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Flexible plastics in Europe's circular economy

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1 Introduction

In 2021 the EEA published a report exploring the main challenges involved in transitioning towards a circular plastics economy. Recognising that plastics play an essential role in modern society, action is needed to reduce their impacts on the environment and move towards a more circular and sustainable plastics system. Three focal pathways (smarter use; increased circularity; and use of renewable raw materials and decarbonisation) were reviewed, all supporting the continued longer-term move towards a sustainable and circular plastics system.

Building on that work, EEA is now in focusing on a particular plastic waste stream which is considered particularly challenging in terms of circularity, showing gaps both with regards to recovery and end-of-life processing. This work is intended to advance the knowledge on flexible plastics and interest in its position in a circular economy. It will provide an evidence-based update on the current situation, with an emphasis on moving forward. The report draws on sources in academic and grey literature, market reports and expert interviews. It tells the story of flexible plastics, their main uses and current management options and looks at their place in a European circular economy

In the next sections, the journey of flexible plastics is followed from cradle to cradle. The first section gives some context on the plastic types and their main applications. These products and applications are discussed in Section 1.2. The journey of flexible plastics ends when products have fulfilled their useful life. When collected and offered for recycling, the waste plastics can be recycled into a limited number of secondary raw materials, which is discussed in Section 1.3. Finally, in Section 1.4, a summary is provided of the challenges involved in the cycling of flexible plastics in a circular economy. These are further developed in the core chapters of the report.

1.1 What are flexible plastics?

Popularly, flexible plastics are plastics that can be scrunched easily in your hand. The opposite are hard or rigid plastics that cannot be scrunched into a ball but are moulded and hold their shape. This distinction made in common parlance is used in this report as it is intuitive and easy to understand.

Most plastics, also called resins, have polymers as a main ingredient, with varying concentrations of additives providing the exact performance or appearance needed for a specific application. Additives include plasticisers, flame retardants, heat stabilizers, fillers, impact modifiers, antioxidants, colourants, lubricants and light stabilisers.

Flexible plastics products are usually films, either mono- or multilayer. Monolayer film consists of a polymer sheet, the thickness of which normally lies within the range of 20–200 micrometre (µm). These films are commonly used in the production of secondary and tertiary **packaging** such as stretch film and in **agricultural** and **building** applications. Multilayer films are made of a number of sheets including both different polymers and other materials, such as paper or aluminium foils. Multilayer films can contain 2–17 different layers, depending on the desired barrier qualities, which are determined by the product the film is designed to protect. The different layers deliver excellent barrier properties with an overall lower use of plastic raw material. Their most important application is primary packaging for perishable products. In recent years, ever thinner films have come on to the market providing lighter-weight packaging and reducing the use of plastics

Flexible plastics are mainly used in packaging, building & construction, and agriculture sectors.

1.2 Materials and applications

The polymers most frequently employed to produce flexible plastics are low density polyethylene (LDPE) used for plastic bags, wraps and as a waterproof layer in liquid packaging board; high density polyethylene (HDPE) in bags, house wraps, geomembranes and envelopes; and polypropylene (PP) and biaxially-oriented polypropylene (BOPP) which are used, for example, in packaging labels and medical grade plastics.

Other polymers and polymer types include:

- polyethylene terephthalate (PET) used, for example, in tape and monofilaments for agricultural applications;
- polyvinyl chloride (PVC) used, for example, in extruded wire covering, film and fabric covering and geomembranes;
- polystyrene (PS) used, for example, in packing and thermal insulator foam;
- biaxially-oriented polyethylene terephthalate (BOPET) used, for example, in food packaging and thermal insulation;
- ethylene-vinyl alcohol copolymer (EVOH) used, for example, in food and medical packaging with high gas barrier qualities;
- polylactic acid (PLA) used, for example, in sweet wrappers and label film.

In general, these polymers, with the exception of PLA which often is mostly produced from biological sources, are derived from fossil sources. The molecular composition of the polymer will determine the range of possible recycling outputs. Most of the polymers used in flexible plastic applications are polyolefins derived from ethylene that is produced from the steam cracking of fossil-based naphtha and/or ethane. This includes the different types of PE, PET, PS and PVC (Petrochemistry Europe, 2019). In the case of PLA, lactic acid is used as a monomer. Lactic acid can be produced by chemical synthesis using fossil resources as a feedstock, but also by microbial fermentation of biomass. PLA resins are used to produce sheet and films.

The pure polymer is combined with varying concentrations of a range of additives, and sometimes with other polymer types, to produce plastics with specific, customised properties. The resulting typically very light films are increasingly used due to their versatility. And their increasing volumes in waste are both the result of increasing numbers of applications and the growing demand for packaging.

Table 1.1 gives an overview of main application areas and uses of multi- and monolayer flexible plastics.

Table 1.1 Overview of plastic film applications

Packaging	Monolayers: bags, stretch film, can liners, textile packaging, flower wrapping
	Multilayers: food and chemical packaging, sweet wrappers, food bags
Agriculture	Monolayers: greenhouse and tunnel films
	Monolayers: mulch films, bags and sacks, protection of agricultural products, silage covers
	Multilayer: packaging for food products
Construction	Monolayer: construction film, protection of construction products
	Multilayer: flooring

1.3 From discarded product to recycled material

When products made of or containing are discarded by households, commerce and industry, they are categorised as waste. When that waste is collected, either as mixed municipal solid waste comingled with non-plastic material fractions or through separate collection systems, it has the potential of being recycled. Plastics-containing waste that is discharged into the environment, landfilled or incinerated after collection is, however, lost as a resource.

Box 1.1 Definition of waste recycling

In the context of the current analysis, waste is defined as any substance or object which the holder discards or intends or is required to discard, in line with Article 3 of the **Waste Framework Directive 2008/98/EC**, amended by Directive (EU) 2018/851. Recycling means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling. This definition implies that **only waste can be recycled**, and that it can **only be recycled once (*)**. From the moment waste has been recycled it can be used as a secondary raw material for the production of new products. However, once recycled materials, molecules or elements have been integrated in a product, they cannot be distinguished anymore from their primary equivalents; a recycled copper atom does not behave differently from a copper atom produced from ore, and recycled polypropylene has exactly the same molecular structure as compared to polypropylene made by oil and gas processing. Products of which the recycled content has been documented and certified, can become waste again. From this point, the materials contained in the product can be recycled, and the generated recyclate be used as recycled content This means recycled content concentrations in products always refer to the last cycle only.

(*) *This was confirmed by the 19 June 2003 judgement of the European Court of Justice, with respect to Case C-444/00 Mayer Parry Recycling Ltd.*

In general, a recycling process consists of consecutive steps, with activities and processes performed by dedicated companies often at different locations. An overview is given in Figure 1.1.

Figure 1.1 Plastics waste recycling process steps

Waste collection

- Separate curbside collection **at source** of generated waste that contains discarded products that partially or entirely consist of plastics, for example, liquid-packaging board.
- Collection **at bring points**, including civic amenity sites and deposit/refund redemption centres or retailers.
- Post sorting of municipal solid waste.
- Collection of production residues containg plastics **at industrial facilities**.

Waste sorting

Automatic (optical and/or density based) and/or manual sorting often connected with the recycling facility. Results in **separated, concentrated and homogenous material fractions**, and the removal of some contaminants. Baling for shipment or direct recycling at the recycling facility.

Plastics recycling

The industrial activity that accepts plastic-enriched material fractions from waste generators, dismantlers, and sorters, and involes further separation and the removal of contaminants.

- Recyclers carry out mainly **mechanical operations**, including size reduction, to produce saleable grades of mixed or discrete plastic resin types (pellets).
- Chemical recyclers apply **chemical treatments** to sorted plastics, to produce oligomers, monomers, or solid, liquid and gaseous hydrocarbons and other substances for use in the chemical industry.

Market uptake

Trade of recyclates (pellets or chemical feed stock) and their **conversion** into intermediate or finished goods. The recyclate is typically a drop in with the major part being virgin material to ensure product quality.

Secondary raw materials obtained from flexible plastics vary with the collection system, the efficiency of sorting techniques, the choice of the recycling technologies, and the chosen target output material. Each step generates some residual material, which is not suitable for recycling.

Annex 1 contains more detailed information on currently applied recycling processes and their outputs.

1.4 Challenges related to flexible plastics

Broadly, flexible plastic waste presents the same issues as others plastic wastes. Production is increasing globally, yet less than a fifth is recycled. The environmental consequences of plastic are significant. As plastic does not break down naturally, it pollutes natural systems, including rivers and oceans.

The production, use and disposal of plastics also generate significant greenhouse gas emissions throughout their lifecycle. In the context of the United Nations Framework Convention on Climate Change (UNFCCC) goal of limiting global warming to 1.5º C, the Center for International Environmental Law estimates that greenhouse gas emissions from plastic could make up 10–13 per cent of the entire remaining carbon budget by 2050 (James, 2019). Amongst flexible plastics, PET film production has the largest carbon footprint, generating up to 4.5 kilograms (kg) of greenhouse gases per 1 kg of PET film, 60 per cent from the use of processing fuel and 28 per cent from the use of electricity. The climate impact of the production of flexible plastics, however, very much depends on the specific polymer type. High-density polyethylene film production, for example, accounts for less than half the amount emitted per kilogram of PET (Li et al., 2022).

Flexible plastics present particular additional challenges, set-out below:

- use and circularity:
  - increasing production and use, especially in packaging applications due to its convenience and light weight;
  - flexible plastics are often used in products and/or circumstances with a high risk of diffusion to the environment, either by littering of, for example, on-the-go snack wrappers, or because of the absence of effective waste management systems;
  - short lifetimes with limited reuse possibilities due to issues of contamination or durability.
- waste management:
  - end-of-life flexible plastics are generally low-value material and without (regulatory) incentives, there is little economic incentive to invest in good end-of life management;
  - many products are composite material, such as multilayers, which present fewer options for recycling. Multilayer materials are not compatible with mechanical recycling, which, to produce economically attractive outputs, requires separation of the plastic waste into mono-material feeds;
  - recycling flexible plastics is challenging especially when it is mixed in with other waste and when the material consists of multilayers. Mono-material flexible plastics can be processed in established mechanical recycling systems;
  - flexible plastics waste is often significantly contaminated – for example, by food residues in packaging or soil in agri-plastics. Contamination can be as high as 50 per cent by weight of the plastic waste. Rigorous washing is normally needed before processing, adding to the costs and use of resources;
  - it is also noted that when a mechanical recycling installation is not equipped with a dedicated film and foil separation step, the presence of films and foils, such as in retail bags, can physically hinder subsequent pre-treatment steps;
  - though technically flexible plastics can be recycled, their presence in plastic waste flows can cause mechanical problems. Flexible plastics, such as plastic bags, tend to become tangled in recycling machinery, risking process stops with consequent time and monetary losses in the entire recycling process (Plastics for Change, 2021).

2 Current and projected volumes

2.1 Production and market demand

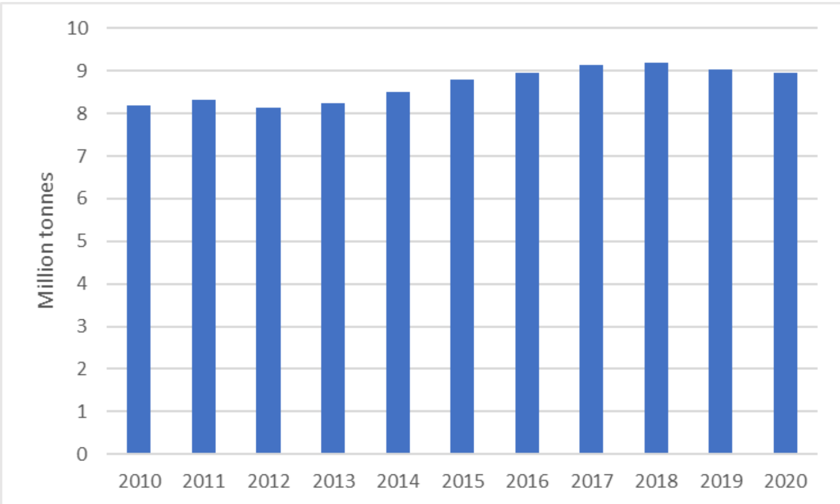
Global annual plastic production has increased in the last decade and was estimated to be around 367 million tonnes in 2020, with Asia producing 49 per cent, followed by 19 per cent produced in the North American Free Trade Agreement (NAFTA) countries (Canada, Mexico and the United States), Europe 15 per cent, and the Middle East and Africa 7 per cent. In Europe, the production of plastics has been relatively constant since 2010, albeit with a slight decrease since 2016. In 2020 about 55 million tonnes of plastics were produced in EU27+3 countries ([1]), and the plastic industry demand reached 49.1 million tonnes. The six European countries, namely Germany, Italy, France, Poland, Spain and the UK, accounted for almost 70 per cent of this demand in 2020 (PlasticsEurope Market Data, 2021).

Among industrial sectors, flexible plastics are mainly used in packaging, building and construction, and agriculture. Between 2010 and 2020, these three sectors represented around 64 per cent of the end-user market for plastics in Europe (PlasticsEurope Market Data, 2021).

2.1.1 Flexible packaging

Based on the Applied Market Information (AMI) 2019 European Polymer Demand Report (CEFLEX, 2022), about 45 per cent of plastic packaging in the EU is flexible packaging including that used in consumer and industrial applications. Assuming that the same ratio applies since 2010 and using the publicly available data on plastic production (PlasticsEurope Market Data, 2021), the amount of flexible plastics used for packaging in Europe is estimated to be 8.2–9.1 million tonnes between 2010 and 2020 (Figure 2.1).

Figure 2.1 Estimated amounts of plastics used in Europe for flexible packaging, 2010–2020, million tonnes



Source: AMI 2019 European Polymer Report of 2019 (CEFLEX, 2022) and Plastics Europe's Market Research and Statistics Group (PEMRG), 2010–2021

The types of polymer used in the packaging industry in EU27+3 in 2021 are estimated and compared in Figure 2.2. Low-density polyethylene including linear low-density polyethylene (LLDPE), HDPE, PP and PET

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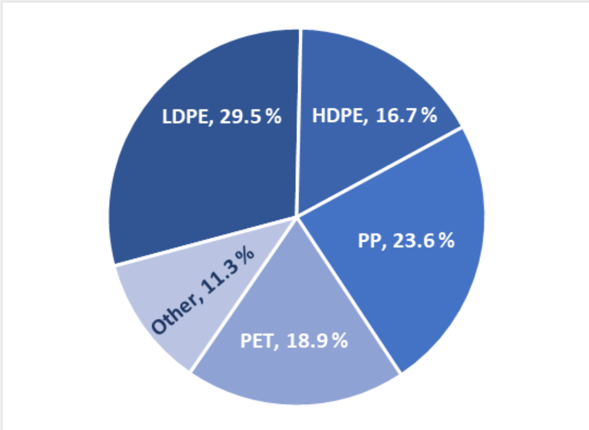
[1] EU 27+3 is made up of the EU (Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden) + Switzerland, Norway and the UK.

are the most frequently used polymers in production of plastic packaging. Based on the AMI 2014 European Polymer Demand Report (Nonclercq, 2016), more than 40 per cent of the materials used for production of flexible packaging in Europe are PE (LDPE, LLDPE and HDPE) polymer types. Based on the 2019 AMI Report (CEFLEX, 2022), 60 per cent of consumer flexible packaging was mono-material, while PE mono-materials accounted for around 90 per cent of commercial and industrial packaging.

Figure 2.2 Share of polymer types used in packaging, Europe, 2020, per cent



Source: Plastics Europe's Market Research and Statistics Group (PEMRG), 2021

Flexible plastics mainly used for household packaging applications are produced in form of:

- plastic film: made and used as sheet materials for food protection and packaging for a large range of products, including food, cleaning products, cosmetics and personal care).
- plastic bags: different types of bags from consumer items (such as sandwich/freezer bags etc.) to carrier bags provided by retailers;
- plastic pouches: due to their strong self-supporting and sealable qualities, pouches are now more frequently used as food packaging.

(WRAP, 2016)

2.1.2 Agriculture

In Europe, the demand of plastics in the agricultural sector has slightly decreased since 2017 and, for 2020, was estimated to be 1.8 million tonnes in 2020, 3–4 per cent of the total European demand. As indicated in a recent study by the Food and Agriculture Organization) of the United Nations (FAO) (FAO, 2021) there is a gap in the availability of data on the quantity of plastics used in different agricultural sectors and in most cases, the data needed to be derived from a range of different sources and based on a set of assumptions. More specifically, there is a lack of data for plastics used in the agri-food value chain between the production and food packaging phases, including data on storage, processing, transportation and distribution.

Plastic products are used extensively in plant and livestock production, fisheries and aquaculture, as well as in distribution and retailing to enhance production and protect and maintain the quality of agricultural products. The type of products and the extent to which they are used, however, vary by region and by country depending on the level of mechanisation, the length of the supply chain and the dependence on exports (FAO, 2021).

Films, which generally represent the largest quantities of non-packaging plastics used in agriculture, are mainly used for the following applications:

- mulch films used in horticulture and fruit production to increase crop yields, improve efficiency of water use, control soil temperature and moisture and prevent nutrient loss and erosion, control weeds and reduce herbicide use;

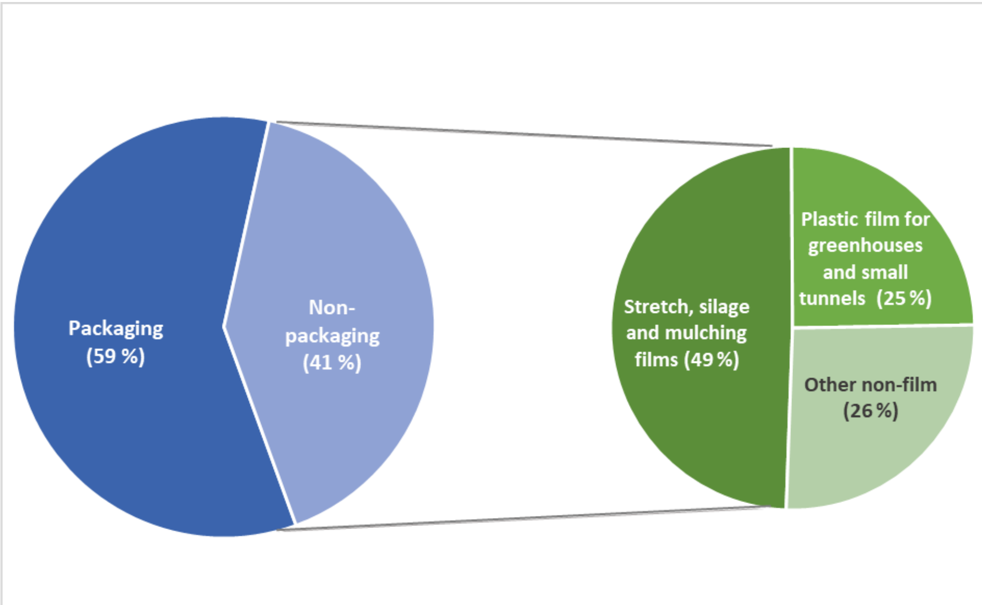
- flexible plastic grow bags, for example, for ornamental plants;
- greenhouses, walk-in high and low polytunnels, insulating non-woven textile fleeces used to extend growing seasons, increase yields, control the growing environment and reduce pesticide use;
- silage films to aid fermentation of grasses for animal fodder and avoid the need for storage buildings;
- light-weight plastics for reducing food losses and packaging in which final products are distributed or sold.

(FAO, 2021)

According to the FAO (FAO, 2021), in 2019 59 per cent of agricultural plastics were used for packaging and the remaining 41 per cent for non-packaging purposes. Flexible plastics in form of films account for 74% per cent of all non-packaging plastic types used for agricultural purposes (Figure 2.3).

Figure 2.3. Share of plastics used for packaging and non-packaging in the agricultural sector and the share of plastic film used for non-packaging purposes in Europe, 2019, per cent

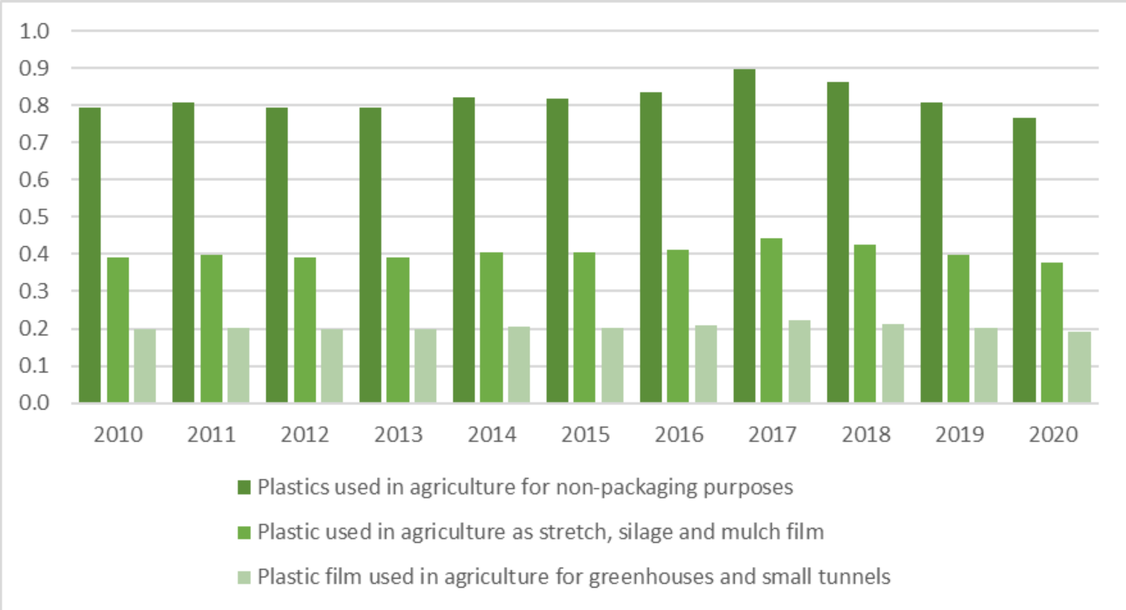
Figure 2.3. Share of plastics used for packaging and non-packaging in the agricultural sector and the share of plastic film used for non-packaging purposes in Europe, 2019, per cent



Source: Data readapted from FAO, 2021

Assuming that the above-mentioned ratios can be applied to Europe's plastic production data for 2010-2020 provided by Plastics Europe, the amount of flexible plastics used for the production of stretch, silage, mulch films and greenhouses and small tunnels is estimated and illustrated in Figure 2.4.

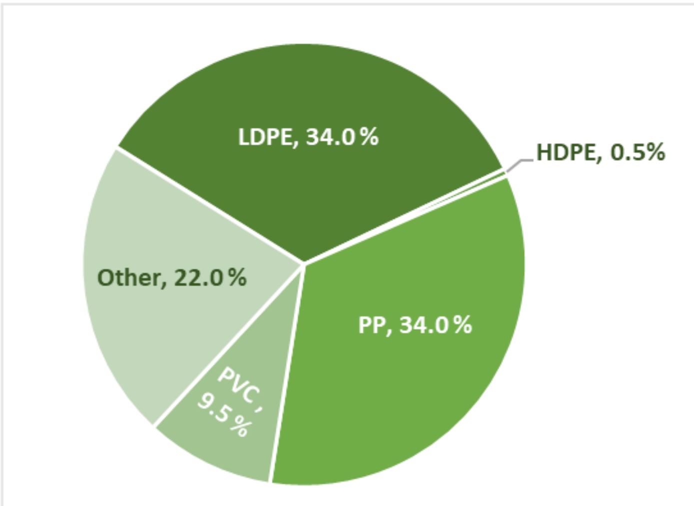
Figure 2.4 Estimated amount of plastics used in the agriculture sector, Europe, 2010-2020, million tonnes



Source: Data readapted from FAO, 2021 and Plastics Europe Research and Statistics Group (PEMRG), 2010–2021

As shown in Figure 2.5, the main polymer types used in the agricultural sector are PE (both LDPE and HDPE), PP and PVC. The dominant polymer used in film production is LDPE (Plastics Europe, 2021b).

Figure 2.5 Key types of polymer used in the agricultural sector, Europe, 2020, per cent



Source: Plastics Europe Market Research and Statistics Group (PEMRG), 2021

Given the large share of plastic films being used for silage, mulch, stretch greenhouses and small tunnels, it is estimated that at least 50 per cent of the film used in agriculture lasts for only one cropping cycle and then becomes waste (FAO, 2021), an important factor that needs to be considered in the design and waste management stages. In response to environmental and disposal issues, silage and mulching films made from biodegradable plastics have been introduced.

2.1.3 Construction

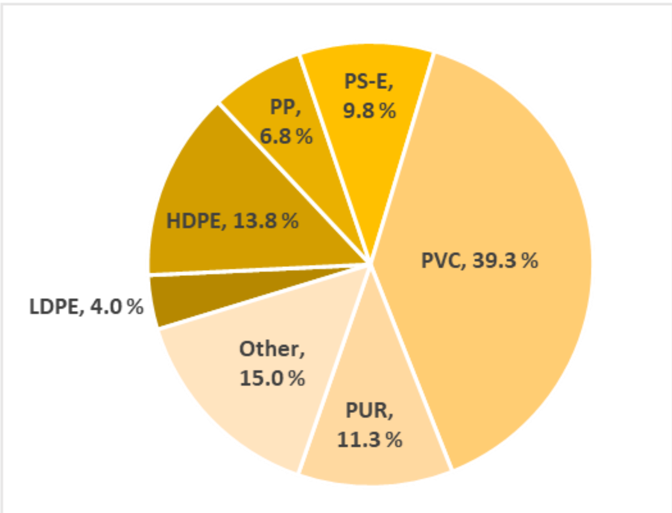
After the packaging industry, the building and construction sector represents the largest end-user of plastics in Europe. Between 2010 and 2020 on average 20.6 per cent of total demand for plastic in the EU27+3 was from this sector. Flexible industrial packaging is used in the construction industry to protect products from damage, contamination, moisture and weather conditions. The demand for flexible plastic sheeting has increased due to such properties as flexibility, resistance against corrosion and chemical attack, and lightweight nature, which makes it ideal for use in various applications.

Based on a recent study conducted by the German Environment Agency (UBA, 2021), flexible plastic packaging in the construction sector is mainly used for the following applications:

1. film used for construction products, installations and gardening. More specifically, film is of particular importance as transport packaging, mostly used to wrap palletised goods to secure loads and protect them from the weather;
2. stretch films and shrink wraps are mainly used for pallet packaging for building materials and installations. Shrink wraps are also used for gardening products;
3. padding materials used for construction and gardening products, and installations;
4. sacks for construction materials, construction chemicals and gardening products;
5. Indication tapes mainly used on construction sites and gardens;

The types of polymer used in the building and construction industry are shown in Figure 2.6 (Plastics Europe, 2021b). The polymers most commonly used for packaging purposes in this sector are LDPE, HDPE, PP and PET, together accounting for 87 % of all plastic packaging in the sector (UBA, 2021).

Figure 2.6 Key types of polymer used in the building and construction sector, Europe, 2020, per cent



Source: Plastics Europe Market Research and Statistics Group (PEMRG), 2021

2.2 Projected volumes

The wide-ranging benefits of flexible plastics, such as their low weight and lower fossil material input, and thus a reduced waste generation compared to rigid plastics, could lead to an increase in their global use in the future, in part driven by the growth of e-commerce and the increasing demand for food and beverage packaging (The Business Research Company, 2021). Indeed, the global flexible plastic packaging market is expected to increase by 3–4 per cent per year in this decade (Sazun, 2021; Frost & Sullivan, 2020). This growth could speed up as due to the increasing substitution of rigid plastic with flexible packaging for retail and consumer products to reduce the volume and weight of packaging and overall waste (Sazun, 2021). Pouches, for example, are gaining significant popularity as their production requires less raw material compared to rigid products such as bottles and jars. Moreover, the convenience of multiple closure options in pouches, such as a zippers, tear notches and (retractable) spouts, can reduce consumer transportation losses and therefore lead to an increase in demand (Mordor Intelligence, 2022). In the agricultural sector, the global film market is expected to increase by 50 per cent by 2030 (FAO, 2021).

As indicated in Chapter 1, recycling flexible plastics remains a challenge due to issues associated with the sorting or separation of resins. With a focus on the end-of-life process for multilayer products, the market is pushing towards developing mono-material products to facilitate the recycling process and is witnessing a gradual increase in the development of alternative bio-based plastics (Frost & Sullivan research, 2020)that are mainly used for food packaging and agriculture films. However, factors such as price and degradability of these types of plastics (which can be both bio-degradable or non bio-degradable) are important to be studied to compare their risks and ensure their environmental benefits for successful usage.

3 Policy framework

3.1 EU policies and strategies

The ambition of the European Green Deal is to build a climate-neutral circular economy, in which economic growth is separated from resource use. The New Circular Economy Action Plan, which is one of main constituents of the European Green Deal, was launched in 2020 and focuses on sustainable resource use, especially in resource-intensive and high impact sectors such as construction and building; packaging; plastics and textiles (European Commission, 2020a).

The European Plastics Strategy, published in 2018, aims to improve the economics, quality and uptake of plastic recycling and reuse, together with reducing plastic leakage into the environment, greenhouse gas emissions and the dependence on fossil fuels as a feedstock. Key objectives are also to keep the values of plastics in the economy and minimize waste. The Strategy is part of Europe's transition towards a circular economy and will also contribute to reaching the Sustainable Development Goals, the global climate commitments and the EU's industrial policy objectives.

The Strategy puts a special focus on the following.

- Single-use plastics (SUP) – products designed to be used once and then thrown away. Under the SUP Directive (Table 3.1), EU has banned certain single-use plastics. Furthermore 77 per cent of beverage bottles will have to be collected separately by 2025. and 90 per cent by 2029.
- Member States will have to significantly reduce their consumption of plastic food containers and cups used for beverages according to a timeline of six years after the new rules have been transposed.
- Plastics production and use and work towards the goal of ensuring that all plastic packaging is recyclable by 2030 ([2]).

Currently there is no EU law in place applying specifically to bio-based, biodegradable and compostable plastics. The Framework for bio-based, biodegradable and compostable plastics is an initiative of the European Commission foreseen to be adopted at the end of 2022. This initiative aims to promote bio-based, biodegradable and compostable plastics that lead to genuine environmental benefits. Consumers should be offered clear and trustworthy options. The initiative aims to contribute to a sustainable plastics economy. Parallelly, another initiative of the European Commission relates to restrictions on microplastics and measures to reduce the release of microplastics into the environment.

Additionally, in March 2022 the European Commission proposed a sustainable product initiative ([3]) within the New Circular Action Plan to widen the scope of the Ecodesign Directive (EU, 2009) beyond energy-related products to the broadest possible range of products. The proposal sets requirements, based on sustainability and circularity, for such aspects as durability and reliability, reusability, upgradability, reparability, the possibility of maintenance and refurbishment, the presence of substances of concern, energy and resource efficiency and recycled content.

Extended Producer Responsibility (EPR) is a tool to enhance recycling of specific products; it requires that producers are responsible for the waste management of their products, and also reaching set recycling targets. Typically, the producers are organised into a Producer Responsibility Organisation (PRO), and pay

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[2] https://eur-lex.europa.eu/resource.html?uri=cellar:2df5d1d2-fac7-11e7-b8f5-01aa75ed71a1.0001.02/DOC_1&format=PDF

[3] Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing a framework for setting ecodesign requirements for sustainable products and repealing Directive 2009/125/EC https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12567-Sustainable-products-initiative_en

a fee based on the products they put on the market; the sum of the fees should cover the expenses of waste collection and treatment for the end-of-life products. Extended Producer Responsibility systems exist in a number European countries for both rigid and flexible plastic packaging and, to a lesser extent, for agricultural plastics.

3.2 Regulation influencing plastic waste management

Table 3.1 provides an overview of regulations affecting plastic waste management.

Table 3.1 Overview of EU regulations and policies affecting plastic waste management

Code	Name	Type
1999/31/EC	Directive on the Landfill of Waste	Directive
2018/850	Amending Directive 1999/31/EC	Directive amending
1013/2006	Waste Shipment Regulation	Regulation
2020/2174	Amending Regulation 1013/2006	Regulation (amended)
1907/2006	Regulation concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)	Regulation
1272/2008	Amending Regulation 1907/2006	Regulation (amended)
2008/98/EC	Directive on Waste: Waste Framework Directive (WFD)	Directive
2018/851	Amending Directive 2008/98/EC	Directive (amended)
10/2011	Regulation on plastic materials and articles intended to come into contact with food, amendment 2020/1245	Regulation and amendment
94/62/EC 1994	European Parliament and Council Directive on Packaging and Packaging Waste	Directive
2018/852	Amending Directive 94/62/EC	Directive amending
COM/2020/98 final	A new Circular Economy Action Plan for a Cleaner and More Competitive Europe (GREEN DEAL)	Communication (pursuant to)
COM/2018/28 final	A European Strategy for Plastics in a Circular Economy	Communication
COM/2018/029 final	Communication on a monitoring framework for the circular economy	Communication
COM/2018/32 final	Communication on the implementation of the circular economy package: options to address the interface between chemical, product and waste legislation	Communication
COM (2018) 326 final	Proposal for a COUNCIL REGULATION on the methods and procedure for making available the Own Resources based on the Common Consolidated Corporate Tax Base, on the European Union Emissions Trading System and on Plastic packaging waste that is not recycled, and on the measures to meet cash requirements of the Plastic Tax (GREEN DEAL)	Proposal for regulation
2019/904	Directive on the reduction of the impact of certain plastic products on the environment: Directive on Single-use Plastic Products (SUP)	Directive
2020/2151	Regulation laying down rules on harmonised marking specifications on SUPs listed in Directive (2019)/904	Regulation
	Restriction on microplastics & Measures to reduce the release of microplastics in the environment	proposal (Q4 2022)
	Policy framework for bio-based, biodegradable and compostable plastics	proposal (Q2 2022)

Source: EEA/ETC-CE

It is foreseen that the proposal COM (2018) 326 on Own Resources will be a major driver of plastics' recycling and will add an impetus to either a) an increase plastic recycling, including difficult plastics; or b) a reduction in the use of plastic. The plastics Own Resource, in place since 1 January 2021 in the EU budget, consists of a national contribution based on the amount of non-recycled plastic packaging waste. Member States contribute EUR 0.80/kg of their plastics packaging waste that is not recycled. A correction is applicable for less prosperous Member States.

Very relevant also for flexible plastics is the Directive on Single-use Plastic Products (SUP), which establishes different measures for different product categories. Though the ban imposed on certain the single-use plastics products concerns mostly non-flexible products, the Directive also establishes an obligation to reduce the use of food containers and beverage cups, some of which are flexible products. Regarding packets, wrappers and lightweight plastic carrier bags, the SUP Directive establishes the obligation to implement EPR schemes.

Moreover, certain products have been found to have significant littering impacts and the SUP Directive strives to limit their use through marking/labelling requirements, awareness-raising measures, and EPR obligations for producers. Such products include balloons (EPR and awareness-raising measures), wet wipes (EPR, labelling and awareness raising measures) and sanitary towels - pads, tampons and applicators (labelling and awareness raising measures) (Copello de Souza, 2019).

Table 3.2 summarises targets given for plastic waste in different regulations. New targets for minimum recycling or material recovery have been introduced affecting plastic waste management. Furthermore, the ban on the disposal of biodegradable waste in landfills in the Landfill Directive is typically implemented in Member States as a limit on the organic content and thus also affects plastic waste. Besides the target, Member States are also required to ensure separate collection of plastic waste and establish EPR schemes for packing waste. Furthermore, the Plastics Strategy requires that all plastic packing is reusable or recyclable by 2030 and also plastic sorting and recycling capacities are increased fourfold by 2030 compared to 2015.

Table 3.2 Summary of recycling targets for different waste streams relevant to flexible plastics, per cent . ***Note the new rules for reporting compliance with recycling targets.***

Targets	**Previous dates**	**By 2025**	**By 2030**	**By 2035**	Sources
Municipal waste – recycling target (all Member States excluding those with 5-year derogations *)	50 % (2020)	55 %	60 %	65 %	WFD, Directive 2008/988/EC, EU 2018/851
Landfill reduction target (all Member States excluding those with 5-year derogations)				-10 %	Landfill Directive 1999/31/EC, EU 2018/850
Recycling of packaging waste (all packaging)		65 %	70 %		Packaging Waste Directive 94/62/EC (EU, 1994), EU 2018/852
Plastics packaging **	2020: minimum recycling target 22.5 % by weight for plastics	50 %	55 %		
All plastic waste recycled			50 %		Strategy for Plastics 1/2018
Construction and demolition waste (all wastes) *Note: The European Commission shall by 2024 consider preparing-for-reuse and recycling targets for* construction and demolition waste *and its material-specific fractions* *	Recycling and reuse of 70 % by weight of non-hazardous construction and demolition waste (2020).				WFD, Directive 2008/988/EC EU 2018/851

* new rule on reporting by Decision 2019/2000 amending 2011/753/EU
** new rule on reporting by 2019/665 amending 2005/270

The calculation of recycling rates for packaging waste was changed in 2019 (new rule on reporting given in Decision 2019/665 amending 2005/270): the weight of recovered or recycled packaging waste shall be divided by the amount put on the market (here moisture content and non-plastic fractions in packaging waste are also considered). The earlier rate was calculated based on plastic waste sent for recycling in relation to the amount of waste generated. Eurostat has also published a guidance document on the calculation rules (Eurostat, 2021).

The European Commission has published the rules for verifying compliance with the WFD target for the recovery of waste. The reporting format for the data and for the quality check report are defined in the

Commission Implementing Decision (EU) 2019/1004. Data are required on waste treated and not sent for treatment. For construction and demolition waste reporting, a guidance has been published for clarifying the reporting obligations on the source for information on waste generated and the recommendations for the point of measurement, for example, output from a recycling plant ([4]).

Under the Waste Shipment Regulation (1013/2006), amendment (2174/2020) bans the export of plastic waste from the EU to non-Organisation of Economic Co-operation and Development (OECD) countries, except for clean plastic waste sent for recycling. Exporting plastic waste from the EU to OECD countries and imports to the EU will also be more strictly controlled. The aim is that these rules should end the export of plastic waste to third countries that often do not have the capacity and standards to manage it sustainably.

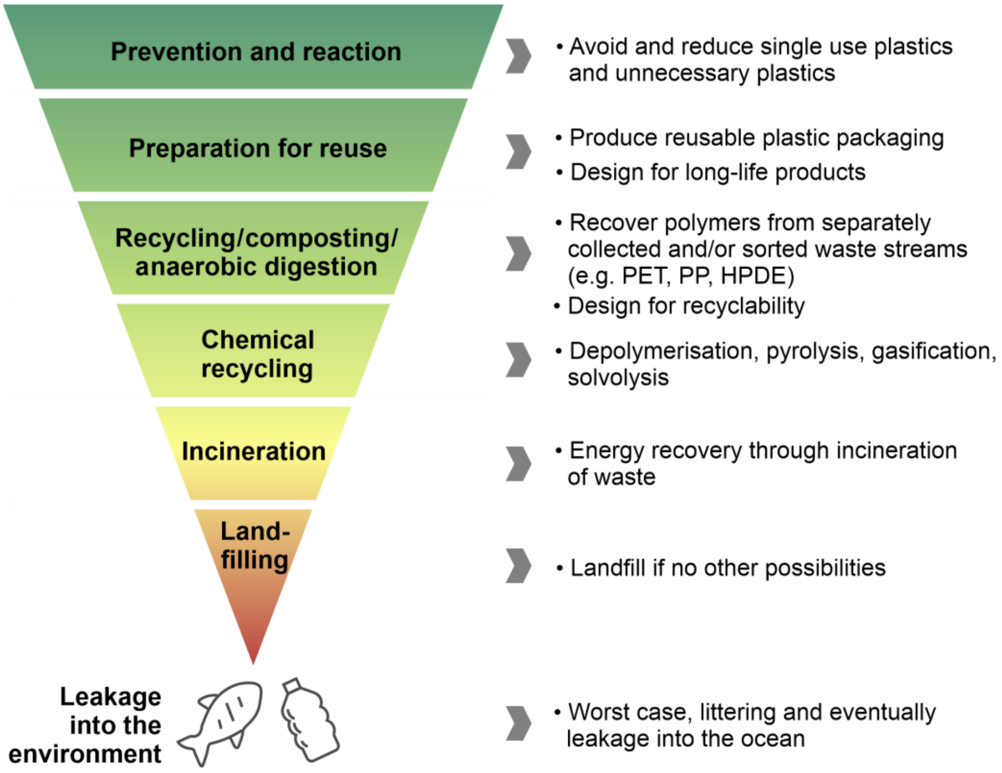
The EU Plastics Regulation on Food Contact Materials (EU 10/2011) contains a list of monomers and polymers aids that can be used as raw material for the manufacture of food contact plastics. Recycled plastic, such as PET bottles may also be used under certain conditions in food contact materials. A separate Regulation has been issued to control the recycling processes (Commission Regulation (EC) No 282/2008 on recycled plastic materials and articles intended to come into contact with foods).

3.3 The waste hierarchy

The key piece of the EU waste legislation, presented in WFD, 2008/98/EC amended by Directive (EU) 2018/851) relates to the waste hierarchy, which sets the highest priority on waste prevention, including the reduction of the use of plastics (Figure 3.1.). The WFD encourages member states to take measures to prevent waste generation by the reuse of products and the setting up of systems promoting repair and reuse activities, particularly mentioning construction materials and products. The European Plastic Strategy also emphasises the importance of the design of plastic products to ensure that they are reusable or recyclable.

[4] EC 2021. Reporting on material recovery of construction and demolition waste, guidance for the reporting of the data according to Commission Decision 2011/753/EU and Commission Implementing Decision (EU) 2019/2000. *Note: the rules and calculation methods for monitoring, which are set out in Commission Decision 2011/753/EU, remain unchanged from 2011, whereas the reporting format is slightly changed.*

Figure 3.1 The waste hierarchy according to Waste Framework Directive



Source: Rubel et al., 2019

4 Current management of flexible plastics waste

The EU's circular economy strategies and related recycling targets and directives have promoted the collection and utilisation of flexible plastic waste, although a significant proportion of flexible plastic waste still does not get recycled due to obstacles such as restricted collection, mixed waste streams and undeveloped end markets. In 2014, only 14 per cent of flexible plastic was recycled. In 2018, the ETH reported that to achieve the EU's 55 per cent recycling target for plastic packaging by 2030, countries would need to increase sorting capacity for flexible packaging by a factor of 2.6 and their recycling capacity by a factor of nearly five compared with the level in 2014 (ETH Zurich, 2018).

At the same time, smarter logistics has enabled the expansion of the collection of plastic film by non-profit and corporate agencies globally. This includes distributors backloading empty delivery trucks with waste, delivery to distribution centres for centralised collection and recycling, and retrieval of waste film alongside established paper and cardboard waste collections from retailers, and the centralised collection of agricultural films from farms.

Collection systems in Europe vary between countries and regions. The Horizon 2020 project "Collectors - Waste Collection Systems assessed, and good practices identified" has documented 135 waste collection systems in European cities and municipalities for the separate collection of paper and packaging waste, covering about 12 per cent of the EU's population. All over the European Union, these systems (i) target the same packaging products (ii) are governed by a common pan-European regulatory framework, and (iii) aim to collect packaging materials produced with the same technologies by globally active manufacturers and used by global brand owners. Nevertheless, the project found all 135 analysed collection systems to be different and unique. The diversity was observed to originate in different scopes, objectives and drivers, and the fact of operating in dissimilar socio-economic contexts. Harmonisation is seen as important for improving plastic waste collection, since the economic/competitive production of recycled plastics, monomers or chemicals from plastic-containing products require waste volumes that typically exceeds locally collected volumes.

Separate collection is essential. The recovery of flexible plastics from mixed household waste is technically challenging, although there are examples installations that can achieve it. Separate collection of plastic waste, possibly comingled with packaging made of other materials that are easy to separate from the plastic products, such as steel and aluminium cans, drink cartons and glass, facilitates the recycling of flexible plastics.

Contamination with food or soil remains a key restraint for the collection and recycling of flexible plastics. Moreover, in many countries film recycling can only be facilitated through store drop-offs and not through more convenient curbside collection.

Multilayer film, commonly used in the packaging of perishable products, cannot be segregated easily and thus cannot be mechanically recycled. Furthermore, laminating materials, typically ethylene-vinyl alcohol (EVOH) and polyvinylidene chloride (PVDC), and fluoropolymers are not easily recycled.

Box 4.1 Impacts of COVID-19 on single use plastic

One effect of the European response to the COVID-19 pandemic was the increase in the use of personal protective equipment, such as face masks and gloves, both in medical settings and by citizens.
Imports of face masks into the EU more than doubled compared to before the pandemic, and this increase occurred alongside EU production also increasing. The consumption of face masks in 2020 more than doubled compared to 2019 to > 0.75 masks per person per day. At the same time the consumption of plastic gloves increased by 80 per cent.
The growth in the use of masks comes with a climate impact. Graulich et al. (2021) estimated the production of each mask caused greenhouse gas emissions of 38-90 grams of carbon dioxide equivalent, which is equal to emissions from a 127–300 metre drive in a medium-sized petrol vehicle.
The littering of single use face masks and gloves has been a visible side effect of their increased use. This give also rise to significant ingestion and entanglement risks for animals and causes microplastics pollution (Adyel, 2020; Hirsh, 2020).
The effect on single use packaging again points in different directions. Although the closure of physical shops and restaurants together with financial uncertainty may have reduced consumption, a growth in online sales of goods was observed. This is linked to an increase in the use of plastic packaging for e-commerce.
The briefing by EEA on the environmental impacts of COVID-19 highlighted the importance of ensuring that society is better prepared for the continuing impacts of the pandemic (EEA, 2021).

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4.1 Current uptake of recycled flexible plastics

In recent years, the use of recyclate has grown strongly in Europe due to a combination of factors. These include improving public perception of it, a growing desire among brand owners and retailers to be perceived as operating sustainably, and technological advances that have increased its quality, allowing a greater use of recyclate in more applications.

The largest end uses of flexible plastics are non-food film, foil packaging and refuse bags. Smaller amounts are used for other bags/sacks, in building and construction and agriculture. Plastics Recyclers (2020) estimated that recycled flexible film output could supply 20 per cent of total demand for PE across non-food flexible film applications. Limitations in the use of for recycled flexible film due to the quality of outputs relate primarily to colour, additives and odour.

Significant development work has taken place in recent years to improve the performance of recyclates, as recycled resins often exhibit lower barrier properties than virgin alternatives. AMI recently estimated that the main source of feedstock for recycled film is the commercial sector, from which shrink and stretch PE wraps provide a consistent volume and quality of feedstock for film recyclers. Roughly 45 per cent of all PE recyclate produced came from feedstock from this source in 2021 (AMI, 2022).

4.2 Flexible packaging

Eurostat estimates that in 2019 41 per cent of plastic packaging waste was recycled in the EU (Eurostat, 2021). This figure includes both rigid and flexible packaging, but shows that the recycling of flexible packaging is considerably lower. Indeed, Plastics Recyclers (2020) has estimated that the rate of recycling of household flexible plastics across the EU is only 14 per cent. They further estimate that around 62 per cent of household and commercial PE flexible film is collected in Europe, 21 per cent originates from households and 41 per cent from the commercial sector (Thompson and Harkins, 2020).

The EU's Packaging and Packaging Waste Directive has driven the development of collection and recycling for flexible packaging and most countries have established EPR schemes for it (Europen, 2021). Moreover, several countries, notably Belgium, Denmark, France, Hungary, Iceland, Ireland, Italy, Portugal and Spain (Andalusia), apply a levy on plastic bags. The effects of these taxes have proved to be very positive in reducing the environmental impact of these. In Ireland, for instance, the levy on plastic bags has led to a 90 per cent drop in their use (Sastre et al., 2018).

Although in principle, flexible or thin plastics are not more difficult to treat than rigid ones, practical circumstances render recycling difficult. Nearly a quarter of all flexible plastic packaging material is used for food and will thus become contaminated with it. As a result of the flexible nature of the plastic, the food waste gets trapped within the folds of the packaging, rendering it unfit for recycling in many cases (Thompson and Harkins, 2020).

Flexible packaging is lightweight and often small in size, which makes it difficult for the current technology to pick the material out for recycling processing. Flexible packaging is also frequently used for perishable goods, calling for high functionability of the protective packaging material. To achieve that, flexible packaging is usually multi-layered, which means the different layered materials cannot be effectively separated for recycling. Waste characterisation is key for the efficiency of mechanical recycling leading to high-quality end-products, but conventional waste management systems are not designed to identify, sort and recycle multi-material multilayers. Today, multilayer packaging is often sorted as mixed plastic waste in post-consumer streams and frequently incinerated with energy recovery in European countries. Chemical recycling can provide a solution for multilayer materials and investment in this evolving technology is currently taking place in Europe as well as Asia and the United States (Mapleston, 2021).

Research has shown that perceived inconvenience hinders proper household sorting (CITEO, 2021; Rousta and Ekström, 2013), and that used paper and plastic packaging have high rates of mis-sorting, affected by, for example, the distance between local collection and residential areas. A large percentage of packaging is used for food, and food packaging is the most frequently mis-sorted fraction of household waste (Nemat et al., 2020).

Currently, most recycled flexible packaging ends up in applications that are different from their initial use. Major end uses of recyclate include composite lumber for applications such as decking and park benches, plastic bags and crates, and construction products including pipes, pallets and playground sets. Multilayer film is considered a contaminant and is thus used, depending on the type of material and its volume, in low value applications such as fishing floats (Niaounakis, 2020).

4.3 Flexible plastics in agriculture

Around 63 per cent of agri-plastic non-packaging waste generated in the EU was collected in 2019, with the fate of the remaining 37 per cent unknown. Despite having a high potential for recycling, only 24 per cent of non-packaging agri-plastic placed on the market annually is actually recycled – meanwhile, only 60 per cent of generated agri-waste is made up of plastic, with the remainder being contaminants in the form of soil and organic matter (Hann et al., 2021).

Recovery rates vary significantly by type of agri-plastic, and heavily contaminated fractions, such as mulch films and bale nets, are not recycled to a notable extent at present. The collection and recycling of greenhouse films is, however, relatively well established due to the high quality and comparatively less contaminated nature of this type of agri-plastic (Hann et al. 2021).

Based on reports from Spain, greenhouse and polytunnel film is often collected clean (15–20 per cent soil contamination rate) and its recycling is simple, while the recycling process for mulching film, which has higher contamination rates of 40-–60 per cent, is more complex. Greenhouse and polytunnel film, however, is used for longer than mulching film, 3–4 years compared to 1 year for the mulch, and the longer the use, the more degraded the material is when it is collected. The degradation of the collected waste material affects the quality of the recycled material.

A prerequisite for recycling is efficient collection, which is facing some major barriers across the EU. Mulch films are difficult to completely remove from the soil without tearing and thus fragments are remaining in the soil and act as a significant source of microplastic pollution (Zhang et al., 2021). Moreover, in many countries there are still insufficient economic and/or regulatory incentives for the separate collection of agri-plastic waste. With a few exceptions, most agri-plastic products do not have a positive value for recyclers, and therefore there is little economic incentive for waste managers to collect it separately. The legal requirement of separate collection of plastic waste, including waste from agriculture, has not yet been implemented in all EU Member States.

Furthermore, areas with separate collection schemes have relatively low rates of collection, largely due to a lack of awareness among farmers. For example, although a scheme for collection was launched in Germany in 2013, the rate of collection remains at 40 per cent (Plasteurope.com, 2019). The incentives for farmers to participate in the separate collection of agri-plastic waste may be insufficient and farmers may choose to burn their agri-plastic waste on site to avoid bearing the extra cost of separate collection.

On the other hand, examples from countries and regions where EPR systems have been implemented for agri-plastics indicate that high recovery rates are possible. Areas with compulsory or voluntary EPR systems, supported by strong regional enforcement, including Ireland, Norway and Sweden, report recovery rates in excess of 80 per cent. Key success factors are the involvement of all relevant stakeholders, guaranteed technical capacity for all steps involved and a carefully planned cost structure (Maloney, 2022).

Main technical barriers to recycling agri-plastics in the EU are high processing costs primarily due to high contamination rates. Mulch films are, in this respect, especially problematic, and even when best practice is applied, a contamination rate of 30–40 per cent can be expected. Another barrier is the low value and limited end markets for recyclate. The quality of pellets produced from agri-plastics is generally relatively poor, with exception of greenhouse film. Yields vary significantly by type of agri-plastic, with no reports of recycling mulch film and bale nets taking place in 2021. Across Europe, the major share of collected plastics is incinerated (Hann et al., 2021).

Box 4.2 Implementing an established collection system for agricultural film in Switzerland

Only small proportion of the 6,000–10,000 tonnes of construction and agricultural film used annually in Switzerland were recycled in 2019. As a response to this, since January 2022 the independent association ERDE Schweiz, in collaboration with the system operator RIGK, has implemented a system it established in Germany. Under it, silo/stretch film and nets are collected for recycling. If the recycling capacity in Switzerland is exhausted, the collected waste is exported to specialized recycling companies in the EU. The system is financed by subsidies from the agricultural film manufacturers. These contributions, which are in principle advance recycling fees, are received by the collection points to keep the total expenditure in logistics and further processing for the disposal company as low as possible.

4.4 Construction

Construction and demolition plastic waste is inheritably different and should be separated and treated differently. Construction waste contains a large amount of flexible plastic packaging used for protecting construction products, and other left-over installation products such as pipes and insulation. Demolition plastic waste also consists of (contaminated) pipes, insulation and flooring together with other materials the constituents of which may be unknown. Generally, continuous changes in the composition of construction and demolition waste due to the variety of building materials used at different times and collected in different regions create challenges for sorting and recycling.

The share of flexible plastic waste from construction activities (protective films, packaging, etc.) tends to be high, whereas demolition generates a considerable amount of hard plastic waste. Demolition waste may contain plastics from several time periods and substances which should not enter the recycling loop. Additionally, plastic flooring, made, for example, of PVC, is a considerable constituent of demolition waste. Based on a Swedish study, flexible plastics account for around 15 per cent of combustible waste, which also includes other plastics and wood (Ahlm et al., 2021). Although by weight, the proportion of plastic is minor compared, for example, to concrete and other heavier elements, the volumes of plastic waste can be considerable.

A variety of sorting processes for construction and demolition waste recycling are applied in different geographic areas in Europe (Hyvärinen et al., 2020). Separating plastic waste on construction sites is common practice today where space allows and based on economic and/or regulative incentives such as high disposal fees for mixed waste (Itälä, 2022; Ahlm et al., 2021). Post-collection separation of mixed construction and demolition waste also occurs using advanced sorting technology (Remeo, 2021). Several initiatives, including by Rampo in Finland and CirEm in Sweden are on-going to increase the recycling of plastics (Chalmers Industriteknik, 2020; LAB, 2021) and develop closed loops (Box 4.3).

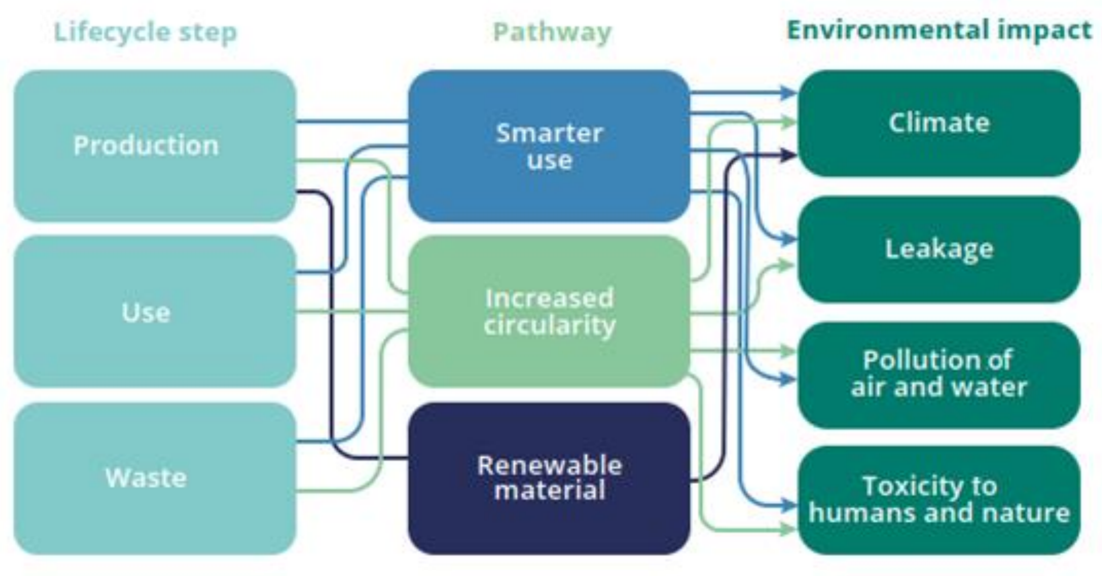
Box 4.3 The green deal in the Finnish construction sector

As a part of Finland's plastic road map, in 2020 Finnish public and private partners established a voluntary green deal with the aim of increasing the share of recycled plastic film on the market and decrease the share of incineration with energy recovery. The target is to recycle 40 per cent of the plastic film waste generated in construction by 2027. Several sectors, covering the whole value chain of plastic construction waste utilization have committed to the deal, including plastic film manufacturers, retailers, construction companies and circular economy experts. Activities include training and the production of guidelines, and commitments to include recyclates in production, reduce waste generation and include minimum requirements for source separation in public procurement of construction projects. As a critical factor for success is to ensure the quality of end products containing recyclate, material development involving research organizations will take place simultaneously (Kärhä, 2022).

5 Outlook: Improving sectoral circularity

The following chapter aim to give a view on possible directions for improving sectoral circularity of flexible plastics. The framework is the EEA's three pathways to circularity as set-out in the EEA/ETC report *Plastics, the circular economy and Europe's environment* (EEA, 2020). The three pathways are smarter use, increased circularity and renewable material. These pathways should not be seen as alternative options but rather as pathways that are in line with current policies and that offer options for continued policy development towards circularity and sustainability in the longer term (Figure 5.1) (Nielsen et al., 2018).

Figure 5.1 Scope of different pathways towards a more sustainable plastics system



Source: Nielsen et al., 2018

Moreover, several of the actions discussed in the following paragraphs link with key EU action for circular and sustainable products, which are:

- design to reduce products' environmental impacts;
- improve product sustainability information for consumers and supply chain actors;
- prevent destruction of unsold consumer products;
- promote more sustainable business models;
- increase green public procurement;

5.1 Three pathways to circular flexible plastics

5.1.1 Smarter use

Build demand for recycled content made from flexible packaging to support its wider use

The uptake of recycled plastics is much affected by the quality delivered. The supply of premium-grade recycled material is scarce, and in some countries, regulators may only allow chemically recycled plastics that are near or equal in terms of quality to virgin material. Although building chemical recycling plants for plastics is typically capital intensive and technologically complex, several large scale projects are currently being developed in Europe, for example, in Austria and the Netherlands (Mapleston, 2021). Several other European countries, however, including Germany, do not currently allow chemical recycling of plastics.

The supply of recycled material is currently insufficient to fully replace virgin plastics in the near term given current infrastructure, the technological and economic challenges and, most importantly, increasing demand for flexible plastics. The quality of recycled polymers is normally lower than that of virgin ones, and therefore the production of recycled plastic products normally includes a share of virgin polymers as well. Saying that, a good share of recyclates originating from used plastics films are used for plastic lumber or included in road asphalt. The global demand from such robust low-value applications is expected to grow steadily the coming years (bcc research, 2022; Pramukh et al., 2020).

Reuse of flexibles

Reuse systems for packaging are evolving, especially in food services. As durability and hygiene are key factors in such reuse systems, reusable packaging is almost always rigid, easily washable containers. Additionally, multilayer flexible packaging is increasingly being replaced by alternatives that make reuse easier, such as the use of glass jars for some food and cosmetic packaging (Taylor, 2022).

Beyond the food, medical and other sectors that have necessarily strict hygienic requirements, examples of flexible packaging reuse do exist. An increasing number of cosmetic and detergent businesses provide refill stations in shops for a both flexible and rigid packaging; E-commerce is increasingly promoting the reuse of its plastic envelopes for returning goods while trials are being carried out on more widely reusable plastic envelopes (Jenkins, 2020).

Awareness raising and training has also proven efficient in enhancing the reuse of some flexible plastic products and films in, for example, the agricultural sector (Maloney, 2022).

5.1.2 Increased circularity

Circular design

Major manufacturers are committed to improving the recyclability of packaging products. Considerable efforts are put on improving the recyclability of multilayer packaging, particularly that used for the perishable goods. The task is technically challenging as most packaging has been optimised to use the minimum material for a given function, which usually implies a multilayer structure. The industry is facing challenges in balancing material functionality and manufacturability with increased recyclability at a realistic cost. Major development strategies relate to designing simpler structures including multilayer made of the same material; more easily separated layers; and, for selected applications such as agricultural mulches, the introduction of bio-based or biodegradable alternatives.

Design guidelines for packaging recycling have been widely made available in the last few years. The Circular Economy for Flexible Packaging (CEFLEX) initiative (Box 5.1) has developed general guidelines for packaging design and these have been complemented with various national initiatives. The Netherlands Institute for Sustainable Packaging, for example, has published a roadmap containing a technical examination of current and future developments pertaining to the design and recycling of multilayer flexible plastic packaging materials (KIDV, 2020). Other tools to foster the design of more recyclable packaging materials have also been launched, such as Recyclass ([5]), which assesses compositions of packaging and suggests best practices for recyclability.

[5] https://recyclass.eu/recyclability/design-for-recycling-guidelines/

Box 5.1 Towards mono-material packaging

Trends towards mono-material packaging are increasing, especially in Europe encouraged by the CEFLEX consortium of more than 190 stakeholders who cover the complete packaging value chain. The organisation has launched a series of voluntary guidelines, *Designing for a Circular Economic* (D4ACE), aimed at increasing the recycling of flexible packaging (CEFLEX, 2022).

Design for recycling includes the maximisation of recyclable components in structures, the avoidance of hazardous or non-recyclable materials and the reduction of complexity. The guidelines focus on flexible packaging made of PE, PP and PE/PP mixes, and contain information and practical advice on designing polyolefin-based flexible packaging to be recyclable, covering the key structural elements. These include setting limits on specific materials and elements to enable designers to maximise the sortability and recyclability of their flexible packaging.

The EU's Sustainable Product Initiative, which will revise the Ecodesign Directive, aims to make products placed on the EU market more sustainable. Ecodesign concerns a broad range of products and lays down a framework for setting ecodesign requirements based on sustainability and circularity aspects, such as product durability, reusability, upgradability and reparability, the presence of substances of concern, energy and resource efficiency, the recycled content of products, product remanufacturing and high-quality recycling, and reducing products' carbon and environmental footprints. The proposed regulation will enable the setting of rules for any physical product placed on the market.

As for packaging, the proposal may complement the Directive on Packaging and Packaging Waste (94/62/EC), which is also being revised, by setting product-based requirements focussing on the packaging of specific products when placed on the market. Such complementary requirements would aim to minimise the amount of packaging used, and in turn contribute to the prevention of waste generation in the EU.

Enhanced collection

As a response to EU's recycling target for packaging waste, municipalities are increasingly providing curb side collection of separated waste fractions. While separation at source reduces the amount of mixed municipal solid waste which normally goes to incineration or landfill, evidence suggests the efficiency of such systems is questionable as it is reliant on citizens' commitment to separate their waste (Dijkgraaf and Gradus, 2020; HSY, 2019). Post-collection separation has evolved as a solution to this flaw and installations, based on optical identification and mechanical separation, are becoming serious alternatives or complements to source separation in, amongst others, the Netherlands, Norway and Sweden (Eriksson, 2021; Gradus, 2020; Syversen, 2019). In addition to increased recovery rates of plastic waste, another benefit is the lower carbon footprint of waste incineration due to reduced fossil input.

Recycling technology development

Cleaning plastic packaging film is an integral part of the plastic film recycling process and only clean or cleaned PE and PP flexible packaging is currently recycled on an industrial scale. Solutions for water reuse are pivotal to achieving sustainability (Altieri et al., 2021). Dissolution, purification and chemical recycling technologies that can handle multi-material and multilayer packaging are currently in different stages of development. Globally, chemical recycling is new, so the infrastructure to provide feedstocks is still catching up with the technology – current recycling technology companies and investors are partnering with waste management organisations, who are their feedstock providers, to secure raw material for their facilities.

Compared with mechanical recycling, chemical recycling is a more complicated processes, which is often associated with larger investment needs and energy requirements compared to mechanical processes. Chemical recycling will probably not be the main route in future plastics recycling, but it can make a significant contribution, especially for that fraction of waste plastics that do not meet the criteria for mechanical recycling processes. Ramping up chemical recycling is indeed seen essential to achieve the EU's recycling targets for plastic packaging. The European trade organisation for plastics, Plastics Europe, foresees a threefold increase in chemical technology investment in Europe between 2025 and 2030 (PlasticsEurope, 2021a).

All recycling technologies require some pre-treatment of the collected waste. The resource intensity and cost of the pre-treatment depend on the effectiveness of the separate collection system used, whereas the potential scale of the operations will be determined by the efficiency of the overall collection system – its ability to provide a relatively clean and homogeneous feedstock of plastic waste.

Ecomodulation in extended producer responsibility systems

Two European countries, France and Italy, use the ecomodulation of fees to provide specific cost incentives for producers to ensure that their products meet recyclability criteria. Ecomodulated fees could be more widely used across all EPR schemes as a way of helping to meet increased targets for the recycling of plastic packaging and agri-plastics (APR, 2020; Thompson and Harkins, 2020). Extending producer responsibility has also been suggested as one possible measure to encourage more sustainable construction in Sweden, exempting bio-based and renewable products from the fee (Ahlm et al., 2021).

5.1.3 Renewables

The most widely produced biodegradable bioplastics are starch-based blends followed by PLA-based plastics. Packaging is the largest field of application for bioplastics accounting for more than 53 per cent of the global bioplastics market in 2019. Total bioplastics production globally in 2019 was around 2.1 million tonnes (approximately 1 per cent of total plastic production (European Bioplastics, 2022)), of which 43 per cent were biodegradable and 57 per cent were not (Goel et al., 2021). This is in contradiction to the quite common public perception that most biopolymers are biodegradable.

Although still only making up a minute share of overall flexible plastic production, bio-based and biodegradable plastics have developed significantly in the last years. Cellulose-based materials can be processed into plastics and their barrier qualities have improved, narrowing the gap with fossil films. Bioplastic film, however still tends to be thicker, and thus heavier, than fossil plastics equivalents while its strength is somewhat lower than that of conventional plastics (VTT, 2020).

While bioplastics can be used for the same applications as their fossil peers, biodegradable plastics are only applicable to products with a relatively short lifecycle. In the agricultural sector, commercial applications are available for mulching, whereas silage packaging, for example, requires material that lasts longer (Moloney 2022). The use of biodegradable plastics in the construction sector is limited to packaging and short-term protection of construction products. Only 3 per cent of the global production of flexible and rigid bioplastics was used in building and construction, whereas agri- and horticulture accounted for 9 per cent (European Bioplastics, 2022).

5.2 Sectoral outlook

5.2.1 Flexible packaging

Design

The packaging industry has undergone significant transformation during the latest decade. Packaging is being engineered to be light weight and have better barrier qualities and designed with an increasing emphasis on end-of-life.

Soares et al. (2022) estimate that there will be no mainstream solution for recycling multi-material, multilayers plastic packaging in the next 5–10 years. While there is investment in chemical recycling concerns remain about its costs and genuine environmental benefits. Harmonisation of processes – multilayering, waste management, sorting, etc. – is critical for improving post-consumer recycling rates (Soares et al., 2022).

Industries along the packaging supply chain are responding to the new EU legislation by increasing their collaborative efforts to close plastic packaging loops. Industry commitments, for example, to improve the circularity of plastic packaging have been made and alliances, such as the Alliance to End Plastic Waste ([6]), are forming to explore new solutions across value chains. This includes the common search for technological innovation and the active participation in setting such standards as those regard to design for recycling (Bening et al., 2021).

The revision process of the EU Directive on Packaging and Packaging Waste (94/62/EC) is considering a set of measures to close the loops for packaging and packaging waste and is likely to strongly advance the circularity of flexible plastic packaging. In the future, all packaging placed on the market will need to be reusable or recyclable. The introduction of recycled content targets for specific packaging formats and minimum mandatory green public procurement (GPP) criteria and targets for packaging are currently being considered (European Commission, 2020b).

Waste management infrastructure:

One of the major barriers to the expansion of recycling is not only the recycling capacity *per se* but the collection and sorting infrastructure, which is still less than adequate in many countries. Moreover, even with adequate collection infrastructure, separate collections recover 80 per cent of household packaging waste, with the rest ending up in mixed waste fractions destined for landfills or incineration with energy recovery (calculated from (Brouwer et al., 2019; HSY, 2019)).

Against that background, it is important to improve the convenience of collection for consumers and increase processing capabilities to support separation of multilayer films and contaminant removal. The Circular Plastics Alliance ([7]) is an example of cross sectoral commitment including industry, the public sector and academia which aims to boost the EU market for recycled plastics. Similar commitments also exist at the national level, for example, Finland's Plastic Roadmap ([8]). Such alliances are good indicators of the need to intensify the dialogue between recyclers and film manufacturers to support increased recycling efforts by manufacturing film with fewer and more easily separable layers.

5.2.2 Construction

Strengthening demand is central to increasing the use of recycled and bio-based plastics, and major private and public procurement can play a leading role in stimulating this. Procurement could entail the requirement that plastics used in construction products should contain a minimum proportion of recycled

[6] https://endplasticwaste.org/
[7] https://ec.europa.eu/growth/industry/strategy/industrial-alliances/circular-plastics-alliance_en
[8] https://muovitiekartta.fi/in-brief/

and/or bio-based plastic. When widely applied, this will increase the demand for recycled plastics. Consequently, such requirements can also have positive impact on waste sorting at construction sites and serve as awareness raising and training in plastics recycling in the construction sector. To achieve such impact, large procurements should take the lead, and ensure stability of such new directions in the entire construction sector (Ahlm et al., 2021).

Cooperation between the collection and recycling of plastic from the construction sector and demand for recycled raw material needs further development. Among other things, product or material performance requirements, for which standards either do not allow the use of recycled raw material or lack clear definitions of recycled raw material, have been seen as obstacles.

The construction industry is also, however, an outlet for recycled flexibles. Major products manufactured from mechanically recycled flexibles are construction lumber and composites, used for decking, playgrounds and in other robust applications.

Plastic use in construction varies considerably across regions and building types. Water- and weatherproofing as well as electrical installations are major users of plastic in many applications, but data on these flows are difficult to find. Mapping both the inflow and outflow of plastic in the construction sector is important when developing measures and instruments. The effects of planned measures or instruments should be both understood before implementation, and the actual effects clearly visible afterwards. For smoother data collection, digital logbooks for reporting on plastic flow could be developed.

Separate collection of different plastic wastes at the construction sites is to be encouraged and accompanied by supporting logistics. This connects to general awareness raising and developing initiatives that create behaviour change and increased focus on plastics on construction sites.

5.2.3 Agriculture

The use of plastics in agriculture helps increase productivity. Mulch film, for example, reduce weed growth, while polytunnel and greenhouse films and nets protect plants and boosting growth, extend the cropping season and lower the need for irrigation. Furthermore, plastic packaging help maintain food’s nutritional qualities thus improving food security and reducing greenhouse gas emissions from food losses.

Against this background, it is easy to understand the increased use of agri-plastic and with that the importance of developing efficient recovery and recycling systems. The widespread, long-term plastic use and the lack of systematic collection and sustainable management leads to an accumulation of plastic in soils, which are estimated to contain larger quantities of microplastics than the oceans (Freiberg, 2021). The FAO has estimated that without viable alternatives the plastics demand in agriculture is set to increase, and the global demand for greenhouse, mulching and silage films will increase by 50 per cent to 9.5 million tonnes by 2030.

While the average collection rate of agricultural plastic waste is slightly above 60 per cent in Europe, five countries, France, Iceland, Ireland, Norway and Sweden, have achieved higher collection rate of more than 70 per cent with established national collection schemes. These countries apply EPR schemes for the collection of plastics, which are either mandatory as in Ireland or on a strong voluntary base as in Sweden. Indeed, EPR schemes have proved to be an efficient way of increasing circularity of end-of-life plastics.

As an example, a mandatory EPR system for converters and distributors of agri-plastic products in Andalusia, Spain caused recovery rates to rise rapidly to 80 per cent (Hann et al., 2021). In this case and also stressed by Maloney (2022), the cost structure of the EPR system must be well planned and all stakeholders, public and private, must be involved in order for the system to be efficient (APE Europe, 2017).

Several countries have developed instruments for more efficient collection schemes. Amongst others, ecomodulated EPR schemes have been discussed as a tool to boost more sustainable plastic use. Such systems could, for example, incorporate certified biodegradable plastics in agri-plastics EPR schemes, but exempt biodegradable plastic producers from contributing to EPR collection and treatment costs, as they would not apply to these plastics.

The use of biodegradable plastics is, however, not currently widespread in the European agricultural sector due to a variety of factors including their cost, which can be significantly higher than conventional plastics (Hann et al. 2021). Limited knowledge on material quality, lack of certainty of its behaviour and the rate of biodegradation in a particular environment as well as limited lifecycle data have also been considered as barriers to their widespread use. The development of standards and technical specifications that would provide indications of performance, and the rate of and conditions for their biodegradation Is a basic step that could improve the uptake of biodegradable plastics (FAO, 2021).

The benefits of biodegradable plastics also need to be assessed against their operational environments. Weather conditions in the northern hemisphere are, in general, less favourable for the use of biodegradable films, where, for example, mulch films can be used for up to 3 or 4 years, although in some southern European countries with milder weather conditions, they may last for only for two seasons (Rayns et al., 2021). There is a relative lack of information on the performance of biodegradable films in northern European climates and whether growers there could expect the same benefits from biodegradable films as conventional fossil-based LDPE films.

6 Conclusion

Flexible plastics are used in many applications today and volumes have increased significantly in the last decades. They are generally light and relatively low-cost materials that provide good barrier properties against moisture and gases and are largely used for the protection of goods or enhancing cultivation. The major application areas identified for flexible plastics are packaging, agriculture and construction; and a considerable portion of the usage in agriculture and construction are packaging applications. Flexible plastics play an important role in preventing perishable products degrade and in lowering the carbon footprint of transport due to their light weight. However, their potential for reuse is limited and, at end of life, they present a range of issues that complicate recycling.

- Plastic is highlighted as a significant issue in Europe's circular economy framework and recent developments in regulatory and financial policy instruments are highly relevant for flexible plastics. The Packaging and Packaging Waste Directive requires Member States to meet targets for the recovery and recycling of packaging waste; the Directive on Own Resources will widen the scope of fiscal action for plastic products; and the SUP Directive proposes wider extended producer responsibility and includes flexible plastic products in its scope.

- The largest application of flexible plastics is for packaging as films add little weight to a product and fit closely to its shape, thereby wasting little space during distribution. Market reports suggest that the global flexible plastic packaging market will increase by 3-4 per cent per year in this decade. Material flows in this area are relatively well known, due to well established legislation and the extended producer responsibility schemes which exist in most European countries.

- Less data is available on the use of flexible plastics in the construction sector. Analyses on waste generation on construction sites point to diverse volumes and types, depending on the building type and construction environment. In demolition and renovation works, the occurrence of hazardous substances in plastic waste is an issue that also hampers recycling.

- Reuse of flexible plastics is currently not common as the used products, such as food packaging, are frequently contaminated and generally not designed for durability. Shifting to reusable rigid containers is an option, but this needs careful consideration to ensure its sustainability in terms of logistics, container losses and hygiene.

- Due to environmental concerns, such as greenhouse gas emissions and littering, improving the management of flexible plastic waste is an important, emerging issue. Flexible plastics present special challenges in their end-of-life phase as the film is often contaminated and has little economic value. Multilayer products are especially difficult to recycle due to the mix of materials used and give rise to significant technical difficulties in existing recycling processes.

- Policy direction and technological innovation suggests that the volume of recycled plastics put on the market will increase considerably in the future. Improving the quality of the recycled material is critical to increasing the market for secondary materials and thereby supporting tighter material loops. Chemical recycling is emerging as a complement to existing mechanical recycling and may provide a partial solution, especially for multilayer flexible plastics.

- Bio-based and biodegradable materials are an emerging alternative to fossil-based plastic materials. Nonetheless, the market share of bio-based and/or biodegradable plastics is not very high - even in the packaging sector, where their use is most prominent.

- Extended producer responsibility schemes have shown good potential to support the enhanced recovery of end-of-life flexible plastics. Examples from the agricultural sector show that, with a functioning scheme, it is possible to recover 90 per cent of agri-plastics. However, appropriate infrastructure must be in place to facilitate recycling of this collected material.

- Voluntary agreements also provide a means to improve the handling of end-of-life flexible plastics. Engagement of the whole value chain is of utmost importance if the full impact of voluntary agreements, based on companies' commitment to recycling and using recycled materials, is to be achieved.

With proper end-of-life solutions in place, flexible plastics provide useful and versatile products with good potential to provide a source of secondary raw materials. However, if not properly managed they present a serious pollution risk, not least the highly visible presence of flexible plastics in terrestrial and marine litter across the globe.

List of abbreviations

Abbreviation	Name
AMI	Applied Market Information Ltd.
BOPET	Biaxially-oriented polyethylene terephthalate
BOPP	Biaxially-oriented polypropylene
CEFLEX	Circular Economy for Flexible Packaging
EEA	European Environment Agency
EPR	Extended producer responsibility
ETH	*Eidgenössische Technische Hochschule Zürich* (Swiss Federal Institute for Technology)
GPP	Green public procurement
EVOH	Ethylene-vinyl alcohol copolymer
FAO	Food and Agriculture Organization of the United Nations
HCl	Hydrogen chloride
HCN	Hydrogen cyanide
HDPE	High-density polyethylene
LDPE	Low-density polyethylene
LLDPE	Linear low-density polyethylene
NAFTA	North American Free Trade Agreement (Canada, Mexico and the United States of America)
NH_3	Ammonia
NIR	Near Infrared
OECD	Organization for Economic Co-operation and Development
PA	Nylon
PA-6	Nylon 6 or polycaprolactam
PE	Polyethylene
PET	Polyethylene terephthalate
PLA	Polylactic acid
PMMA	Poly(methyl methacrylate)
PP	Polypropylene
PS	Polystyrene
PS-E	Polystyrene-expandable
PUR	Polyurethane
PVC	Polyvinyl chloride
PVDC	Polyvinylidene chloride
SUP	Single-use plastics
UNFCCC	United Nations Framework Convention on Climate Change
WFD	Waste Framework Directive

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Annex Current recycling processes and their outputs

All plastic-containing waste streams that are collected for recycling are submitted to pre-treatment processes to remove the non-plastic materials contained in them. In the case of the comingled separate collection of packaging waste, the non-plastic materials often consist of metals, such as steel and aluminium cans, and/or multilayer beverage cartons, which are separated from the plastic packaging for metal and fibre recovery respectively. In the case of agricultural film, the pre-treatment removes sand, soil, plant-based residues, dust and other non-plastic contaminants that are adhered to or entangled in the film. The stream of plastic waste is then ready for feeding into a recycling process.

Not all plastic-containing waste is fit for recycling nor can be converted into suitable feedstock in an environmentally and economically meaningful way. Therefore, treatment processes need to carefully match to the characteristics of the output of the preceding process with the input requirements of the next step, always with an eye on the standards and specifications of the envisioned client of the recycled plastic, polymer, monomer or chemical. Basically, three types of recycling routes are considered:

- mechanical recycling of plastic, resulting in regrind and granulate of the plastic, the quality of which will depend on the level of impurities and additives. All additives that were present in the original plastic, will be conserved in the recycled plastic;
- dissolution of the plastic, resulting in the pure polymer without additives and contaminants;
- chemical recycling for recovering either monomers or chemical feedstock.

The mechanical recycling process and its outputs

Collected plastics-containing packaging waste is often contaminated with organic residues, and metals, paper and other inorganic materials, and will contain a mix of different plastics. The mechanical sorting process, in many cases accompanied by the manual picking out of unwanted materials, usually starts with a pre-sorting step that includes the removal of steel and non-ferrous metals by respectively a magnet and an eddy current separator.

Flexible plastic bags, foils and films can be separated from rigid plastics early in the sorting process by wind sifters, by using a ventilator that blows out or sucks up those plastics with the highest surface-to-mass ratio. Ballistic separators, that consist of shaking screens, also might serve to separate heavier plastics from lighter ones. Wind sifting and ballistic separation allow the separation of LDPE, LLDPE and PP foils from other plastics. The removal of residues and unwanted impurities before grinding the plastics can be done by pre-washing or friction-based dry surface cleaning. After size reduction, the obtained mixed polymer flakes can be further separated through float-sink separation, in which polymers such as PE and PP packaging with densities below 1 gram per cubic centimetre will float and can thus be separated from the heavier polymers. Research is ongoing into chemical washing of pre-sorted flexible plastics to achieve delamination (adhesive removal), deinking and odour removal.

Alternative or complementary separation techniques include heavy density separation, in which salt is added to create a different density gradient in the floating medium, and centrifuges and hydrocyclones. In addition, plastics are commonly sorted using optical sensors. Near infrared (NIR) can be used, for instance, for the identification of multilayer materials, coloured or printed films. The washed and cleaned flakes are then dried, melted and turned into pellets.

The output material of **mechanically recycled flexible plastics** is either washed flakes, extruded pellets or granules that consist of recycled, either discrete or mixed polyolefin fractions (PE-, PP-, and PS-based polymers), together with all the additives used in the original plastic(s), non-plastic impurities, and not-targeted plastics. Higher grade recycled LDPE can be used in the production of LLDPE. Lower grades are used in piping, sheeting, film, rubbish bags, composite lumber, liners, waste bins, panels and other products. Food contact applications are not possible.

Dissolution purification and process outputs

Dissolution is a purification process through which a single target polymer present in a mixed plastics waste is selectively dissolved, allowing it to be separated from the waste and recovered in a pure form without changing its chemical nature ([9]). After separation, the polymer is precipitated again by using an antisolvent.

Dissolution purification offers several benefits over mechanical and chemical recycling technologies:

- high-quality polymers can be obtained by the removal of both impurities and additives, even when multicomponent plastic mixtures are used as an input;
- the energy use for dissolution is low, as the polymer chain is not chemically or thermally degraded;
- fewer pre-treatment steps are required for producing a suitable waste feedstock.

These process characteristics make dissolution a more environmentally friendly option than chemical recycling. The technology is, however, still evolving and at present few full-scale installations exist globally. Research on and development of dissolution techniques is often realised in partnerships that involve brand owners, technology providers, research institutes and chemical companies. Such partnerships have resulted in demonstration plants in Indonesia, to recover PE from multilayer sachets, as well as in Germany, where multilayer films were targeted.

Dissolution is, however, not applied on polyethylene, which limits the practical applicability of the technology for LDPE films.

A combination of mechanical and dissolution processes has been tested on multilayer films. Mechanically shredded films have been treated with chemicals that break-up the bonding between the different layers, separating them into their individual constituents. The technology has been used to separate PE and aluminium film, PP from aluminium, and PE from PP, and a demonstration facility targeting flexible packaging is being set up in Germany.

The output material of dissolution purification processes is the pure target polymer, without additives or impurities. The technology has been tested specifically on single-use plastic bags (LDPE), and is applied at pilot and/or commercial scale for recovering PE from multilayer sachets and films, as well as pure PVC, PS, nylon (PA) or PP (Naviroj et al., 2019; Poulakis and Papaspyrides, 1997).

Chemical recycling processes and their outputs

a) Chemical depolymerisation

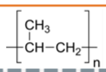
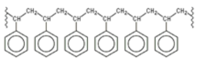
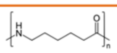
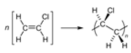
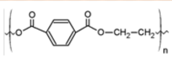
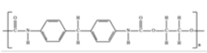
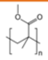
In contrast to the dissolution purification process, depolymerisation breaks up the target polymer into single monomers or into its constituents. No examples of the application of chemical depolymerisation specifically of foils and film were identified.

[9] https://plasticseurope.org/sustainability/circularity/recycling/recycling-technologies/

b) <u>Thermochemical recycling</u>

Thermochemical processes break down the long hydrocarbon chains constituting plastics into shorter **hydrocarbon fractions** or **monomers** by thermal or catalytic (chemical/thermal) processes. The resulting, shorter molecules can be used as feedstock for new chemical reactions to produce new recycled plastics and other chemicals (Plastics Europe, 2022). More specifically, the outputs of thermochemical recycling processes are solid hydrocarbons (waxes), oils and gases (Ragaert et al., 2017). The shares and nature of each of the hydrocarbons is determined by the applied pyrolysis technique and by the process input as indicated in Figure A.1.

Figure A.1 Plastics to liquids through pyrolysis – monomers and products

RESIN	STRUCTURE	MAJOR ORIGIN OF WASTE	PYROLYSIS PRODUCT	
PE		Household, industrial plastic packaging, agricultural plastics	Waxes, paraffins, olefins	OIL REFINERY FEEDS > CHEMICALS, DIESEL
PP		Household and industrial plastic packaging, automotive	Waxes, paraffins, olefins	
PS		Household, industrial plastic packaging, construction, demolition, WEEE	Styrene, its oligomers	MONOMERS
PA-6		Automotive waste	Caprolactam	
PMMA		Automotive, construction waste	MMA (methyl methacrylate)	
PET		Household plastic packaging	Benzoic acid, vinyl terephthalate	UPGRADING > CHEMICALS, FUELS
PUR		Construction, demolition, automotive	Benzene, methane, ethylene, NH3, HCN	
PVC		Construction plastic waste	HCl (< 300C), benzene	

Source: (Qureshi and Oasmaa, 2019)

Pyrolysis processes are quite mature and investment in industrial scale processes has recently taken place both in Europe and globally. Over the next five years, chemical recycling will become part of the plastic waste processing infrastructure in several European countries, including Belgium, Finland and the Netherlands (Arnold, 2022).

European Topic Centre on
Circular economy and resource use
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