepted through this system is marked with a logo (in Germany the **DPG logo**), to create an easy recognition system for the acceptable packaging, and to prevent any attempt of fraud.

3.2.2 Stakeholders

The stakeholders of the deposit-refund system are:

- **The government**, which has to decide and implement the deposit refund scheme through legislations. Additional taxes can be implemented on the packaging to encourage participation of the brand-owners and other entities. In some cases, the system alternatively can be operated by an entity related to the government, such as the ministry of environment.

- **Brand-owners**, which are the producers of the packaging. Their participation is a crucial part of the deposit-refund scheme.

- **Retailers**, which act as the service providers for the system. They manage the flow of the packaging, and communicate the packaging and deposit data to the central operator.

- **Clearing system**, which can be a dedicated entity to the deposit refund system, that manages and operates all the variables. They administrate, promote and advertise the deposit-refund system through marketing campaigns that inform the consumers about circular economy.

3.2.3 Targets

A deposit-refund system is one of the most efficient and closed-loop systems for beverage containers. The main target is always to achieve 100% recycling rate, which would almost be impossible through regular municipal post-consumer waste collection.

In a calculation made by Reloop (Morawski, 2019), it is estimated that through municipal waste collection:

if 95% of household in a nation have collection facilities,
and if 90% of households participate and contribute with 90% of recyclable material,
and if 90% of the material is left after removal of contamination,
=
the maximum amount of plastic material that can be recycled is 70%.

In the ten countries that implemented the deposit-refund system in Europe, the median rate of collection of beverage containers has reached 92% in 2018. Germany is currently the leading country with a collection and recycling rate of 98%.

3.3 Collection of beverage containers

3.3.1 Manual collection

Through a manual collection system, the post-consumer packaging is received at the check-out counters of retailers. The cashier places the packaging in a dedicated bag and gives the deposit refund manually to the consumer. The receipt data, along with the containers, are transported to a counting center, where all the packaging is counted and verified. The manual collection is often preferred by smaller retailers.

3.3.2 Automatic collection (Reverse Vending Machines)

Automatic collection is done through reverse vending machines. This machinery can have various dimensions and options. Retailers can have a dedicated backroom to store the material received through the reverse vending machine. This is a common option for reverse vending machines that accept refillable containers. Some vending machines can also have a compaction mechanism in order to store more containers inside. Although this option is more expensive in relation to reverse vending machines without compaction, the deposit value returned to the consumer may vary accordingly.

Containers that are accepted through reverse vending machines with compaction do not have to be re-counted at the counting centers.

With a reverse vending machine, the consumer can have additional payment options, for instance, direct payout with coins, through loyalty cards, or contactless payment Alternatively, they can choose to make a donation. Additionally, reverse vending machines can print out receipts, so that the consumers can receive the payment through the cashier of the retail store.

Figure 31: Reverse vending machines for different waste material

CHAPTER 4

A deposit-refund scheme for flexible packaging in Italy

WHAT

A system that creates a **circular economy** for **flexible packaging**.

WHY

There are too many **technical problems** with current technologies for **sorting** correctly and **recycling** flexible packaging.

HOW

By creating a **collection scheme** through **reverse vending machines** that **collect** and **separate** mono material and multi material films.

WHEN

The calculations are done using **2020 to 2023 data estimations**, althought the project can be in action only **earliest in 3 years,** for the preparation of the system and **national scale legislations**.

WHERE

Main **retailers** (supermarkets) or **publicly** accessible **indoor** buildings, **in Italy**.

4.1 Objectives

The primary objective of this thesis is to understand the constraints of recycling post-consumer flexible packaging with current technologies (section 2.2). To briefly list them:

- Possible multilayer - multi-material structure of the flexible packaging.
- The current technologies are not sufficient to correctly and efficiently recognize the structure of the flexible packaging in order to sort it in the correct material batch.
- Flexible packaging can entangle within the machinery and the conveyors used in sorting and material recovery facilities during processing. This can lead up to blocking the whole recovery system.
- Extra processes are needed to recycle for multi-layer packaging. This can lead up to causing the recycled material costing more than the virgin material, creating a paradox. Therefore, spending resources to recycle a material would be in vain.
- There is currently no end-market availability for recycled post-consumer flexible packaging.

The second step is to propose a collection scheme that overcomes most or all of these constraints to facilitate recyclability and to take a step towards creating a circular economy for flexible packaging. It is necessary that this collection scheme already manages to sort mono-material film structures (mono-layer or multi-layer) from multi-material film structures (only multi-layer).

4.2 System in Italy

Deposit refund systems and voluntary systems (based on collection through reverse vending machines) were analyzed and compared in order to create a proposal for the most expedient consumer drop-off scheme for Italy.

Taking into consideration both advantages and disadvantages of both system types, it became clear that a deposit refund system should be implemented. Adding additional features from a voluntary system increases sustainability of the system to create a circular economy for flexible packaging for Italy.

The deposit refund system for flexible plastic packaging in Italy is designed as a **non-profit scheme.** It works only for the purpose of creating a true circular economy for plastic flexible films.

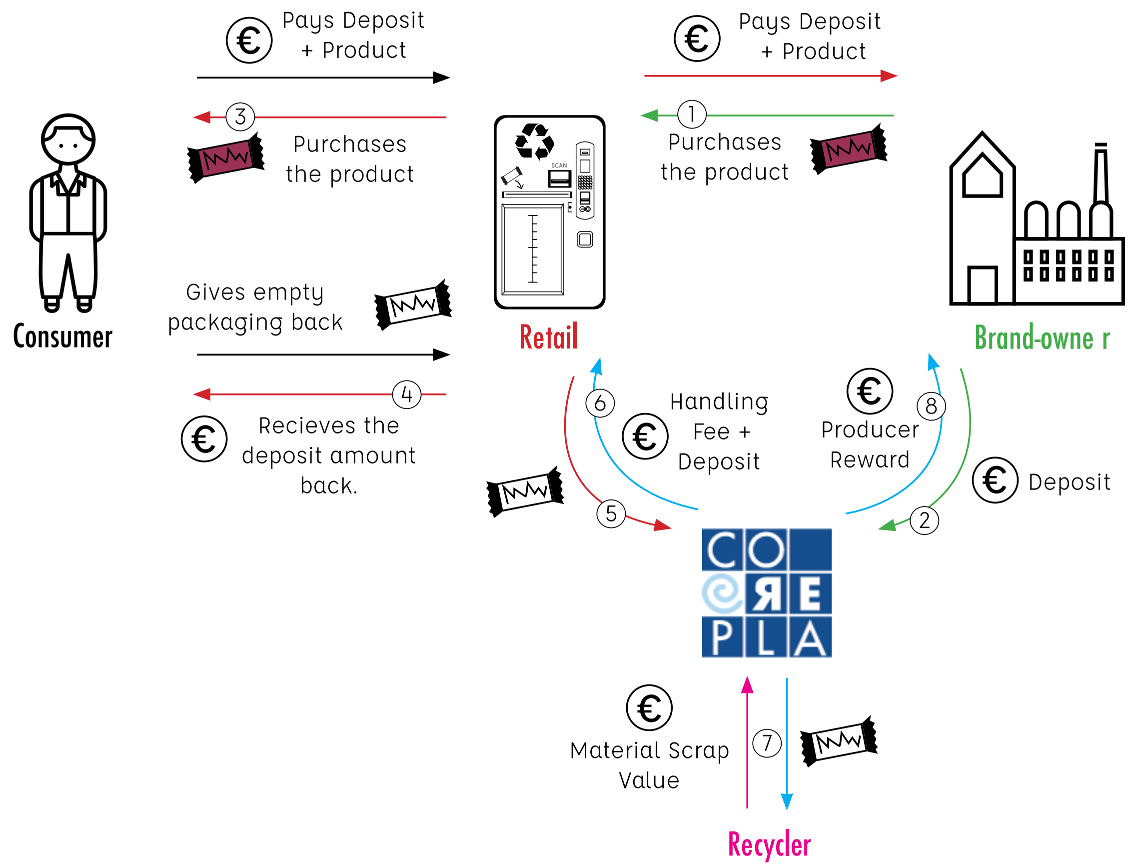
DEPOSIT REFUND SYSTEM (DRS)	VOLUNTARY SYSTEM (UNIVERSAL)
Project will be for the **future** because all existing flexible packaging must be **modified** and **printed**	Project will be **current** and can work for **any flexible packaging**.
Not all films have prints on it: **Additional costs** for the **brand-owners** (producers).	RVM will be **more expensive** due to recognition technologies.
The system is usually implemented through **legislations**, therefore **government** participation is **mandatory**.	It will require the **cooperation** of the **municipality** (or government) for **collecting** the waste material.
Through legislation, **companies** are **required** to **participate**.	**No active participation** is **required** by **companies** or other business entities.
The "**reward**" of the packaging is predefined by the "**deposit**" taken from the **consumer**. (Making it a more **controlled** system)	Rewarding system will work based on the **weight of the material** which is inserted.
It can be managed by a **3rd party**, through legislations government involvement is obligatory.	Could be **managed by anyone**: Brand-owner, Government, 3rd party
A system proven to be **fully functional** with a logo and a universal barcode currently for **PET bottles**, in 10 countries (only Europe).	A **voluntarily** operated system with many **variables**.

Advantages
Disadvantages

The collection of the post-consumer flexible packaging will be handled by reverse vending machines that are designed dedicated for this type of packaging. The brand-owners that are participating in the system must mark their packaging with a dedicated logo, QR code or a barcode for an easy identification. The reverse vending machine contains a sensor technology specialized in identifying multi-layer plastic film structures, so that also the flexible packaging from non-participant brand-owners

can be accepted, sorted and recycled.

1. Retailer purchases the product with the deposit value, from the brand-owner.
2. Brand-owner pays the deposit value and the producer fee to the clearing system (the system operator).
3. Consumer purchases the product and pays the deposit value.
4. Consumer returns the packaging to the retailer and receives the deposit value.
5. Clearing system arranges the transportation of the post consumer packaging from the retailer to the material recovery facility.
6. Clearing system reimburses the deposit value to the retailer as well as the handling fee to the retailer.
7. Clearing system receives the material scrap value (material revenue).
8. Brand-owners receive a producer reward for their participation.



4.3 Comparison of DRS Scheme in Italy to Norway

The main difference between the Norwegian and Italian system is the producer fee/ reward.

In Norway, a producer fee is introduced in the system in order to balance the costs and revenues in a non-profit mechanism (section 3.2.1). The brand-owners must pay this additional fee for every single unit of packaging that they place on the market. This cost is minimal in comparison to the tax rates that a brand-owner must pay in case they are not participating in the deposit refund system.

In Italy, a producer reward is introduced instead of a producer fee. This cost is based on the total savings of the non-profit economic balance. For the voluntary collaboration of the brand-owners, they are rewarded 10% of the total income of the deposit refund system.

In both systems, the deposit flow is initiated by the brand-owners.
It is not mandatory for brand-owners to collaborate in the either system, while both systems provide advantages to brand-owners in case of participation.

Both of the systems have a centralized operation system. It is administered and operated by a clearing system. (Infinitum in Norway and CorePla in Italy)

4.4 Stakeholders

4.4.1 Clearing System

The clearing system is the operator of the deposit refund scheme in Italy.

Main activities of the clearing system are:

- Administration and operation of the whole deposit refund system in Italy.
- Integration of retailers and brand-owners in the system.
- Communication and marketing to promote and inform the consumers about the working principles of the system and to create awareness about circular economy for flexible plastic films.
- Transportation of the collected post-consumer flexible packaging.
- Recovery and valorization of the material.

- Finding additional end-market options for the flexible packaging material to be reconverted into new products.

Advantages of the deposit refund scheme to the clearing system are:

- Helping the government in meeting recycling targets.
- Creating new job opportunities and positions.
- Help expanding the end-market for recycled materials, specifically for flexible packaging films.
- Sustaining a circular economy for plastic flexible packaging.

4.4.2 Brand-Owners

Participation of the brand-owners is crucial for the deposit refund system for flexible packaging in Italy. For analyzing the main role and advantages for the brand-owners, Ferrero Spa has been taken as a case study.

The main activities of a participating brand-owner would be:

- Investments on modifying the graphics on their packaging, adding a deposit logo.
- Correctly encoding packaging material and weight information within the barcode or QR Code on every single flexible packaging unit.

Main advantages for the brand-owners would be:

- Good publicity for the brand, creating additional public press.
- Less packaging containing the brand name will be seen on the streets. This phenomenon is called “branded litter”.
- Higher reputation in global company rankings.
- Company engagement and additional action in sustainable packaging.

4.4.3 Retailers

As retailers, in this thesis mostly considered hypermarkets (>4500 m^2), superstore mini-hypermarkets (2500-4499 m^2) and supermarkets (400-2499 m^2).

The main activity of the retailers will be as following:

- Labor for emptying and operating the reverse vending machine(s).
- Payment to the customers from cashiers if the reverse vending machine gives out receipts to track deposit data. Retailers can also use dedicated loyalty cards for deposit payment.
- Electricity and wifi supply for the reverse vending machine.
- Keeping the reverse vending machine clean.

The main advantages for the retailers are:

- Creating additional customer loyalty (therefore, having returning customers).
- Increasing staff satisfaction (Established from the case study of Tesco, in a research made by ERM in 2008)
- Increasing customer satisfaction.
- Possible profits from handling fees paid out by the clearing system.

4.5 Collection System: Reverse Vending Machines

The main function of the reverse vending machines will be to collect the post-consumer flexible packaging and to sort them into two groups:

Mono-material flexible films (which can either be monolayer or multi-layer)
Multi-material flexible films (which can only have a multi-layer structure)

Following the market trends and the evolution of flexible packaging, brand-owners are commitmented to be environmentally sustainable and to only put packaging in the market that is "recycle-ready". Ferrero's sustainability commitment can be given as an example, stating that by 2025, they will have all their packaging from reusable, recyclable or compostable material. If these commitments are complied by all the brand-owners, the sorting system integrated in the reverse vending machines can be re-programmed into identifying and sorting mono-material polypropylene (PP) from mono-material low density polyethylene (LDPE).

Amount of reverse vending machines to be placed in Italy

The collection method of the post-consumer flexible plastic packaging will be

Totale Italia - 2018	Numero esercizi	%
Ipermercati (>8000 mq.)	92	0,16
Ipermercati (4500/7999 mq.)	270	0,48
Superstore mini-iper (2500/4499 mq.)	538	0,95
Supermercati (400/2499 mq.)	8.202	14,43
Libero servizio (100/399 mq.)	11.645	20,49
Discount	5.207	9,16

Figure 32: FederDistribuzione

	RVMs per City with...	Amount of Cities/ Municipalities	TOTAL	CITY	TARGET RATIO Population/#RVMs
2.856.133	714	1	714	ROMA	4000
1.378.689	345	1	345	MILANO	4000
959.188	240	1	240	NAPOLI	4000
875.698	219	1	219	TORINO	4000
663.401	166	1	166	PALERMO	4000
578.000	145	1	145	GENOVA	4000
390.636	98	1	98	BOLOGNA	4000
378.839	95	1	95	FIRENZE	4000
320.862	80	1	80	BARI	4000
311.584	78	1	78	CATANIA	4000
260.520	65	1	65	VENEZIA	4000
257.993	64	1	64	VERONA	4000
232.555	58	1	58	MESSINA	4000
>100.000	25	20	500		4000
>50.000	13	77	1001		4000
>30.000	8	151	1208		4000
>20.000	5	139	695		4000
>10.000	2	706	1412		5000
>5.000	1	1186	1186		5000
TOTAL # Municipalities >5.000 in Italy		2292			
		Total amount of vending machines	9369		

implemented through an automated system, which is reverse vending machines/ RVMs). In order to obtain the required amount of reverse vending machines that must be placed in retailer locations, the total amount of retailers in Italy that are at least of the size of a supermarket (>400 mq) has been used as a basis for the following calculations.

An additional calculation has been made in order to obtain a target ratio of a towns'/ municpalities' population to the amount of reverse vending machines required to be placed in that single town/municipality. If this ratio is set to 4000 people per reverse vending machine, we get the average amount of reverse vending machines that must be placed in a town this can be calculated.

As the target ratio of people using one reverse vending machine is 4000 poeple towns with a population more than 5000 people, it is calculated that at least 9369 reverse vending machines are needed to obtain this ratio. This amount is only used as a verification method of the total amount of reverse vending machines that might be needed in Italy.

The total number of supermarkets in Italy that are bigger than 400 m^2 is 9102. Assuming that the hypermarkets in average will need two instead of one reverse vending machine per store, the total amount of reverse vending machines to be placed in Italy is estimated to be 9464.

Recognition technology

The reverse vending machines will have an integrated technology which allows them to accept packaging from non-participating brand-owners. In order to accurately analyze and identify the possible multilayer structure and chemical identity of layers of a plastic flexible packaging, an Fourier transform infrared spectroscopy (FT-IR) sensor is needed (Morris, 2017, p658).

Some technologies that can be found on the market were analyzed for the purpose

Articolo	Quantità	Codice	Descrizione	Costo Unitario IVA esclusa	Costo Totale IVA esclusa
			Neospectra Micro Dev Kit		
1	1	SWS62231-2.5-DVK-P		€ 2.690,00	€ 2.690,00
			Neospectra Micro Sensor		
2	1	SWS62231-2.5-16	MOQ 1pz	€ 2.315,00	€ 2.315,00
3	1000	SWS62231-2.5-16	MOQ 1000pz	€ 870,00	€ 870.000,00
4	5000	SWS62231-2.5-16	MOQ 5000pz	€ 538,00	€ 2.690.000,00
5	10000	SWS62231-2.5-16	MOQ 10000pz	€ 462,00	€ 4.620.000,00
6	1	SPESE	Spese di spedizione ed assicurazione merce.	incluse	incluse

Figure 33: NeoSpectra

of this thesis. The NeoSpectra sensor from SiWare systems had the fitting specifications for the industrial application inside a reverse vending machine. For a more accurate cost estimation of the reverse vending machines, the Italian distributor, Optoprim, was contacted for a price range for different quantities of batches. After directly talking to engineers from SiWare systems, it was established that many tests and detailed experimentation must be conducted in order to confirm the proper functionality of the NeoSpectra sensor in a reverse vending machine, by recording reference spectrum values of different multilayer films compositions. It must be considered in the product design phase of the reverse vending machine, that the NeoSpectra sensor was designed to work in direct contact with the material that is to be analyzed.

4.6 Advantages of the system

A deposit refund system for flexible packaging can have many possible advantages for all involved stakeholder and actors in the recycling system. In addition, this system for flexible packaging is analyzed and compared according to the roadmap created by the CEFLEX initiative to create a circular economy for flexible packaging.

Consumer's perspective	**Educational** by raising **awareness** for **recycling** and the **value** of the material.	**Rewards** and **contributing** to the **circular economy**	
Recycler's perspective	**Easier to manage** already **sorted** items.	**More materials** are **recovered**. (The ones which are less than 5cm are not discarded). It is **proven** by the **deposit refund system** for **beverage bottles**.	The **technological aspect** of the existing machinery remains **untouched**. **No** additional **investments** must be made to the **sorting centers**.
Brand owner's perspective	**Good publicity** for the brand. (Public press)	Possibility of adding the initiative in **CSR (Corporate Social Responsibility)** document of the company.	
Material re-converter's perspective	Creating a more **structural, economical market** for PE/PP films.	**Larger variety** of **recycled PE/PP** material will be **available** in the **market.**	**Higher quality** of recycled material will be converted.
Government/ municipality's perspective	Possible **cost efficiency** for recovery of waste.	It's an efficient system to meet **recycling targets**.	Can gain **additional data** about recycling, packaging use and consumer behaviour.

CEFLEX Project - Roadmap to circular economy for flexible packaging		Deposit Refund System for Flexible Packaging
DESIGN OF THE PACKAGING (D4ACE Guidelines NOT RELEASED) **FIACE** Project: Offers several options for recycling the packaging. Just as TetraPak, having different thickness' of multi layered materials in one single packaging, depending on the municipality, the packaging is collected with different waste streams (either with plastic or paper). -The project offers a solution of adding higher thickness' to flexible packaging with aluminum layers so that it can be recycled with aluminum waste stream.	W1	DRS system provides a backbone for mono-material flexible packaging without having to change composition or altering required material thicknesses. -It shouldn't be favorable to add additional weight to the material by changing the thickness. -Not all multi-material films are coupled with aluminum layers.
Weight and type of flexible packaging: **REFLEX** Project - For weight and type of the material Understanding the post-consumer flexible packaging waste management in Europe.	W2	In line with the project, as the research is being done for the scope of the system.
Identifying end markets. Currently it is not possible to use the recycled flims in packaging sector due to high contamination levels.	W3	Separating flexible packaging efficiently will give the end product a higher value for any end markets. Multi-material packaging can be sent to chemical recycling.
Creating a sustainable business case.	W4	The deposit refund system for the flexible packaging through an automated reverse vending machine.
Proof of principle of the business case in W4	W5	The system is a controlled closed-loop system that has proven to work for PET bottles, cans and glasses for many European countries.
Assessment and development work on marking, sorting and recycling technologies.	W6	The reverse vending machine will collect the already marked and ready-to-recycle flexible packaging, sorting them into 2 groups depending on the structure. This will prevent altering and further investments in the material recovery facilities.
Communication - supporting stakeholders for legislation	W7	The system already requires full cooperation of the stakeholders and brand-owners.

4.7 Deposit Value

Unlike beverage containers, flexible packaging is very variable in size and weight unlike beverage containers. Therefore, it is more difficult to add a fixed deposit value for flexible packaging. In deposit refund systems implemented for PET bottles in Norway, the deposit value for a PET bottle holding less than 0.5 liter is fixed as 2 NOK (0.21€).

For a deposit refund system for flexible packaging, it would be appropriate to set several deposit values for different weight ranges of the packaging.

Deposit value for weight...	Average weight for range in grams	per package in €	per kilogram in €	per ton in €	per gram in €
0...5 grams	2,5	0,01	4	4000	0,004
5...10 grams	7,5	0,03	4	4000	0,004
10+ grams	12,5	0,05	4	4000	0,004
				AVERAGE	0,004

As flexible packaging is known to be extremely lightweight, even giving the minimum coin value (1 cent) to a weight range between 0 to 5 grams of packaging results in a deposit value that is very high in comparison to other deposit refund systems for different packaging types. Therefore, a lower value than 1 cent is given to a flexible packaging of the same weight range, in the chart below.

Deposit value for weight...	Average weight for range in grams	per package in €	per kilogram in €	per ton in €	per gram in €
0...5 grams	2,5	0,005	2	2000	0,002
5...10 grams	7,5	0,015	2	2000	0,002
10+ grams	12,5	0,025	2	2000	0,002
				AVERAGE	0,002

If lower deposit values are set, the consumers might consider this value to be too "insignificant" to return any packaging at all to the retailers. Having a higher value as 1 cent as a minimum deposit value will become more encouraging to the consumers to return the packaging and contribute to the circular economy.

4.8 Target collection rates

Most recent data of packaging waste consumption in Italy from 2018 indicates a total annual packaging waste of 2.292.000 tonnes based on data given by Corepla.

	2018	2019	2020 (Year 1)	2021	2022	2023 (Year 4)
IMMESSO AL CONSUMO	**2.292.000**	**2.317.000**	**2.345.000**	**2.378.000**	**2.414.000**	**2.450.000**
RICICLO COREPLA	643.544	691.000	734.000	769.000	808.000	847.000
RICICLO INDIPENDENTE	376.000	379.000	382.000	386.000	390.000	394.000
TOTALE RICICLO	**1.019.544**	**1.070.000**	**1.116.000**	**1.155.000**	**1.198.000**	**1.241.000**
Incidenza %	***44,5%***	***46,2%***	***47,6%***	***48,6%***	***49,6%***	***50,7%***
RECUPERO ENERGETICO COREPLA*	383.057	507.000	572.000	640.000	698.000	739.000
RECUPERO ENERGETICO RSU	603.360	573.000	533.000	488.000	438.000	383.000
TOTALE RECUPERO ENERGETICO	**986.417**	**1.080.000**	**1.105.000**	**1.128.000**	**1.136.000**	**1.122.000**
Incidenza %	***43,0%***	***46,6%***	***47,1%***	***47,4%***	***47,1%***	***45,8%***
RECUPERO TOTALE	**2.005.961**	**2.150.000**	**2.221.000**	**2.283.000**	**2.334.000**	**2.363.000**
Incidenza %	***87,5%***	***92,8%***	***94,7%***	***96,0%***	***96,7%***	***96,4%***

(*) Al netto della Frazione estranea;

Figure 34: Corepla, Programma Specifico di Prevenzione 2019-2023

44% of the total amount of plastic packaging format is flexible packaging. Primary flexible packaging in Italy amounts to 70%, while secondary packaging is 7% (ISPRA and FISE Unicircular, 2019).

As the estimations given by CorePla starts from the year 2019 until 2023, all the calculations are based on a 4 year period. For the first year calculations, the data estimations for 2020 are taken into account, while the fourth year calculations are based the data estimations for 2023.

Year 1
Year 1 calculations are based on the 2020 data estimations of Corepla, which state a total plastic packaging waste of 2.345.000 tonnes.
The total number of flexible packaging is calculated to be 1.031.800 tonnes, estimating that the flexible packaging remained as a fixed percentage of the total plastic packaging. The target post-consumer packaging categories are primary and secondary packaging. Therefore, the total quantity of post-consumer flexible packaging is calculated to be 794.486 tonnes in 2020.

Year 4
Year 4 calculations are based on the 2023 data estimations of Corepla, which is a total plastic packaging waste of 2.450.000 tonnes.
The total number of flexible packaging is calculated to be 1.078.800 tonnes, again estimating that the flexible packaging remained as a fixed percentage in plastic packaging. The target post-consumer packaging categories are primary and secondary packaging. Therefore, the total quantity of post-consumer flexible packaging is calculated to be 830.060 tonnes in 2023.

4.9 Costs and Revenues

In 2018, a study was made for a deposit refund system for beverage containers in Turkey. Some of the cost and revenue analysis is based on this document in order to make accurate estimations.

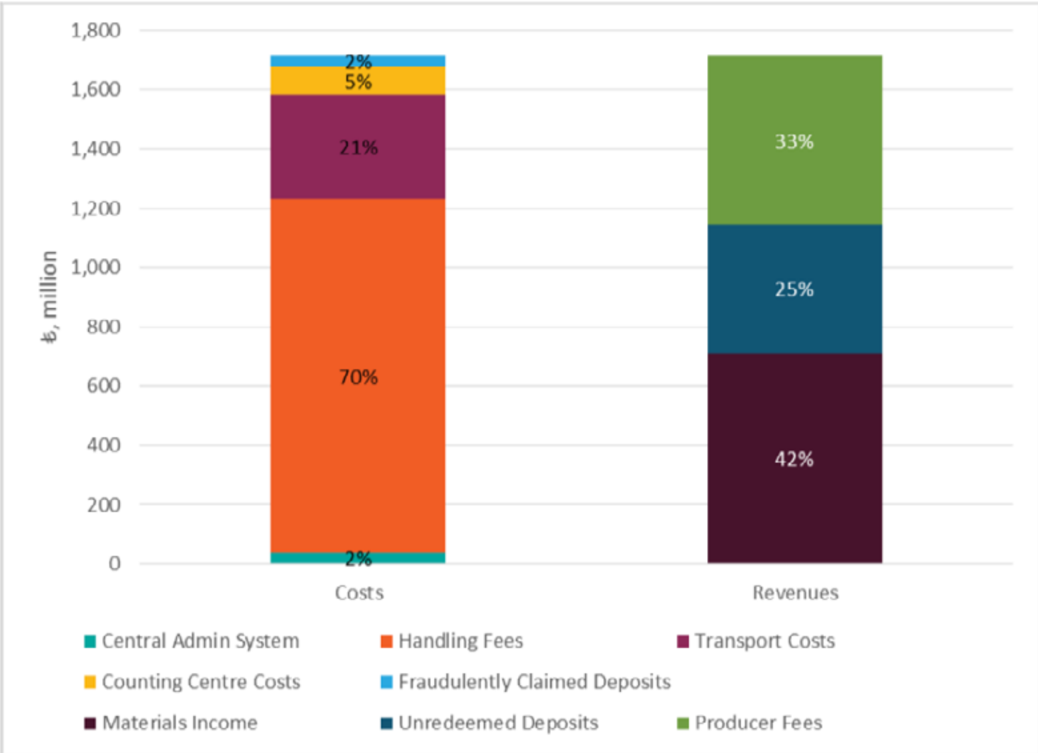


Figure 35: Reloop 2018

The deposit-refund system for post-consumer flexible packaging in Italy, is designed as a non-profit scheme. A small profit margin, which will remain to the system operator, is left in the calculations in order to compensate for any additional costs.

4.9.1 Handling Fee - Retail

Handling fees is the amount paid to retailers to compensate for the service costs of taking back post-consumer packaging. For the deposit refund system in Italy it is calculated as a variable cost that is dependent on the savings. This cost is calculated as 85% of sum the material revenues and unredeemed deposits (savings of the system).

4.9.2 Producer (Brand-owner) Reward

The producer reward is a cost based on the total savings of the non-profit economic balance of the deposit refund system. For their collaboration, the brand-owners are rewarded 10% of total income of the deposit refund system.

4.9.3 Handling Fee of Reverse Vending Machines

Handling fee of the reverse vending machines are divided into two, as the cost of the reverse vending machine and the maintenance costs.

The cost of the reverse vending machines are calculated over 10.000 units and it is estimated that all the machines are bought in the year 1. In order to have an accurate cost estimation for a single unit of a reverse vending machine, the price ranges were discussed with the market leader for reverse vending machine systems, Tomra. It was concluded that their T70 series would be a fitting reverse vending machine, both technology and cost wise. For volume efficiency it is a reverse vending machine with an integrated compaction system. The given price for this machine was an estimated 20.000€, shipment costs included.

Adding the cost for the FT-IR technology of NeoSpectra, the estimated price for a single unit of a reverse vending machine is 20.462€.

It is calculated that within the first year of the deposit refund system the cost for the additional technology will be compensated.

In the first year of the scheme, if 20% of the packaging, which is eqiuvalent to 144.452 tonnes of material is collected:

70% of this material is estimated to be separated as mono-material (101.116,4 tonnes) which is sold for 60€/tonne, is equal to 6.066.984 €.

30% of this material is estimated to be separated as multi-material (43.335,6 tonnes) which is sold for 2€/tonne, is equal to 86.671,2 €.

This sums up to a total of 6.153.655€, while 10.000 units of the NeoSpectra sensor, with shipment included, cost 4.620.000€. This is also a further validation that collecting packaging from non-participating companies is both profitable and environmentally sustainable for creating a circular economy for flexible packaging.

The annual maintenance costs for the reverse vending machines are calculated as 5% of a single unit cost. It is estimated (section 4.5) that 9464 units of reverse vending machines will placed in retailers across Italy. The total annual maintenance cost is calculated as 5% of the total cost 9464 units of reverse vending machines.

	tonnes	Additional notes	percentages	Euro/Tonnes	1 unit	Euros (TOTAL)
Handling Fee RVM		Purchasing 10.000 RVMs. Life expectancy: 7 years			20462	204.620.000
Handling Fee RVM		Maintenance costs of 9464 RVMs	5		20462	9.682.618,4

4.9.4 Transportation Costs

Transportation costs are taken from calculations of ISPRA, Istituto Superiore per la Protezione e Ricerca Ambientale. According to this data provided by ISPRA, the cost for multi-stream kerbside collection and transportation of municipal waste has a value of 13 cents per kg.

Medie, per macroarea, dei costi specifici per chilogrammo di rifiuto (dati riferiti al campione di comuni)

Area geografica	Perc. RD (%)	Pro capite RU kg/ab.	CRTkg	CTSkg	CACkg	CGINDkg	CRDkg	CTRkg	CGDkg
			(Eurocent/kg*anno)						
NORD	67,8	515,4	11,04	13,86	2,40	**27,30**	10,50	3,98	**14,49**
CENTRO	54,6	556,4	9,18	14,46	1,68	**25,32**	16,87	3,29	**20,16**
SUD	46,9	458,5	12,70	13,21	2,42	**28,33**	19,02	5,89	**24,91**
Italia	**59,4**	**507,3**	**11,14**	**13,79**	**2,22**	**27,15**	**13,57**	**4,23**	**17,81**

Figure 36: ISPRA

4.9.5 Administration Costs

The administration costs are estimated to account for 50 people working in the administration offices, each being paid 3500€ monthly.

Administration Fee

	Amount of administrative workers	Salary per month in €	Months in a year	Total costs for administration in €
	50	3500	12	2.100.000

4.9.6 Fraudulently Claimed Deposits

0.5% of all refunded deposits are estimated to be fraudulently claimed.

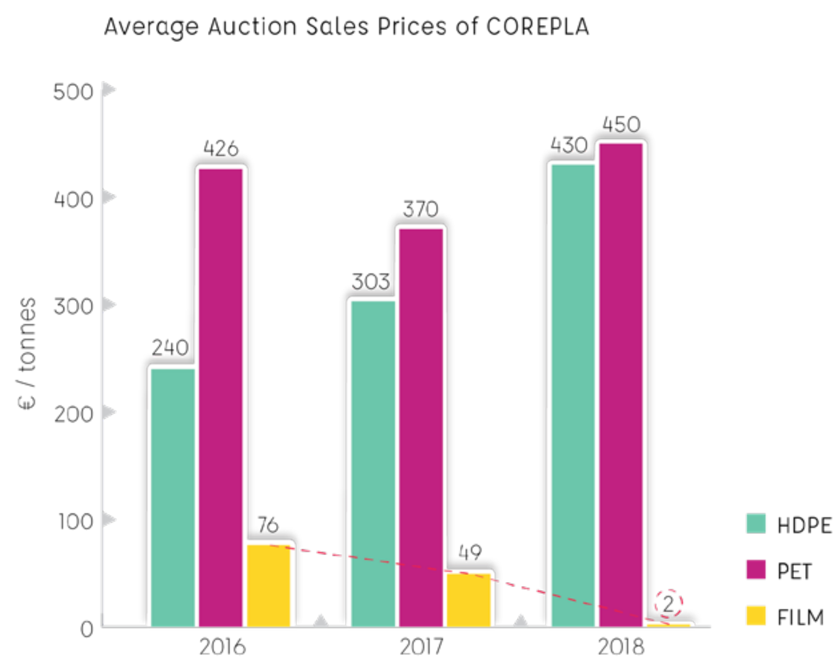
The year 1 collection rate of flexible packaging an assigned deposit value is estimated to be 30%. It is equivalent to 238.345 tonnes of flexible packaging.

The year 4 collection rate of flexible packaging with an assigned deposit value is estimated to be 76,5%. It is equivalent to 577.269 tonnes of flexible packaging.

4.9.7 Material Revenues

Currently in Italy, Corepla's flexible packaging separation is not based on the material composition but mostly based on their color and size. In 2018, the material value for flexible packaging was a symbolic value of 2€/tonne. According to the REFLEX project made by CEFLEX, 70% of all flexible plastic packaging has a mono-material structure and therefore technically is "recycle-ready".

After a sorting based on material structure and composition is made by the reverse vending machine, 70% of the mono-material flexible packaging can be sold for an estimated 50€ to 70€ price range (values obtained during an interview done with Corepla). This mono-material post-consumer flexible packaging can be mechanically recycled. For all of the calculations, the material revenue for mono-material flexible packaging is considered as 60€/tonne.



The remaining 30% is estimated to have a similar value to the 2018 range, which is 2€/tonne, as it will be sorted in a similar way to current batches. The multi-material post-consumer flexible packaging batch can be chemically recycled or sent to energy recovery.

4.9.8 Unredeemed Deposits

Unredeemed deposits are the biggest source of income for the deposit-refund systems. Comparing the deposit-refund system for flexible packaging to the one for beverage containers, the unredeemed deposit rate for flexible packaging is much higher than the unredeemed deposit rate for beverage containers.

The main reason for this is that flexible packaging has a much higher deposit value-weight ratio than beverage containers.

The unredeemed deposits are calculated based on the average deposit value of flexible packaging, which is calculated to amount to 0,004 €/gram.

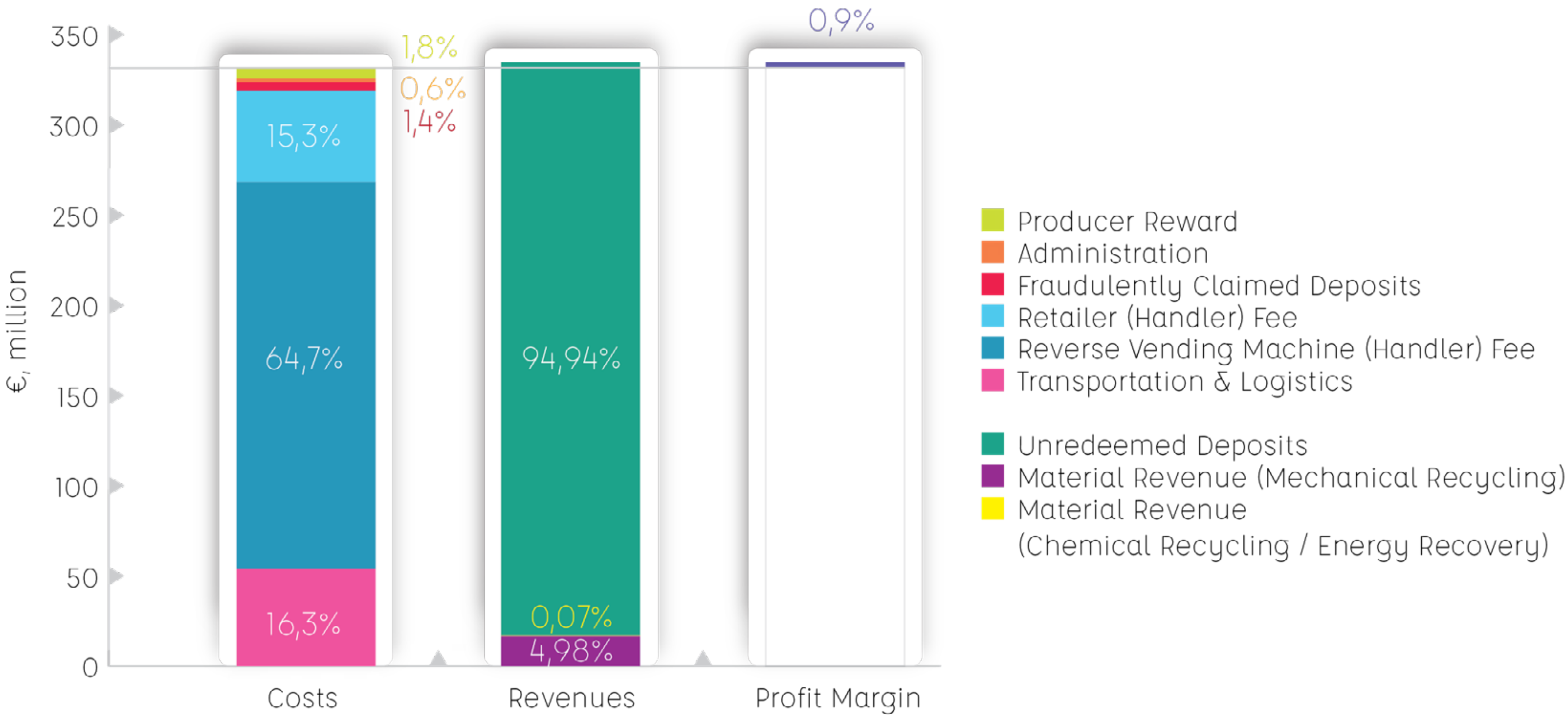
In year 1, the unredeemed deposit rate is estimated to be 25% which is equivalent to 70.448,6 tonnes of flexible packaging. In contrast, in year 4, the unredeemed deposit rate is estimated to be 10%, which is equivalent to 70.555,1 tonnes of post-consumer flexible packaging.

4.10 Economic Balance Breakdown

4.10.1 Year 1

	tonnes	Additional notes	percentages	Euro/Tonnes	1 unit	Euros (TOTAL)	Euros/Gram	% relative to (costs or revenues)
BASE COSTS								
Total transportation cost				135,7		53.905.875,1		16,25
Handling Fee RVM		Purchasing 10.000 RVMs. Life expectancy: 7 years			20462	204.620.000		61,68
Handling Fee RVM		Maintenance costs of 9464 RVMs	5		20462	9.682.618,4		2,92
Fraud		In % of all redeemed deposits	0,5			4.766.916		1,44
Administration						2.100.000		0,63
BASE TOTAL						275.075.409,5		
COLLABORATION COSTS								
Handling Fee Retail		In % of Deposit Value:	85	210		50.695.311	0,00021	15,28
Producer Fee (Reward for joining)			10			5.964.154,2		1,8
COLLABORATION TOTAL						56.659.465,2		
TOTAL COSTS						331.734.874,7		
REVENUES								
Material revenue mechanical recycling			70	60		16.684.206		4,98
Material revenue (chem + energy rec.)			30	2		238.345,8		0,07
Unredeemed deposits	79.448,6		25			317.794.400	0,004	94,94
REVENUES TOTAL						334.716.951,8		
BASE BALANCE	without collaboration costs					59.641.542,3		
BALANCE	**(Profit Margin)**					2.982.077,1		0,9

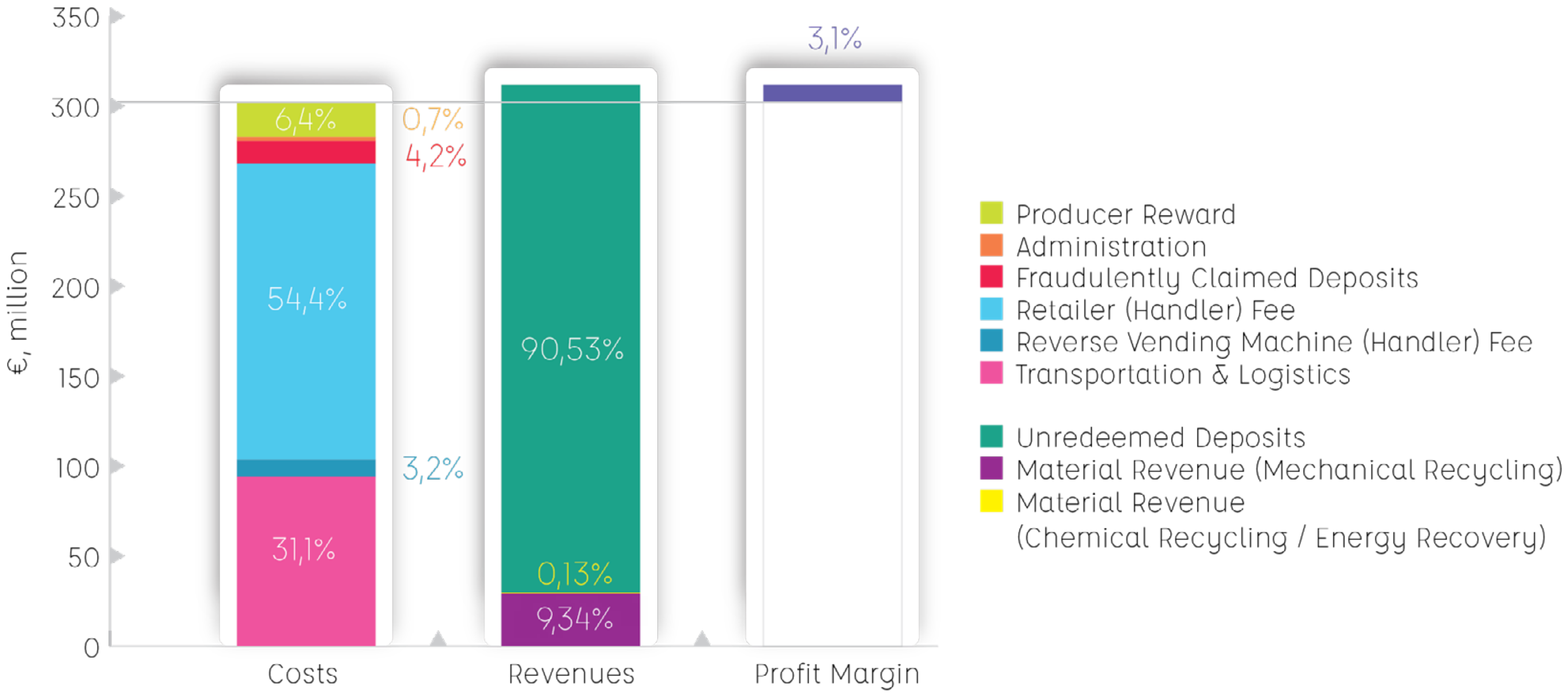
Year 1 Estimation
(2020 Data Estimation, CorePla)



4.10.2 Year 4

	tonnes	Additional notes	percentages	Euro/Tonnes	1 unit	Euros (TOTAL)	Euros/Gram	% relative to (costs or revenues)
BASE COSTS								
Total transportation cost				135,7		94.053.683,6		31,13
Handling Fee RVM		Maintenance costs of 9464 RVMs	5		20462	9.682.618,4		3,21
Fraud		In % of all redeemed deposits	0,5			12.699.918		4,2
Administration						2.100.000		0,7
BASE TOTAL						118.536.220		
COLLABORATION COSTS								
Handling Fee Retail		In % of Deposit Value:	85	260		164.228.707,6	0,00026	54,36
Producer Fee (Reward for joining)			10			19.321.024,4		6,4
COLLABORATION TOTAL						183.549.732		
TOTAL COSTS						302.085.952		
REVENUES								
Material revenue mechanical recycling			70	60		29.110.204,2		9,34
Material revenue (chem + energy rec.)			30	2		415.860,06		0,13
Unredeemed deposits	70.555,1		10			282.220.400	0,004	90,53
REVENUES TOTAL						311.746.464,26		
BASE BALANCE	without collaboration costs					193.210.244,26		
BALANCE	**(Profit Margin)**					9.660.512,26		3,1

Year 4 Estimation
(2023 Data Estimation, CorePla)



4.11 List of assumptions

In order to create the cost calculations and balance equations some of the values had to be estimated.

• For the overall quantity of plastic packaging waste and flexible packaging, Corepla estimations were used.
• After separation of flexible packaging based on its layer structure and material composition, it is predicted that the mono-material batch would have a value of 60€/tonne, while the multi-material batch would have 2 €/tonne as the state in 2018.
• The costs for one reverse vending machine is obtained from Tomra, and estimated to be similar to their single T70 series, as 20.000€.
• The annual maintenance cost of RVMs is assumed to be 5% of a single unit of a reverse vending machine's total cost.
• Year 1 brand owner participation is assumed to equal 40%, while year 4 participation is set to 85%.
• Year 1 unredeemed deposits percentage is assumed to be 25%, while in year 4 it is lowered to 10%.
• Fraudulently claimed deposits are assumed to be 0.5% of all deposits redeemed in a single year.

4.12 Comparison of Recycle Rates (With and Without the Deposit-refund system)

A comparison and prediction is made according to data and estimations provided by Corepla on recycle rates of post-consumer packaging.

The charts are created assuming that the technological improvements would be at the same state in 2023 in material recovery facilities, as it is not possible to predict the material recovery rates as well as material revenue costs for flexible packaging in 2023.

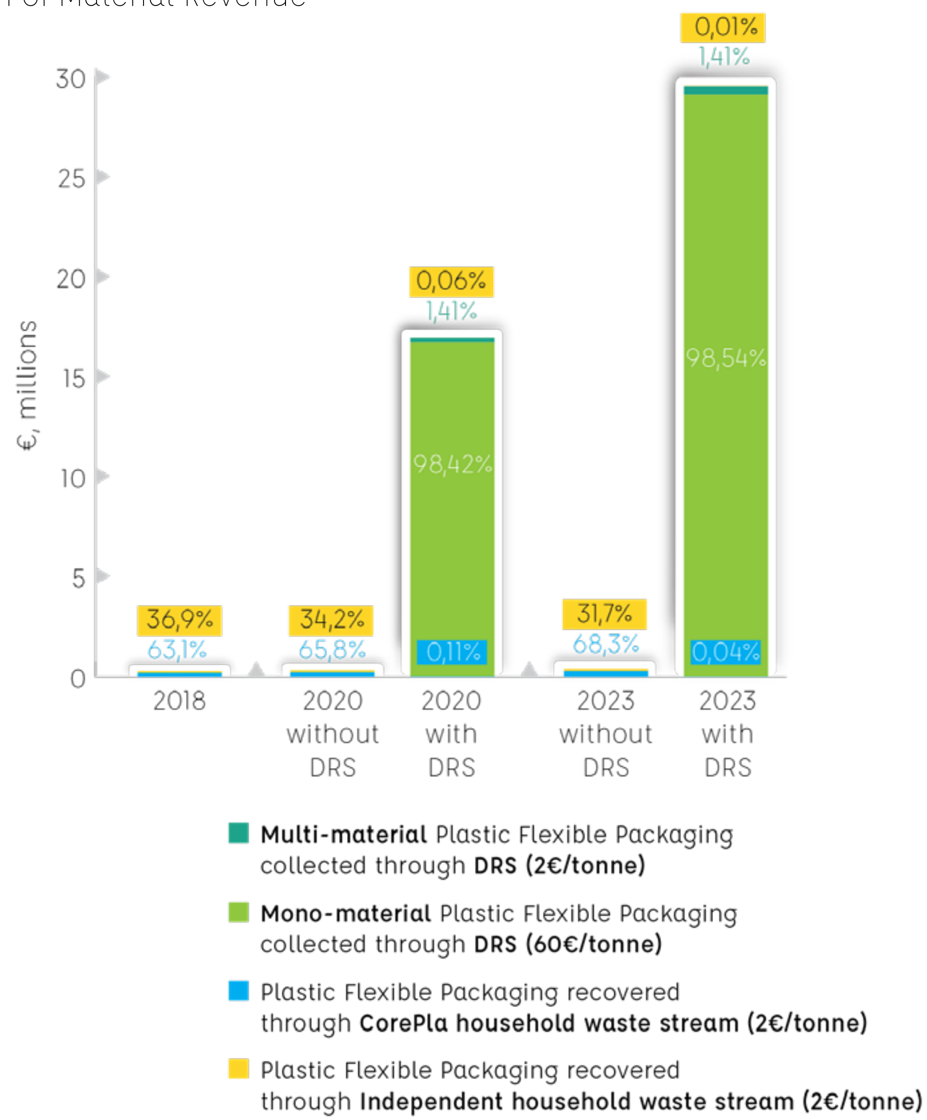
PRODOTTO	2018	2019	2020	2021	2022	2023
PET	244.809	255.000	264.000	273.000	282.000	290.000
HDPE	69.967	71.000	73.000	74.000	76.000	77.000
FILM	84.608	94.000	103.000	113.000	123.000	134.000
PLASTICHE MISTE	212.245	231.000	254.000	269.000	287.000	306.000
SRA	4.549	10.000	10.000	10.000	10.000	10.000
TOTALE	**616.178**	**661.000**	**704.000**	**739.000**	**778.000**	**817.000**

Figure 37: Corepla, Programma Specifico di Prevenzione 2019-2023

Comparison of Recycle Rates

	2018		2020				2023			
	Without DRS (in tonnes)	%	Without DRS (in tonnes)	%	With DRS (in tonnes)	%	Without DRS (in tonnes)	%	With DRS (in tonnes)	%
Total Flexible Packaging	1.008.480	100,0	1.031.800	100,0	1.031.800	100,0	1.078.000	100,0	1.078.000	100,0
Total Recycled	134.041	13,3	156.605	15,2	412.181,1	39,9	196.333	18,2	700.393	65,0
Non-Recycled	874.439	86,7	875.195	84,8	619.619	60,1	881.667	81,8	377.607	35,0
CorePla Waste Stream	84.608	8,4	103.000	10,0	10.246,9	1,0	134.000	12,4	5.175,5	0,5
CorePla DRS	-	0,0	-	0,0	397.243	38,5	-	0,0	693.100	64,3
Independent	49.433,5	4,9	53.605	5,2	4.691	0,5	62.333	5,8	2.118	0,2

Comparison of Material Revenue



	2018		2020				2023			
	Without DRS €	%	Without DRS €	%	With DRS €	%	Without DRS €	%	With DRS €	%
CorePla Waste Stream	169.216	63,12	206.000	65,77	20.493,7	0,12	268.000	68,25	29.110.200,0	0,04
CorePla DRS Monomaterial stream	-	-	-	-	16.684.206,0	98,42	-	-	10.351,0	98,54
CorePla DRS Multimaterial stream	-	-	-	-	238.345,8	1,41	-	-	415.860,0	1,41
Independent	98.866,9	36,88	107.210	34,23	9.383	0,06	124.666	31,75	4.236	0,01
Total	268.083	100,00	313.210	100,00	16.952.428	100,00	392.666	100,00	29.540.647	100,00

CHAPTER 5

Focus on product design for a deposit-refund scheme

5.1 Design roles for creating a deposit refund system

The final part that the thesis will focus on is the design roles that are needed in order to create a functional deposit refund system.

5.1.1 Service-System Designer

The main role of a service-system designer in the creation of a deposit refund system, is analyzing and evaluating the activities of stakeholders, while integrating the customer journey.

5.1.2 Product Designer, Design & Engineer

A product designer has a role of designing the machinery that will collect and efficiently and correctly sort the recyclable material. The design of the product must ensure customer satisfaction and must be highly developed in user interaction, creating an extensive user experience. The consumers bringing in the packaging must feel that they are an integrated part of the deposit system, a crucial actor in creating a circular economy.

5.1.3 Communication Designer

A communication designer must use marketing and graphic tools in order to communicate the functioning and advantages of the deposit-refund system. The main role of the communication designer is to create an awareness towards circular economy for all the stakeholders as well as for the consumers.

5.2 Brief for a product designer: Designing a Reverse Vending Machine

Some set of initial requirements must be met in order to create the best fitting product for the collection and sorting of post-consumer flexible packaging for a deposit refund system.

Objectives

The basic features that the reverse vending machine for flexible packaging must have:

- An integrated technology that efficiently recognizes the material of the packaging, the printed deposit logo, the universal barcode and the QR Code (the barcode or the QR Code will contain the packaging information about material composition and the weight of the packaging).

- The reverse vending machine must have an integrated compactor that reduces the volume of the flexible packaging inside the machine. There must be a maximum weight limit that the machine can store. Current reverse vending machines in the market store up to 11 kg of waste. This can be used to roughly estimate that the machine can accept 7340 units of flexible packaging of Kinder Brioss, each weighting around 1.5 grams.

- The reverse vending machine must have interactive features that makes the user/ consumer feel involved and engage in the recycling system. Users must be aware that they are a key factor in the waste recovery and the circular economy. Therefore, the reverse vending machine must create an interactive user experience that raises the awareness of the consumers towards the fact that they are creating value out of waste.

- There must be two deposit bins for the sorting of the waste. It is a crucial part, as in the current state, the material recovery facilities don't have enough technological advancements to correctly and efficiently sort post-consumer flexible plastic packaging.

- The reverse vending machine must be designed in the most compact way in order to save space in retail stores.

5.3 Reverse Vending Benchmarks

For initial observation and understanding possible solutions as well as the design requirements of reverse vending machine, the available products present in the market must be analyzed.

Tomra holds a market share of 65% of the global market for reverse vending machines. The second largest producer of reverse vending machines is Diebold Nixdorf. Sielaff & Co and Trautwein Sb Technik mostly share the reverse vending machine market in Germany.

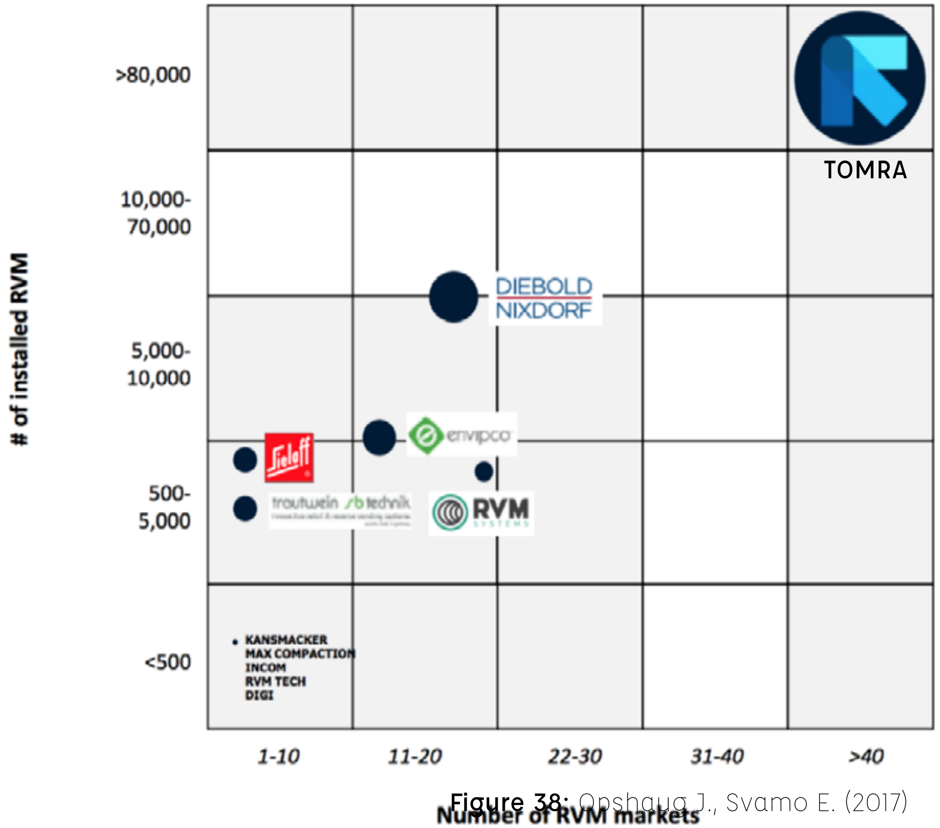
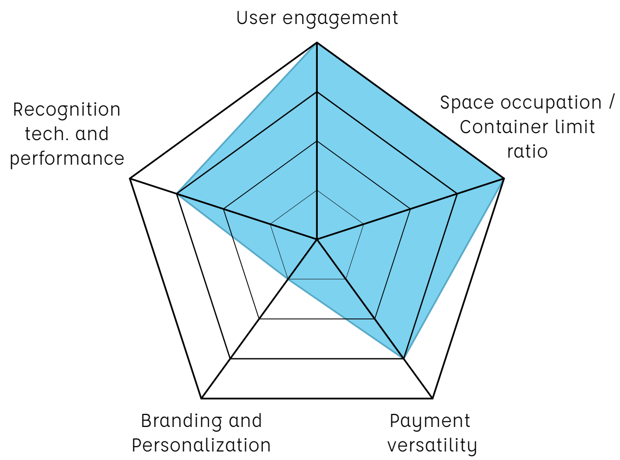


Figure 38: Opshaug J., Svamo E. (2017)

5.3.1 Tomra (T70)

Figure 39



Dimensions:
1897 x 1041 x 810 mm

Container limit:
1100 PET Bottles, 3200 Cans, 300 Glass (weight limited)

Speed/Performance:
45 Containers/min

Compaction:
Yes

Separation:
2 types of continers:
PET Bottles, Cans or
Glass bottles

User Interaction:
LCD Touch Display
with sound and video

Recognition Tech:
Shape recognition (Fresnel lenses),
Metal detection,
Barcode recognition,
360 Full container
detection

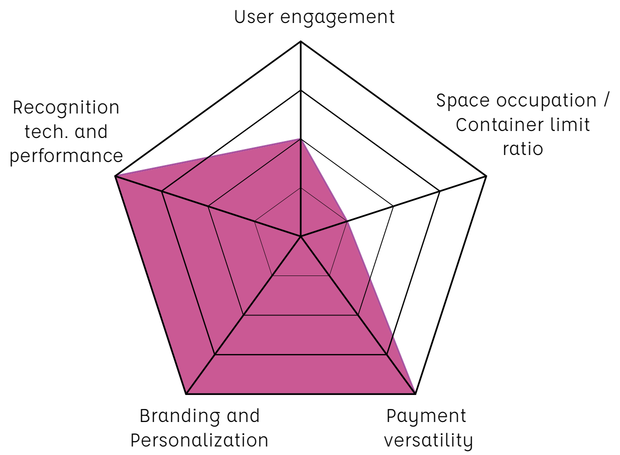
Payment method:
E-receipt/ e-payout with optional barcode reader, Receipt

User Engagement:
ReAct loyalty program:
Possibilty of sharing on
social media and donation
of the deposit

Personalization:
No

5.3.2 Diebold Nixdorf (Revendo 9030 S)

Figure 40



Dimensions:
1720 x 1580 x 900 mm

Container limit:
800 PET Bottles or
3000 Cans

Speed/Performance:
60 Containers/min

Compaction:
Yes

Separation:
PET Bottles and cans
(Required a back room
for refillable PET and Glass bottles)

User Interaction:
LCD Touch Display

Recognition Tech:
360 barcode
recognition,
Shape and color
recognition

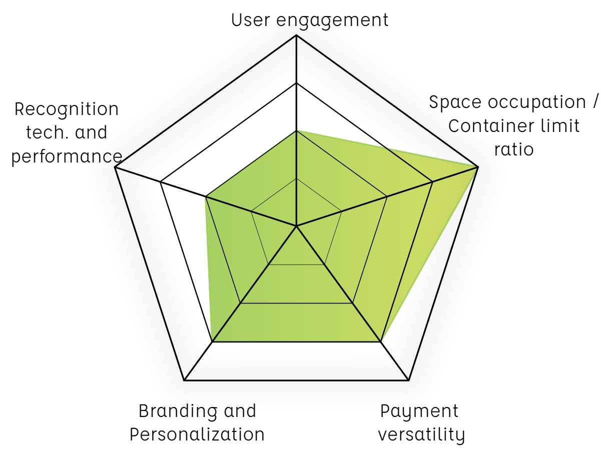
Payment method:
Receipt, Contactless card (optional),
NFC for loyalty card (optional)

User Engagement:
Nixdorf loyalty
program

Personalization:
RAL color options, Branding on front
and side panels, Display graphics

5.3.3 EnvipCo (Flex)

Figure 41



Dimensions:
1836 x 848 x 600 mm

Container limit:
300 PET Bottles (60%)
and 600 Cans (40%)

Speed/Performance:
40 Containers/min

Compaction:
Yes

Separation:
PET Bottles and Cans (standard) and
optional unit for Glass bottles

User Interaction:
LCD Touch Display

Recognition Tech:
Aluminum and PET
detection, multiple wide field barcode
reader, optional
container size
measurement

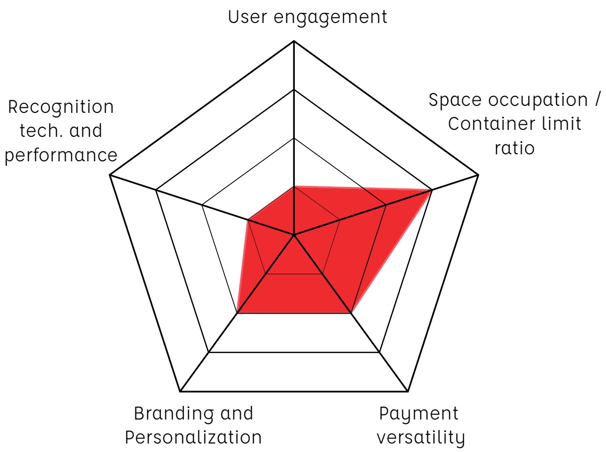
Payment method:
Optional Loyalty card reader, Receipt

User Engagement:
EnvipCo loyalty
program

Personalization:
Custom machine graphics, Display
graphics

5.3.4 Sielaff & Co (Sione)

Figure 42



Dimensions:
1830 x 990 x 880 mm

Container limit:
600 PET Bottles
or 700 Cans

Speed/Performance:
30 Containers/min

Compaction:
No

Separation:
PET Bottles and Cans
or cups (2 types only)

User Interaction:
LCD Display with
buttons

Recognition Tech:
EAN barcode reader or DPG logo read-er
(Germany)

Payment method:
Coins, Receipt

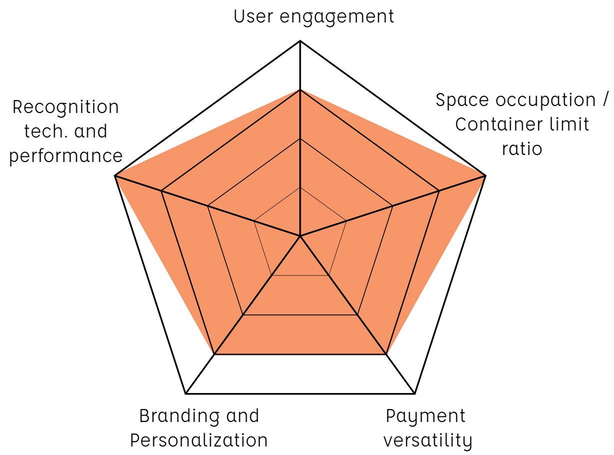
User Engagement:
No

Personalization:
Branding of door and side panels, 3 RAL
color options

For indoor and outdoor use

5.3.5 RVM Systems (X2)

Figure 43



Dimensions:
1789 x 889 x 744 mm

Container limit:
400 PET Bottles
and 800 Cans

Speed/Performance:
60 Containers/min

Compaction:
Yes

Separation:
PET bottles (3l) and Cans (1l), with additional
module that accepts Glass bottles (X3 series)

User Interaction:
LCD Touch Display
with sound option for
warning

Recognition Tech:
360 barcode reading and shape rec-ognition

Payment method:
Digital payout option via phone APP, Receipt

User Engagement:
Donations,
Revend App, NFC
Loyalty programme

Personalization:
Front and side
panel branding,
display graphics

5.3.6 Comparison

The five most comparable features of the reverse vending machines in the market were:

- User engagement (interactiveness of the machine, information that the user can receive and share about recycling and the circular economy, possible donation options).
- Space occupation/ container limit ratio (Dimensions of the machine is compared to amount of containers that it can accept).
- Payment versatility (Payment options that the user can have).
- Branding and personalization (If the machine's exterior and the interface can be modified and personalized).
- Recognition technology, performance or speed of the machine (Amount of containers that the machine can accept in one minute).

The most common elements of the reverse vending machines for PET, glass bottles and cans are analyzed. These are the fixed features and the current working principle of the reverse vending machines for beverage containers.


Figure 44

RVM takes the container through a conveyor belt.

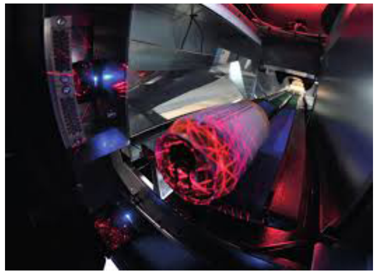


Figure 45

RVM takes a few seconds to analyse the barcode and the shape of the material.

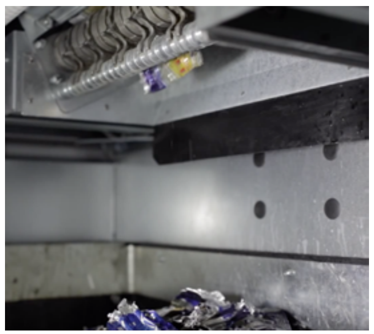
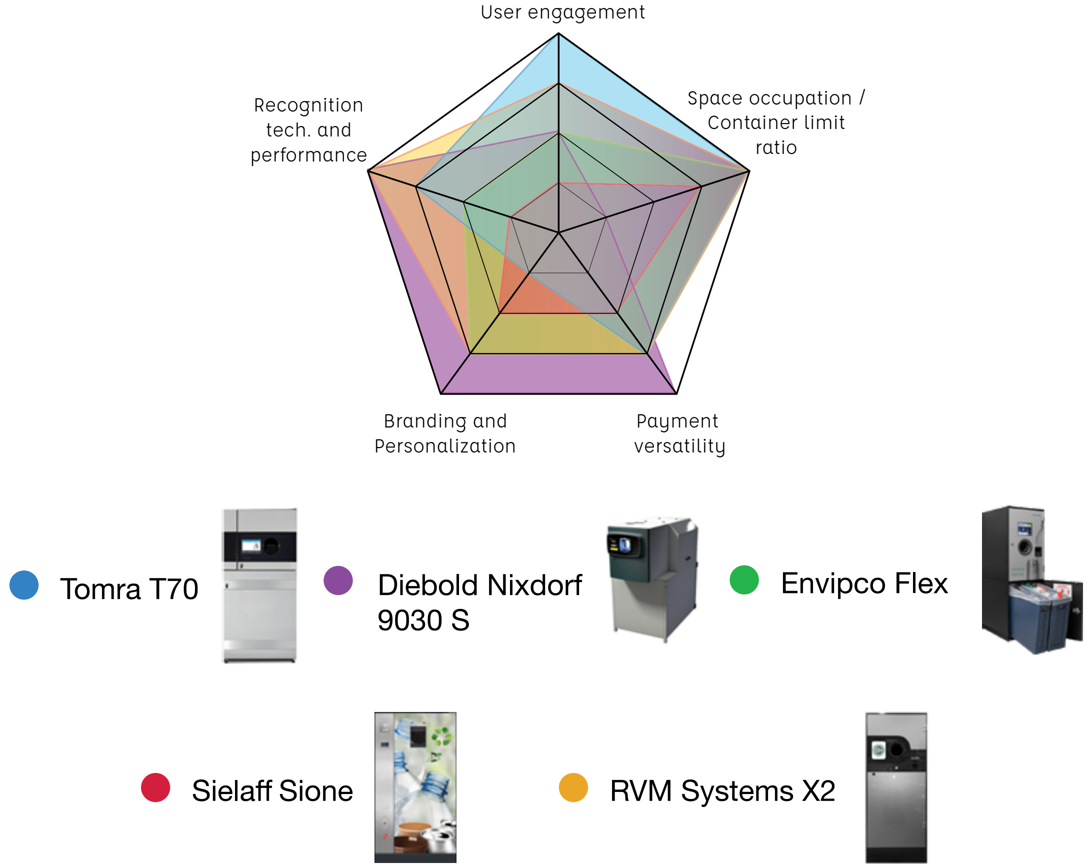


Figure 46

In case the RVM has a compactor, the container is crushed.

RVM drops the material into the deposit bin.
Some supermarkets have a dedicated backroom to trasport and store the collected material. In this case RVM's conveyor belt directly brings the material to the backroom.



5.4 Possible Solutions

A set of possible technical and design solutions are offered for the future design of the reverse vending machine.

Technical solutions

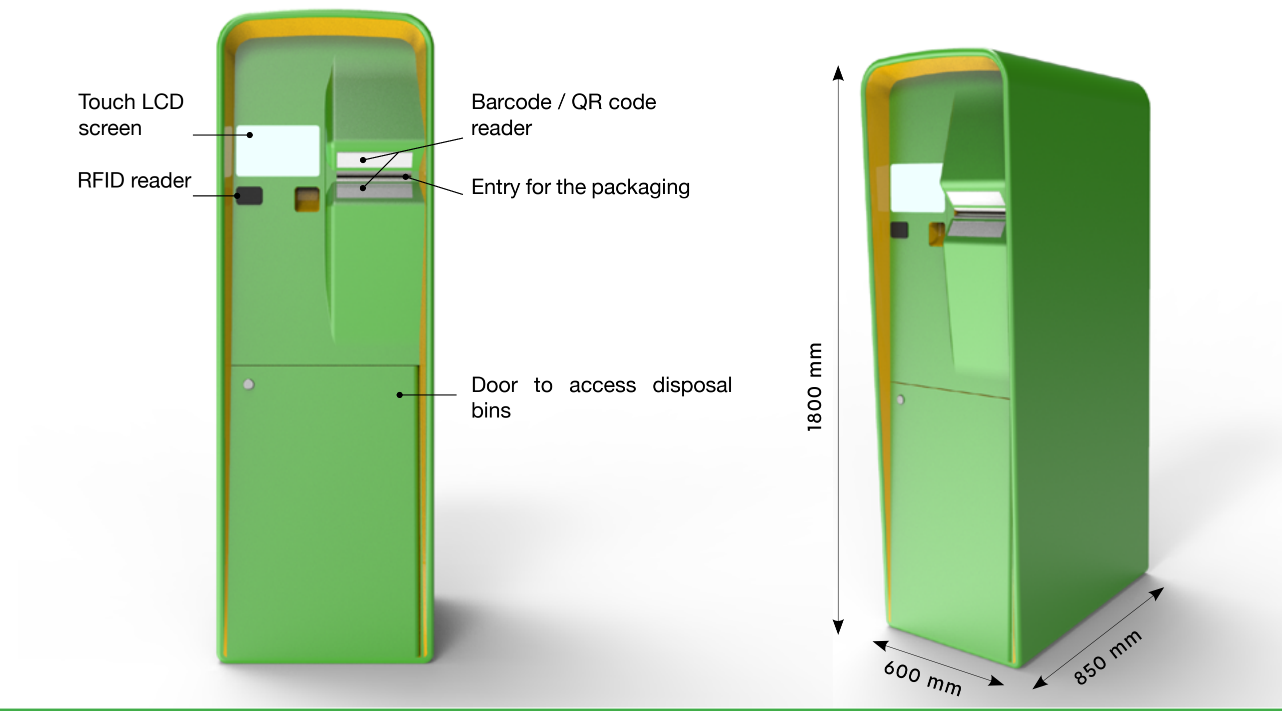
- Conveyors or air vents can be used internally in the reverse vending machine to direct the packaging into the correct deposit bin after sorting.
- Machine must be designed as much as possible, easy to disassemble certain functional parts for easy maintenance and for the reverse vending machine to have a longer life cycle. Therefore, some functional sets of groups or components must be accessible and exchangeable.

Design solutions

- As an interaction and user engagement feature, the reverse vending machine can inform the users how much energy/value was saved by recycling post-consumer flexible packaging through the machine. It must be a value that can be easily relatable. For example the amount of time that an oven would function with the same level of energy saved by recycling packaging. The machine should be designed in a way that promotes user experience, by interacting with the users, setting it apart from the current reverse vending machines in the market.
- The reverse vending machine can be branded/sponsored by brand-owners. Additional posters can be included for donations, events or for seasonal times.
- The reverse vending machine can work with existing loyalty cards of supermarkets. It can give the users loyalty points or prizes when certain limits are achieved in circular economy for post-consumer flexible packaging.

An initial design concept is made, just to give out an idea of how the reverse vending machine can be designed.

Initial concept



5.5 Conclusions

In this thesis, an introduction to recycling is made, pointing out the importance of creating value out of waste and the circular economy. A deeper research is conducted on post-consumer flexible plastic packaging, which is one of the largest and fastest growing sectors in post-consumer plastic packaging. The main constraints that prevent flexible packaging to be recycled is established. The recycling model of Italy is further analyzed. It is established that the bring systems (consumer drop-off) have a minimum level of contamination in post-consumer waste. Therefore, it is taken as a model to develop and transform an existing deposit refund system for beverage bottles to a deposit refund system for post-consumer flexible plastic packaging. This model is strictly analyzed, by defining all the stakeholders and their activity, creating an economical cost analysis of a four year period, and creating a case study for Italy.

Furthermore, the design roles are defined in order to create a fully functional deposit refund scheme. The role of a product designer and the brief that they will receive in order to create a reverse vending machine are further defined. A brief market analysis and benchmarking has been conducted to understand the current products in the market. Finally, some design solutions are offered, concluding with an initial design concept to simply render a reverse vending machine promoting higher levels of user engagement.

The next step for this project must be further developing the reverse vending machine respecting the given brief and guidelines.

References

APK (2019) Newcycling process, accessed April 2020 <https://www.apk-ag.de/en/newcycling/>

APR (2018) Near Infrared (NIR) Sorting in the plastics recycling process, The Association of Plastic Recyclers, accessed April 2020 <https://plasticsrecycling.org/images/pdf/design-guide/Resources/NIR_Sorting_Resource.pdf>

Astrup T., Fruergaard T., Christensen T. H. (2009) Recycling of plastic: accounting of greenhouse gasses and global warming contributions, Waste Management & Research 2009: 27: 763-772, doi:10.1177/0734242X09345868

BASF (n.d.) BASF Chemical recycling, accessed April 2020, <https://www.basf.com/global/en/who-we-are/sustainability/we-drive-sustainable-solutions/circular-economy/mass-balance-approach/chemcycling.html>

Bauer M., Lehner M., Schwabl D., Flachberger H., Kranzinger L., Pomberger R., Hofer W. (2018) Sink–float density separation of post-consumer plastics for feedstock recycling, Journal of Material Cycles and Waste Management (2018) 20:1781–1791, doi.org/10.1007/s10163-018-0748-z

BDE e.V. (2019) Recycling stops greenhouse gasses, Federation of the German waste, water and raw materials management industry industrial and employers' association. accessed April 2020 <https://www.umweltbundesamt.de/sites/default/files/medien/publikation/long/4050.pdf>

Beker E. (2007) Automatic sorting of recyclable materials with NIR technology, RTT SystemtechniK Gmbh, WasteMINZ 19th annual conference & expo, New Zealand, accessed April 2020 <https://www.wasteminz.org.nz/wp-content/uploads/Ernie-Beker.pdf>

Boucher J., Billard G. (2019) The challenges of measuring plastic pollution, Field Actions Science Reports, Special issue 19, pp. 68-75

Bukowski T., Richmond M. (2018) A holistic view of the role of flexible packaging in a sustainable world, Flexible Packaging Association, accessed April 2020 <https://perfectpackaging.org/wp-content/uploads/2018/09/FPA-Holistic-View-of-Sustainable-Packaging.pdf>

CEFLEX (2020) Introduction and progress update, accessed April 2020 <https://ceflex.eu/wp-content/uploads/2020/01/CEFLEX_Presentation_Q1-2020_website-update_Jan_20-1.pdf>

CEFLEX (n.d) What we do?, accessed April 2020 <https://ceflex.eu/what-we-do/>

CEWEP (2018) Latest Eurostat Figures: Municipal Waste Treatment 2018, accessed April 2020 <https://www.cewep.eu/municipal-waste-treatment-2018/>

Citi GPS: Global Perspectives & Solutions (2018) Rethinking single-use plastics, Citibank, accessed April 2020 <https://www.citibank.com/commercialbank/insights/assets/docs/2018/rethinking-single-use-plastics.pdf>

CM Consulting, Reloop (2018) Deposit Systems for One-Way Beverage Containers, Global Overview, accessed April 2020 <https://www.reloopplatform.org/wp-content/uploads/2018/05/BOOK-Deposit-Global-27-APR2018.pdf>

CM Consulting, Reloop (2018) Deposit Systems for One-Way Beverage Containers, Global Overview: EU28 + EFTA, accessed April 2020 <https://www.reloopplatform.org/wp-content/uploads/2018/05/BOOK-Deposit-Global-27-APR2018-EU28EFTA.pdf>

CONAI (n.d.) Guidelines to facilitate the recycling of plastic packaging, accessed April 2020 <http://www.progettarericiclo.com/en/docs/guidelines-facilitate-recycling-plastic-packaging>

CONAI (n.d.) Linee guida per la facilitazione delle attivita' di riciclo degli imballaggi in materiale plastico, accessed April 2020 <http://www.conai.org/wp-content/uploads/dlm_uploads/2017/07/Linee-Guida_Riciclo_Plastica.pdf> (Italian)

Cooper T. A. (2019) Developments in end-of-life technologies for flexible packaging: multilayer films, barrier structures and pouches, ARGO Group International, accessed April 2020 <https://www.aimcal.org/uploads/4/6/6/9/46695933/terence_cooper_presentation.pdf>

Corepla (2018) Il futuro del riciclo della plastica nella circular economy: verso il riciclo intelligente degli imballaggi, accessed April 2020 <https://www.fondazionesvilupposostenibile.org/wp-content/uploads/dlm_uploads/2018/09/Report_COREPLA_DOPPIE150-web.pdf> (Italian)

Corepla (2018) Rapporto di sostenibilita', accessed April 2020 <http://www.corepla.it/documenti/7ebe111b-2082-46d5-8da6-7567154632ca/Rapporto+di+Sostenibilità+2018.pdf> (Italian)

Corepla (2018) Relazione sulla gestione, accessed April 2020 <http://www.corepla.it/documenti/c3cc963b-c446-46c3-809b-e17e487f8e2d/RELAZIONE+SULLA+GESTIONE+2018.pdf> (Italian)

Corepla (2019) Bilancio preventivo annuale 2019, accessed April 2020 <http://www.corepla.it/documenti/4172ccae-850a-4260-bd1a-cc8b89c0303d/Bilancio+preventivo+annuale+2019.pdf>

Corepla (n.d.) Programa specifico di prevenzione 2019-2023, accessed 2020 <http://www.corepla.it/documenti/0a6b2afc-f465-4432-b0cf-2e96ebb7221b/Programma+Specifico+di+Prevenzione+2019-2023.pdf>

De Smet M, Linder M (2019) A circular economy for plastics, European Commission, accessed April 2020 <https://www.hbm4eu.eu/wp-content/uploads/2019/03/2019_RI_Report_A-circular-economy-for-plastics.pdf>

Diebold Nixdorf (n.d.) Revendo 9030 S, accessed april 2020 <https://www.dieboldnixdorf.com/-/media/diebold/files/retail/reverse-vending-solutions-en/revendo-9030-s/dn_productcard_revendo_9030s_a4_landscape_v1-1_042017_fa_us.pdf>

DPG pfandsystem (n.d.) Marking, accessed April 2020 <https://dpg-pfandsystem.de/index.php/en/function-of-the-dpg-system/drinks-manufacturers-and-importers/marking.html>

Earthwatch Institute (n.d.) Plastic rivers: reducing the plastic pollution on our doorstep, accessed April 2020 <https://earthwatch.org.uk/images/plastic/PlasticRiversReport.pdf>

EESTI Pandipakend (n.d.) Requirements of collection point with RVM, accessed April 2020 <https://eestipandipakend.ee/en/requirements-of-collection-point-with-rvm/>

EESTI Pandipakend (n.d.) Requirements of reverse vending machine (RVM), accessed April 2020 <https://eestipandipakend.ee/en/requirements-of-reverse-vending-machine-rvm/>

Ellen MacArthur Foundation (2019) The new plastics economy global commitment: 2019 global progress report, accessed April 2020 <https://www.newplasticseconomy.org/assets/doc/Global-Commitment-2019-Progress-Report.pdf>

Ellen MacArthur Foundation (2019) What is the circular economy, accessed April 2020 <https://www.ellenmacarthurfoundation.org/circular-economy/what-is-the-circular-economy>

Enval Ltd (2019) The Enval Process, accessed April 2020, <http://www.enval.com/process/>

Envipco (n.d.) Reverse vending machine Flex, accessed April 2020 <https://www.envipco.com/products_flex>

Envipco Holding N.V. (2018) Summary document: Introduction to Euronext Amsterdam
Environment victoria (2013) The problem with landfill, accessed April 2020 <https://environmentvictoria.org.au/resource/problem-landfill/>

Eriksen M. K., Christiansen J.D., Daugaard A.E., Astrup T.F. (2019) Closing the loop for PET, PE and PP waste from households: Influence of material properties and product design for plastic recycling, Waste Management, V 96, p 75-85, doi.org/10.1016/j.wasman.2019.07.005

European Commission (2017) The role of waste-to-energy in the circular economy, accessed April 2020 <https://ec.europa.eu/environment/waste/waste-to-energy.pdf>

European Commission (2019) The environmental implemetation review 2019: country report - Italy, accessed April 2020 <https://ec.europa.eu/environment/eir/pdf/report_it_en.pdf>

FAO (n.d.) Food loss and food waste, Food and Agriculture organization of the united nations, accessed April 2020 <http://www.fao.org/food-loss-and-food-waste/en/>

Faraca G., Astrup T. (2019) Plastic waste from recycling centres: Characterisation and evaluation of plastic recyclability, Waste Management, Volume 95, 2019, pp. 388-398

Feder Distribuzione (2020) Mappa distributiva supermercati totale Italia, accessed April 2020 <https://www.federdistribuzione.it/mappa-distributiva/>

Feil A., Pretz T., Jansen M., Thoden van Velzen E. U. (2016) Separate collection of plastic waste, better than technical sorting from municipal solid waste?, Waste Management & Research 1-9, doi: 10.1177/0734242X16654978

Flexible Packaging Europe (n.d.) Recycling, recovery and potentially enabling technology, accessed April 2020 <https://www.flexpack-europe.org/en/sustainability/recycling-recovery.html>

Fondazione per lo sviluppo sostenibile FISE UNICIRCULAR, Unione Imprese Economia Circolare (2019) L'Italia del riciclo 2019, accessed April 2020 <https://www.fondazionesvilupposostenibile.org/wp-content/uploads/dlm_uploads/L'Italia-del-Riciclo-2019.pdf> (Italian)

Forrest A, Giacovazzi L, Dunlop S, Reisser J, Tickler D, Jamieson A and Meeuwig JJ (2019) Eliminating Plastic Pollution: How a Voluntary Contribution From Industry Will Drive the Circular Plastics Economy. Front. Mar. Sci. 6:627. doi: 10.3389/fmars.2019.00627

Futerra sustainability communications (n.d.) The perfect fit: flexible solution for a more sustainable packaging industry, accessed April 2020 <https://www.flexpack-europe.org/files/FPE/downloads/ThePerfectFit.pdf>

Gandy S., Fry J., Downes J. (2008) Review of packaging deposit system for the UK, ERM, Reference 0088452

GESAMP (2015) Sources, fate and effects of microplastics in the marine environment: a global assessment (Kershaw p. J., ed.), IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection, Rep. Stud. GESAMP No. 90, pp. 96

Geyer R., Jambeck J. R., Law K. L. (2017) Production, use and fate of all plastics ever made, Science Advances, Vol 3. no 7, e1700782, doi:10.1126&sciadv.1700782

Geyer R., Kuczenski B., Zink T., Henderson A. (2015) Common Misconceptions about Recycling, Journal of Industrial Ecology, doi: 10.1111/jiec.12355

Grigore M. E. (2017) Methods of recycling, properties and applications of recycled thermoplastic polymers, Recycling, 2, 24, doi:10.3390,7recycling2040024

Hamer G. (2003) Solid waste treatment and disposal: effects on public health and environmental safety, Biotechnology Advances, V 22, issues 1-2, pp 71-79, doi.org/10.1016/j.biotechadv.2003.08.007

Hopewell J., Dvorak R., Kosior E. (2009) Plastics recycling: challenges and opportunities, Philos. Trans. R. Soc. Lond. B. Biol. Sci., 2009; 364(1526): 2115-2126. doi:10.1098/rstb.2008.0311

Horodytska O., Cabanes A., Fullana A. (2019) Plastic waste management: current status and weaknesses, The handbook of environmental chemistry, accessed April 2020 <https://link.springer.com/chapter/10.1007/698_2019_408>

Horodytska O., Valdés F. J., Fullana A. (2018) Plastic flexible films waste management - A state of art review, Waste Management, V 77, pp 413-425, doi.org/10.1016/j.wasman.2018.04.023

Infinitum (n.d.) Articles, accessed April 2020 <https://infinitum.no/english>

ISPRA (2018) Costi di gestione nazionali e per macroarea, accessed April 2020 <https://www.catasto-rifiuti.isprambiente.it/index.php?pg=costinazione>

Locock K., Deane J., Kosior E., Prabaharan H., Skidmore M., Hutt O, E. (2017) The recycled plastic market: global analysis and trends, CSIRO, Australia

Mckinlay R., Morrish L. (2016) REFLEX Project, Axion Consulting, accessed April 2020 <https://ceflex.eu/public_downloads/REFLEX-Summary-report-Final-report-November2016.pdf>

McKinnon D, Fazakerley J, Hultermans R, (2017) Waste sorting plants – extracting value from waste, ISWA, Vienna, Austria

Mieth A., Hoekstra E., Simoneau C. (2016) JRC Technical Reports: Guidance for the identification of polymers in multilayer films used in food contact materials, European Commission, doi:10.2788/10593

Morawski C. (2019) Update on Europe's new waste legislation, Reloop, accessed April 2020 <https://www.reloopplatform.org/wp-content/uploads/2019/03/Prague-January22_Reloop.pdf>

More Recycling Associates Inc (2016) 2015 National post-consumer plastic and film recycling report, American Chemistry Council, accessed April 2020 <https://plasticsrecycling.org/images/pdf/resources/reports/Film/2015Film_Report_FINAL.pdf>

Morris B. A. (2017) The science and technology of flexible packaging: multilayer films from resin and process to end use, ISBN: 978-0-323-24273-8

Niaounakis M. (2020) Recycling of flexible plastic packaging, Chapter 11: Economic evaluation and trends, p 395-425, https://doi.org/10.1016/B978-0-12-816335-1.00011-6

Nonclercq A. (2016) Mapping flexible packaging in a circular economy (FIACE), Deflt Univeristy of Technology, accessed April 2020 <https://ceflex.eu/public_downloads/FIACE-Final-report-version-24-4-2017-non-confidential-version-Final.pdf>

Opshaug J., Svamo E. (2017) Valuation of Tomra systems ASA, Nord universitet, accessed April 2020 <https://nordopen.nord.no/nord-xmlui/bitstream/handle/11250/2565632/OpshaugogSvamo.pdf?sequence=1&isAllowed=y>

Pilz H., Brandt B., Fehringer R. (2010) The impact of plastics on life cycle energy consumption and greenhouse gas emissions in Europe, Denkstatt GmbH, accessed April 2020 <https://www.plasticseurope.org/application/files/9015/1310/4686/september-2010-the-impact-of-plastic.pdf>

Plastic Recyclers Europe (2019) Flexible polyethylene recycling in Europe: Accelerating the transition toward circular economy, accessed April 2020 <https://www.pac.gr/bcm/uploads/flexible-pe-recycling-in-europe_june-2019.pdf>

Plastic ZERO (2012) Action 3.1: Survey on existing technologies and methods for plastic waste sorting and collection, accessed April 2020, <cfm?fuseaction=home.showFile&rep=file&fil=PLASTIC_ZERO_action3.1_collection_and_sorting_technologies_final_july_2012.pdf>

Plastic ZERO (2013) Report on assessment of relevant recycling technologies, accessed April 2020, <https://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=home.showFile&rep=file&fil=PLASTIC_ZERO_annex_d32_action4.2_report_on_assessment_sept2013_final.pdf>

PlasticsEurope (2017) Plastics - Increasing Circularity and Resource Efficiency, accessed April 2020 <https://e.issuu.com/embed.html#14847134/53141242>

PlasticsEurope (2017) PlasticsEurope's Views on a Strategy on Plastics, accessed April 2020, <https://e.issuu.com/embed.html#14847134/53141242>

PlasticsEurope (2018) Plastics-The facts 2018: An analysis of European plastics production, demand and waste data, accessed April 2020 <https://www.plasticseurope.org/application/files/6315/4510/9658/Plastics_the_facts_2018_AF_web.pdf>

PlasticsEurope (2019) Plastics-The facts 2019: An analysis of European plastics production, demand and waste data, accessed April 2020 <https://www.plasticseurope.org/application/files/9715/7129/9584/FINAL_web_version_Plastics_the_facts2019_14102019.pdf>

PlasticsEurope (n.d.) Plastics 2030, accessed April 2020 <https://www.plasticseurope.org/application/files/6115/1700/8779/PlasticsEurope_Voluntary_Commitment_16012018.pdf>

Rada E. C, Ragazzi M., Torretta V., Castagna G., Adami L., Cioca L. I. (2018) Circular economy and waste to energy, doi: 10.1063/1.5039237

Ragaert K., Delva L., Van Geem K. (2017) Mechanical and chemical recycling of solid plastic waste, Waste Management, V. 69, pp. 24-58, doi.org/10.1016/j.wasman.2017.07.044

RecyClass (2019) PE coloured flexible film, accessed April 2020 <https://recyclass.eu/wp-content/uploads/2019/11/PE-Coloured-Flexible-films-guidelines-11-2019-2.pdf>

RecyClass (2019) PE transparent flexible film, accessed April 2020 <https://recyclass.eu/wp-content/uploads/2019/11/PE-Transparent-Natural-Flexible-films-guidelines-29-11-2019-2.pdf>

RecyClass (2019) PP coloured flexible film, accessed April 2020 <https://recyclass.eu/wp-content/uploads/2019/07/PP-Coloured-Flexible-films-guidelines-15-12-2017.pdf>

RecyClass (2019) PP transparent natural flexible film, accessed April 2020 <https://recyclass.eu/wp-content/uploads/2019/07/PP-Transparent-Natural-Flexible-films-guidelines-15-12-2017.pdf>

RecyClass (2019) The recyclability tool for plastic package, accessed April <https://recyclass.eu>
Reloop (2016) Deposit return system: handling fees, accessed in April 2020 <https://www.reloopplatform.org/wp-content/uploads/2017/09/Fact-Sheet-Handling-Fees-New.pdf>

Reloop (2019) Impact of Deposit Return System on French Municipalities in Meeting EU Packaging Recycling Targets, accessed April 2020 <https://www.reloopplatform.org/wp-content/uploads/2020/02/Eunomia-Study-One-pager-v5.pdf>

Ritchie H. (2018) FAQs on plastics, Our World in Data, accessed April 2020 <https://ourworldindata.org/faq-on-plastics#how-much-plastic-and-waste-do-we-produce>

Robertson I. (2015) Characterizing polymer laminates using IR Microscopy, PerkinElmer Inc, accessed April 2020 <https://labsense.fi/uploads/7/1/9/5/71957143/characterizing_polymer_laminates_using_ir_microscopy_012074_01_app.pdf>

RRS (2016) Flexible packaging sortation at materials recovery facilities: research report, Materials Recovery For The Future (MRFF), accessed April 2020 <https://www.materialsrecoveryforthefuture.com/wp-content/uploads/2016/09/Flexible-Packaging-Sortation-at-Materials-Recovery-Facilities-RRS-Research-Report.pdf>

Rubel H., Jung U., Follette C., Meyer zum Felde A., Appathurai S., Diaz M. B. (2019) A circular solution to plastic waste, accessed April 2020 <https://www.bcg.com/publications/2019/plastic-waste-circular-solution.aspx>

RVMsystems AB (n.d.) RVM systems solutions, accessed April 2020 <https://www.rvmsystems.com/solutions/>

Ryberg M. W., Laurent A., Hauschild M. (2018) Mapping of global plastics value chain and plastics losses to the environment, United Nations Environment Programme, accessed April 2020 <https://gefmarineplastics.org/files/2018%20Mapping%20of%20global%20plastics%20value%20chain%20and%20hotspots%20-%20final%20version%20r181023.pdf>

Saperatec GmbH (n.d) Saperatec back to values: Technology, accessed April 2020, <https://www.saperatec.de/en/technology.html>

Schmidt C., Krauth T., Wagner S. (2017) Export of Plastic Debris by Rivers into the Sea, Environ. Sci. Technol. 2017, 51, 12246-12253

Sherrington C., Cordle M., Elliott L., Kelly J., Kemp S., Lugal L., Woods O. (2019) A DRS for Turkey, Reloop, Isbak, Eunomia, accessed April 2020 <https://www.reloopplatform.org/wp-content/uploads/2019/10/Turkey-Report-Final.pdf>

Sielaff (n.d.) Sione series, accessed April 2020 <https://www.sielaff.com/fileadmin/downloads/Prospektmaterial/2014/Englisch/Prospekte/SiOne_Broschuere_EN.pdf>

SiWare Sytems (n.d.) NeoSpectra-Micro, accessed April 2020 <https://www.neospectra.com/our-offerings/neospectra-micro/>

Sustainable packaging coalition (2020) Mechanical recycling options, accessed April 2020 <https://sustainablepackaging.org/multi-material-flexible-recovery-mechanical-recycling/>

The Environmental literacy council (n.d.) What is waste?, accessed April 2020 <https://enviroliteracy.org/environment-society/waste-management/what-is-waste/>
Tomra (n.d) Tomra sure return, accessed April 2020 <https://www.tomra.com/en/collection/reverse-vending/reverse-vending-systems/technologies/sure-return>
Tomra (n.d) Tomra T70 single and dual, accessed April 2020 <https://www.tomra.com/en/collection/reverse-vending/reverse-vending-systems/standalone-line/t70-single-and-dual>

Trautwein sb Technik (n.d.) RC 120, accessed April 2020 <https://trautwein-sb.de/rc-120/?lang=en>

UNEP (2018) Single-use plastics: A roadmap for sustainability, United Nations Environment Programme, accessed April 2020 <https://wedocs.unep.org/bitstream/handle/20.500.11822/25496/singleUsePlastic_sustainability.pdf?isAllowed=y&sequence=1>

USAD (2018) Lithuania's Deposit System, Public Institution Uzstato Sistemos Administratorius, accessed April 2020 <https://www.reloopplatform.org/wp-content/uploads/2019/03/USAD-ppt.pdf>

Wincor Nixdorf (2010) Reverse vending and retail: the perfect match, accessed April 2020 <https://docplayer.net/59037243-Wincor-nixdorf-reverse-vending-and-retail-the-perfect-match.html>

WRAP (2010) Near infrared sorting of household plastic packaging, accessed April 2010 <https://www.wrap.org.uk/sites/files/wrap/NIR%20Good%20practice%20guidance%20for%20existing%20NIR%20users%20Final.pdf>

WRAP (2016) Plastics market situation report, accessed April 2020 <https://www.wrap.org.uk/sites/files/wrap/Plastics_Market_Situation_Report.pdf>

ZeroWasteEurope (2019) Deposit Return Systems: an effective Instrument towards a Zero Waste Future, accessed April 2020 <https://zerowasteeurope.eu/2019/07/deposit-return-systems-an-effective-instrument-towards-a-zero-waste-future/>

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