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Resource (in)efficiency in the EU: a case of plastic waste

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Abstract

Motivation: Plastics are versatile materials with applications in numerous sectors. They contribute to effective resource protection during their usage phase but a great challenge is increasing amount of unmanaged plastic waste and its environmental impact. Meanwhile, plastic waste is a valuable raw material. Appropriate management reduces environmental pressure and brings economic benefits. The transition to circularity is a strategic objective of the EU but it involves numerous obstacles. This article deals with these issues.
Aim: The purpose of the article is to indicate the scale of losses in one of key waste stream — plastic waste — by looking at origin, way of collection and treatment of end-of-use plastics. The analysis aims to show the level of recycling in relation to the demand for plastic (as commonly used recycling indicator refers only to the plastic waste collected), the way the plastic waste is managed in various sectors and the specific barriers to its recycling.
Results: Recycling of plastic waste accounts for only about 5–10% of the total demand for plastic. Overall, post-consumer plastic waste collected for treatment constitutes 49% of plastics production. 32.5% of those collected plastics is recycled, compared with 25% of plastics landfilled and 42.5% recovered for energy. Still a lot of plastic waste is exported to developing countries, some is hidden in untracked trade flow or illegal landfills. The EU is shifting from linear to circular approach but it is only the beginning of economic transformation towards plastics circularity.

Keywords: plastic waste; circular economy; recycling
JEL: Q53; Q57; Q5

1. Introduction

Contemporary economies rely heavily on natural resources. One of them is crude oil, essential for plastics production. Global plastic use increased rapidly, from almost zero in 1950. to 368 million tonnes in 2019. It is projected this number would double to over 800 million tonnes per year by 2050 (Plastics Europe, 2020). The growing demand is due to the fact that plastics are an extensive family of different materials with specific characteristics and applications in numerous sectors (more than 30 types of plastics are in common use). On the one hand, plastics contribute to effective resource protection during their usage phase (for example as building insulation they help save energy or as car components they reduce fuel consumption). On the other side, a great challenge is increasing amount of unmanaged plastic waste and its negative impact on the environment and human health, as reported by numerous studies (Galloway et al., 2017; Lebreton et al., 2018; Mattsson et al., 2017; Wright & Kelly, 2017). Untreated plastic waste should also be considered in terms of costs, as it is a valuable resource that can be recycled and used in subsequent production processes.

According to UNEP's (2018) plastic waste management hierarchy, the most preferred method is to reduce the plastic usage (either by utilizing alternative design/material or by reducing frequency of use), followed by its reuse. At the other extreme, there are two least desirable ways of plastic waste disposal: incineration (to recover the energy it contains) and landfilling (Huysman et al., 2017; Van Eygen et al., 2018). In countries where waste management policy has been developed, plastic waste is collected mostly for recycling, as it reduces significantly environmental impact and resource depletion (it is the third component of the so-called "3Rs", after reduce and reuse). The most effective method of obtaining a valuable raw material for new plastic products is chemical recycling. It involves the transformation of plastics, i.e. plastic polymers, by means of heat and/or chemical agents to yield monomers or other hydrocarbon products that may be used to produce new polymers, refined chemicals or fuels (Ragaert et al., 2017). Chemical recycling is more complex and technologically advanced method than its alternative — mechanical recycling. This is a physical process in which plastic waste is formed by cutting, shredding or washing into granulates, flakes or pellets and then melted to make new product by extrusion. Plastic waste is thus recycled into "new" (secondary) raw materials without changing its basic structure (Schyns & Shaver, 2021). Recycling method depends on polymer type, design and product type, e.g. rigid containers consisting of a single polymer are simpler and more economic to recycle than multi-layer and multi-component packages, thermoplastics — including PET, PE and PP — all have high potential to be mechanically recycled while thermosetting polymers such as unsaturated polyester or epoxy resin have almost none (Rebeiz & Craft, 1995).

Faced with environmental constraints and technological opportunities of various types of recycling, modern economies have no choice but to shift from a linear to a circular approach, where materials are kept in the loop as long as possible (Kalmykova et al., 2018). The EU is also moving in this direction. The framework for these activities constitutes Circular Economy Action Plan (European Commission, 2015). In 2018 the first-ever European strategy for plastics was adopted (European Commission, 2018). It aspires to transform the way plastic products are designed, produced, used, and recycled towards a more circular approach. The assumptions are that all plastic packaging on the EU market will be recyclable by 2030, some recycling targets will increased (i.e. at least 25% of recycled plastic for PET beverage bottles from 2025 onwards and 30% of recycled content for all plastic bottles by 2030), the consumption of single-use plastics will be reduced (a ban for several single-use plastic items) and the intentional use of micro-plastics will be restricted. Numerous pieces of legislation have introduced other targets for plastic waste recycling: (1) for municipal waste: at least 55% by 2025 and 65% in 2035 (2) for plastic packaging: at least 55% by 2030 (3) no more than 10% of waste going to landfills by 2035. On March 2020, the European Commission adopted a new Circular Economy Action Plan (European Commission, 2020) which contains new initiatives along the entire life-cycle of products. The EU's approach remains therefore in line with the general goals for a circular economy (CE) in the plastics sector: improving the economic viability of recycling and reuse of plastics; halting the leakage of plastics into the environment, especially waterways and oceans; and decoupling plastics production from fossil-fuel feedstocks, while embracing renewable feedstocks (EMAF, 2017). A milestone of the circular economy is to increase recycling rates of plastic waste, in particular plastic packaging waste (European Commission, 2020). However, there are still a lot of barriers, mostly technological (to recover more and higher quality secondary raw materials), financial (cost-effectiveness), regulatory (favorable legislation) as well as social (habits, acceptance and understanding of necessary changes). Iacovidou et al. (2021) argue that most of them are not easy to overcome as they are deeply embedded into the way current regimes operate (hence, a holistic approach is suggested).

Plastic waste is a valuable raw material which can be recycled and used in subsequent pro-duction processes, reducing environmental pressure and bringing economic benefits. However, efficient management of plastic waste is a challenge for the EU. The purpose of the article is to indicate the scale of losses in this waste stream by looking at origin, way of collection and treatment of end-of-use plastics. As recycling rates vary not only geographically but also according to plastic type and its application, an industry-specific approach has been taken. The analysis aims to indicate the level of recycling in relation to the demand for plastic, as the commonly used recycling indicator refers only to the plastic waste collected (as in Eurostat (2021) statistics). This kind of approach takes a broader view and shows how much remains to be done to achieve circularity in the plastics. This study focuses on recycling as it is the most effective way of dealing with the plastic waste generated. The main hypothesis is that the EU is only at the beginning of an economic transformation towards plastics circularity as it is shown by low recycling rates in relation to plastic demand. There is still a lot of plastic waste hidden in untracked trade flows and illegal landfills. Furthermore, the EU exports a lot of plastic waste to developing countries which also has an environmental impact (low standards of waste management systems in host countries together with the additional CO2 emissions resulting from plastic waste transport). Circular economy topics are widely discussed in scientific papers but the debate is mostly focused on the importance of achieving goals and the benefits associated therewith. Less attention is being paid to barriers surrounding its implementation, which is also pointed out by Iacovidou et al. (2021). By taking an industry approach (sector-specific barriers) and broader view (recycling as % of plastic demand), this article partially fills this gap.

2. Literature review

The idea of circular economy based on resource efficiency goes back to 60s. (concerns regarding the limits of growth and resource scarcity raised by Boulding, 1966), but it was the last decade that brought conceptual development of this concept. Nowadays, it has attracted an expanding body of research and literature from different fields and geographical areas (Ghisellini et al., 2016; Korhonen et al., 2017). Kirchherr at al. (2017) have gathered 114 CE definitions which were coded on 17 dimensions. Their found that it is most often understood as a combination of reduce, reuse and recycle approaches. Combining the challenges of putting CE into reality and the practice-oriented approach of business model innovation led to the concept of circular business models (Geissdoerfer et al., 2018). A review of the literature for business models contributing to sustainable plastic waste management was carried out by Dijkstra et al. (2020). The importance of holistic view of CE has recently been expressed in European Strategy for Plastics in a Circular Economy (European Commission, 2018). The strategy emphasizes that a circular economy framework requires fundamentally new approaches to the underlying business model and product designs. It recognizes innovation as a key enabler for the transformation of the system, with innovation areas spanning the entire value chain: renewable energy and feedstock, product design, business models and reverse logistics, collection and sorting mechanisms, mechanical and chemical recycling technologies, compostability and biodegradability. This systemic view will require new methods for measuring circularity. So far, they are still focused on the waste management system (with 3 main directives: The Waste Framework Directive, The Packaging Waste Directive and The Landfill Directive, revised in 2018). According to Eurostat (2021) data, the recycling and energy recovery rates are increasing, while the share of plastic waste going to landfills is decreasing. It is a positive trend but a study published by the Material Economic (2018) highlights also other statistics. Recycling of plastic waste accounts for only 5–10% of total demand for plastic and the actual EU secondary plastics production as a share of demand is only about 10%. Another studies: by the World Economic Forum (WEF, 2016) and the EMAF et al. (2016) give the same message. Velis & Brunner (2013) indicate that existing frameworks assessing material circularity are not only inexact (basic indicator refers only to the waste collected and registered) but also insufficient (a lack of qualitative goals) which makes it difficult to measure the contribution of recycling to sustainable resource management. One more problem is so called "waste tourism" (export of plastic waste to other countries, mainly Asian) which contributes to global environmental problems (Barrowclough et al., 2020). Another studies highlight different barriers to achieving circularity in plastics in the EU (Bourguignon, 2017; Dijkstra et al., 2020; Steensgaard et al., 2017): (1) high up-front investment costs and risks in the transformation process; (2) complex international production and consumption supply chains; (3) lack of support for scaling up circular models; (4) difficulties in business-to-business cooperation; (5) inadequate knowledge and capacity for implementation; (6) uncompetitive circular products because subsidies encourage the linear production and use model; (8) lack of consumer awareness. As a result, large fractions of valuable resources are lost due to inefficient waste collection (mixed streams), contamination and the content of additives that hamper recycling, market-related aspects, technological barriers, design complexities and the hazardous nature of embedded materials. There aren't many studies with primary data on the recovery and purity rates of materials recovery facilities (MRFs) and recycling plants in the EU. Cimpan et al. (2015) elaborate the recovery rates of a MRF in the UK, Mastellone et al. (2017) in Italy, Van Eygen et al. (2018) data on MRFs in Austria while Brouwer et al. (2018) for the Netherlands. More studies use secondary data and/or best-guess estimates as input to life cycle assessments or material flow analyses (Cimpan et al., 2016; Faraca & Astrup, 2019; Pressley et al., 2015). All these studies identify similar challenges to recycling and indicate significant losses in the process. Eriksen et al. (2018) found that across all their scenarios (representing a wide range of sorting schemes, source-separation efficiencies and material recovery facility — MRF, configurations and performances), 17% to 100% of the generated plastic mass could be recovered, with higher source-separation and MRF efficiencies leading to higher recovery. Looking from the quality side, at best 55% of the generated plastic was suitable for recycling due to contamination. They conclude that recycling systems in the EU are not efficient (less than 42% of the plastic loop can be closed with current technology and raw material demands) and the attention should be paid to limiting impurities and losses through product design, technology improvement and more targeted plastic waste management. Focusing on the most problematic group of plastic waste — packaging — Antonopoulos et al. (2021) came to similar conclusions. They collected primary data from plants sorting and recycling plastic packaging waste to illustrate process efficiencies, material flows and barriers. They observed that significant losses of target materials occurred both at sorting and recycling stages. According to their estimates, an overall end-of-life recycling rate for post-consumer plastic packaging waste in the EU27 is lower than European statistics (14%). Their scenario for 2030 show that achieving an overall end-of-life recycling rate of about 49% is possible only when best available practices will be implemented. To meet recycling targets, parallel improvements are necessary in many areas: at the plants, product design, collection system and market level.

3. Methods

Statistical and intuitive methods are used in this work. The considerations are based, to a great extent, on literature on the subject-matter and secondary data. The train of thought is characterized by a deductive nature where an argument is the output of research related to the issue of plastic waste. The first part (loss of natural resources) is the result of a review of reports (i.a. from the European Environment Agency and the Center for International Environmental Law) and other studies to show the current state of knowledge on the environmental impact of plastic waste. They are mainly related to CO2 emissions (quantitative indicators) and the effects of the plastic waste accumulation. The data in the second part (loss of recycled raw materials) was taken, among others, from Sitra (The Finnish Innovation Fund), Eurostat, Plastics Europe (associations representing plastics producers), The Ellen MacArthur Foundation (a charity working with business, government & academia to build a framework for a circular economy). The considerations in this section are designed to show the plastic waste treatment in various sectors and the specific barriers to recycling. Although the plastics industry is very complex, four main sectors (packaging, buildings and construction, automobiles and electronics) constitute more than three-quarters of all plastics demand in the EU. Due to this fact and data availability, the paper focuses on the management of plastic waste in these four sectors, in 2017 (the latest available and comparable year). Data on how plastic waste is managed (by sector and overall) are related to the demand volume for plastic. This kind of approach takes a broader view (as Eurostat (2021) data refer only to the plastic waste collected) and allows to see the remaining volumes of plastic waste which are exported, hidden in untracked trade flows, illegal landfills or being a process losses in recycling.

4. Results

4.1 Loss of natural resources

Plastic production involves the use of fossil fuels and causes CO2 emissions (Geyer et al., 2017). CO2 emissions start with the extraction and transport of fossil fuels. Afterwards, oil and gas are used in the plastics production process — both by providing energy and as a production raw material (over 99% of plastics are produced from oil and gas) (CIEL, 2019). Global plastic production absorbs 6% of the world's demand for oil (EMAF, 2017). The manufacture of plastic is among the most energy intense and emissions intensive industries (i.a. through the polymerization, plasticization and other chemical refining processes). CO2 emitted during plastics production represents around 20% of the chemicals industry's emissions EU-wide (the chemical sector is the third largest source of industrial CO2 emissions). It is estimated that each tonne of plastics produced results in 2.5 tonnes of CO2 emissions from the production process alone. These amounts are much higher when emissions over the whole lifecycle are considered, e.g. the production of chemicals used in the plastics production process alone has the second largest sectoral energy demand (EEA, 2020). Carbon embedded in the material corresponds to another 2.7 tonnes of CO2. Depending on how plastic waste is managed, this embedded carbon is released either immediately (incineration) or very slowly (landfilling). Chemical recycling eliminates embedded emissions from new fossil feedstock but entails some CO2 emissions during the processing of plastic waste (CO2 savings can be as much as 75% with technologies now under development). Most emissions can be reduced if mechanical recycling is used. Nowadays, this way of plastic waste disposal produces less than 20% of the CO2 emissions associated with making new plastics (Material Economics, 2018). It should be noted that during the extraction of oil and gas for plastic production not only CO2 are emitted. These include also multiple pollutants (such as nitrogen oxides, sulphur oxides, particular matter, volatile organic compounds, heavy metals), large volumes of waste water containing dispersed oil, hazardous substances and other harmful chemicals leaking into the environment (CIEL, 2019). However, it is the marine environment that suffers the most as a result of increasing amounts of plastic litter. It has been estimated that the world oceans receive between 8 and 13 million tonnes of plastic waste per year, i.e. between 1.5% and 4% of plastics world production (Jambeck et al., 2015). Plastic has continued to accumulate in waterways, agricultural soils, rivers and the ocean for decades. Both plastic objects and microplastics pose a threat to animals and entire ecosystem. Microplastic is of particular concern as it accumulate in the environment and human bodies (HEAL, 2020) and may interfere with the ocean's capacity to absorb and sequester carbon dioxide (Royer et al., 2018).

Barrowclough et al. (2020) look at the environmental effects of the plastics industry from yet another perspective, that is lens of of trade. International flows cover every stage of plastics lifecycle — from feedstocks, to primary plastics in resin pellet and fibre forms, through to intermediate plastic goods, final manufactured plastic goods and plastic waste. Each of them entails further CO2 emissions, with much controversy surrounding the last one, called "waste tourism". Whilst an increasing share of post-consumer plastic waste from Europe is collected for recycling, 46% of them is exported outside of the source country, including intra-EU trade (Chart 2)[1]. By 2017, China was the biggest receiver of European plastic waste (60% of plastics collected for recycling). Export of plastic waste has decreased in 2015–2018 (by 37%), which was due to China's ban on the import of 24 categories of waste (Brooks et al., 2018). Unfortunately, it has been directed to other developing countries, mainly south-east Asian[2] and Turkey (currently — the greatest receiver of European plastic waste) (Eurostat, 2021). They are ill-equipped to deal with the problem of plastic waste (low standards of waste management systems). This factor together with the additional CO2 emissions resulting from the plastic waste transport, are further bricks to global environmental problems (Bishop et al., 2020). In 2021 new rules came into force in the EU. They ban the export of plastic waste from the EU to non-OECD countries, except for clean plastic waste sent for recycling (the lack of transparency in shipping has even led to shipment of mixed waste misrepresented as recyclables). Exporting plastic waste from the EU to OECD countries (and the circulation within the EU) is going to be also more strictly controlled. These regulations are rather late reaction but highlight the role of trade policy in dealing with plastic pollution (Khan, 2019).

4.2. Loss of recycled raw materials

Over the years, recycling and energy recovery rates in the EU have increased (between 2006 and 2019 the amount of plastic waste sent to recycling has doubled and for energy recovery increased by 77%), while the share of plastic waste going to landfills has decreased (by 44%). Differences in performance between countries are, however, still high. Recycling rates range between around 40% (Sweden) and 20% (Bulgaria). The highest energy recovery rate is observed in Austria (72%) while the lowest one in Greece (1,2%). Landfilling of plastic waste is the biggest problem in Greece, Malta and Cyprus (around 23%) meanwhile Austria and the Netherlands completely eliminated it (Eurostat 2021; Plastics Europe, 2020). Overall, about 29 million tons of all post-consumer plastic waste in the EU is collected for treatment, which constitutes 49% of plastics production. 32.5% of those collected plastics is recycled, compared with 25% of plastics landfilled and 42.5% recovered for energy. On average, 52% of all post-consumer plastic waste is collected via mixed waste collection schemes. Unfortunately, the recycling rate of plastic from this scheme is more than 10 times lower than waste collected selectively (tab. 1).

[1] Between 2005 and 2014, annual plastic waste exports increased from 1.62 million metric tons to a peak of 3.24 million metric tons. Plastic waste exports began to decline in the following years, dropping to 2.3 million metric tons by 2018 (the year China introduced a waste import ban). In 2020, the EU exported 2.37 million metric tons of plastic waste to non-EU countries (Statista, 2021).

[2] However, some countries have restricted the import of plastic waste, for example Malasia (in 2017), India (2016) or Cambodia (as regards to plastic bags, in 2017).

A sectoral and type-specific look provides a better understanding of low recycling rates. This approach is further simplified by the fact, that although the plastics industry is very complex, four main sectors (packaging, buildings and construction, automobiles and electronics) and six (of more than 30) plastics types constitute more than three-quarters of all plastics demand in the EU[3]. The single largest end-use market for plastics is packaging, accounting for 39.6% of plastic use (Plastics Europe, 2020). A feature of plastic packaging is that after a short use time it ends up as waste. That is why about 62% of plastic waste is due to the use of packaging material, mostly by the food and beverage industry. Unfortunately, only 42% of such collected waste is recycled which corresponds to 19% of demand for plastics. Three main factors hinder recycling in this sector: (1) at technology level: only a few times recyclability of plastic packaging (due to material degradation); (2) at consumer level: difficulty in sorting of different plastic types and the contamination from use; (3) at the level of the recycling process: lack of technology to facilitate sorting of different plastic polymers (plastic packaging products consist of more than one polymer type which must be recycled in different ways) (Hestin et al., 2015; Material Economics, 2018).

Building and construction is the second biggest market for plastics in the EU, representing about 20.4% of the overall demand. The generated amount of plastic waste in this sector corresponds to only 6% of all plastic waste (Plastics Europe, 2020). This is due to the specific characteristics of this segment where products remain in building for decades before they are removed. What makes recycling difficult is that construction products consist of several materials often attached through gluing (significant part of the plastics used in buildings appears in paints, panels, boards, insulation materials used as resins and binding agents). Obstacles also include chemicals (e.g. phthalates, now restricted) and technical limitations of recycling for thermoset plastics like PUR or foams (mechanical recycling is not possible and the chemical conversion technology is still under development). That is why only a few plastic products (for example PVC windows or tubes) are identified as suitable for recycling (Awoyera & Adesina, 2020). In total, only 24% of plastic waste collected from building and construction sector is being recycled, which corresponds to 5% of demand for plastics reported by this sector (Material Economics, 2018).

The sector with the third highest demand for plastics is the automotive industry (9.6%). Plastic waste from this sector accounts for about 5% of all plastic waste (Plastics Europe, 2020). Plastics in automotive applications are heterogeneous and have strong connections to other plastic. Most of them contain hazardous substances (especially brominated flame retardants) or/and are reinforced plastics with glass or carbon fibre. That is why end-of-life vehicle recycling focuses primarily on recovering spare parts and avoiding the release

[3] These are: polypropylene (PP): 19.4%, low- and linear-low-density polyethylene (PE LD+PE LLD): 17.4%, high-and medium-density polyethylene (PE MD+PE HD): 12.4%, polyvinyl chloride (PVC): 10.0%, polyurethane (PUR): 7.9%, polyethylene terephthalate (PET): 7.4% (Plastics Europe, 2020).

of hazardous substances. High-value recycling is just not feasible or economically attractive and only some plastics easily separable from products are mechanically recycled to new raw materials (Becqué & Sharp, 2020). As a result, recycling rate in relation to the demand for plastic reported by the sector is only 6% (Material Economics, 2018).

The fourth largest market for plastics is electrical and electronic equipment (demand at the level of 6.2%). The plastic waste generated in this industry accounts for 4% of all plastic waste (Plastics Europe, 2020). WEEE (Waste Electrical & Electronic Equipment) plastics recycling is quite complicated because of technical, economic and regulatory challenges (Baxter et al., 2016). One major obstacle is legacy additives in their input (mainly phthalates) which have been abandoned or banned today due to human health and environmental concerns. A serious problem is also a lack of transparency and exact data on reuse and recycling schemes published by companies, making it difficult to evaluate their effectiveness and scale of these schemes. It is estimated that about 60% of WEEE plastics never reaches WEEE plastic recycling facilities, especially due to low WEEE collection rates or losses at the WEEE pre-processing stage. Further process material losses occur at the recycling stage. Due to a number of challenges, including the high complexity of WEEE plastic mixtures and limitations in current plastic sorting technologies, typically only 50 to 60% of the input material to WEEE plastic recyclers is effectively recycled. The rest is sent for energy recovery or landfilling (Haarman et al., 2020).

Plastics are also extensively used in agricultural applications (e.g. films, irrigation and maple tubing nursery containers, containers). Most plastic waste from agriculture are a diverse mixture of different polymers, heavily contaminated with soil, stones or metals. But the biggest problem is lack and inefficiency of agricultural plastic waste management schemes in most European countries (data on how plastic waste is managed is mostly unavailable) which makes the evaluation very expensive and complicated (Vox et al., 2016). Similar problem applies to other sectors however solutions are expected in the near future.

Table 1. and Chart 1 present the origin, collection, general disposal of plastic waste and the treatment of end-of-use plastics in 4 main sectors in 2017. The data are related to the demand for plastic (not to the waste collected, as in the Eurostat (2021) statistics). This kind of approach takes a broader view and shows how much remains to be done to achieve circularity in the plastics. When looking at figures on plastic production and waste generation, one could ask a question: where the remaining volumes of plastic are ending up. When one excludes the exported and treated waste, a significant volume is still unaccounted for. Plastic waste seems to be hidden in untracked trade flows and in illegal landfills (TrashOut, 2021) which are another brakes on circularity. Collected plastic waste corresponds to about 60% of demand for plastic and plastic waste collected for recycling purpose account only for about 20%. The recycling rate becomes even lower if processing losses are taken into account. As a result, less

than 5 million tonnes of plastic waste (which is less than 10 % of the plastic demands) ends up being recycled and only 6% of new plastic materials are derived from recycled plastics (Material Economics, 2018; Plastics Europe, 2018).

5. Conclusion

1. The manufacture of plastic is among the most energy intense and emissions intensive industries. Plastic production and international flows at every stage of the plastics lifecycle have a significant impact on the environment, with unmanaged plastic waste being a huge global challenge for modern economies.
2. Recycling rates vary not only geographically but also according to plastic type and its application. Although the plastics industry is very complex, four main sectors (packaging, buildings and construction, automobiles and electronics) and six plastics types constitute more than three-quarters of all plastics demand in the EU. These four sectors generate the most plastic waste, with the packaging sector accounting for the largest share (62%).
3. Large fractions of valuable resources are lost because of inefficient plastic waste collection, consumer behavior and market-related aspects. Technical barriers are linked to the nature of waste materials and products: some of them are non-recyclable, the others are composed of mixed materials hard to separate or contain hazardous substances. The greatest challenge is single-use packaging waste, i.a. because of the structure of material (more than one polymer type), contamination from use and only a few times recyclability (due to material degradation).
4. Overall, about 29 million tons of all post-consumer plastic waste in the EU are collected for treatment, which constitutes 49% of plastics production. 32.5% of those collected plastics is recycled, compared with 25% of plastics landfilled and 42.5% recovered for energy. Relating recycling rates to the volume of plastic demand (not to the plastic waste collected, as in Eurostat (2021) statistics) gives a broader view and shows how much remains to be done to achieve circularity in the plastics. This kind of approach allows also to see the remaining volumes of plastic waste that are exported, hidden in untracked trade flows, in illegal landfills or being a process losses in recycling.
5. Increasing recycling rates of plastic waste is a key factor for improving resource efficiency and strengthening circularity. The EU is shifting from linear to circular approach but it is only the beginning of its economic transformation.

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Appendix

Table 1.
The origin, collection and disposal of plastic waste in 2017

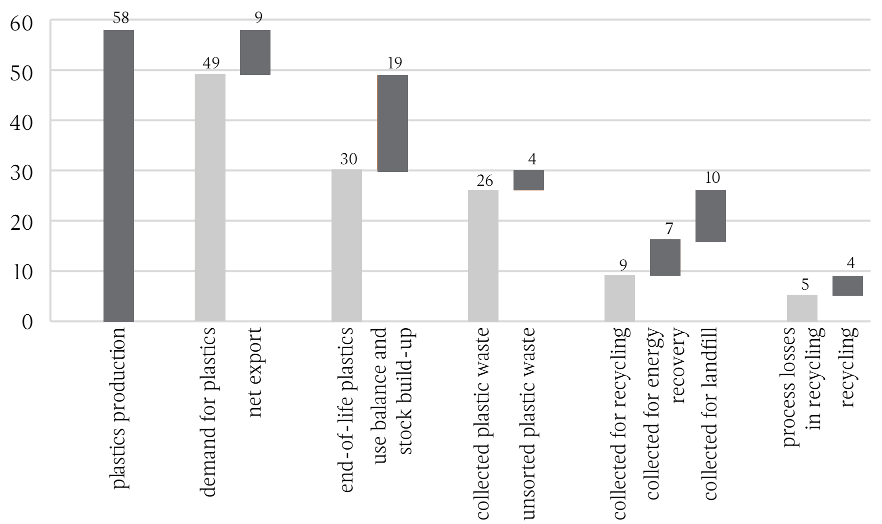
The origin of plastic waste	The way of collection	The way of disposal
Total collected post-consumer plastic waste (29 million tons): – packaging: 61% – building and construction: 6% – automotive: 5% – electrical and electronics: 6% – agriculture: 5% – houseware, leisure, sports: 4% – others: 13%	mixed collection: 52%	recycling: 6% energy recovery: 57% landfill: 37%
	selected collection: 48%	recycling: 62% energy recovery: 27% landfill: 11%

↓

Treatment of end-of-use plastics in 4 main sectors (% of plastic demand)			
packaging	building & construction	automotive	electrical & electronics
– not collected: 21%	– not collected: 76%	– not collected: 47%	– not collected: 60%
– recycled: 19%	– recycled: 5%	– recycled: 6%	– recycled: 24%
– energy recovery: 22%	– energy recovery: 9%	– energy recovery: 5%	– energy recovery: 12%
– landfill: 25%	– landfill: 8%	– landfill: 30%	– landfill: 10%
– yield losses: 13%	– yield losses: 3%	– yield losses: 11%	– yield losses: 2%

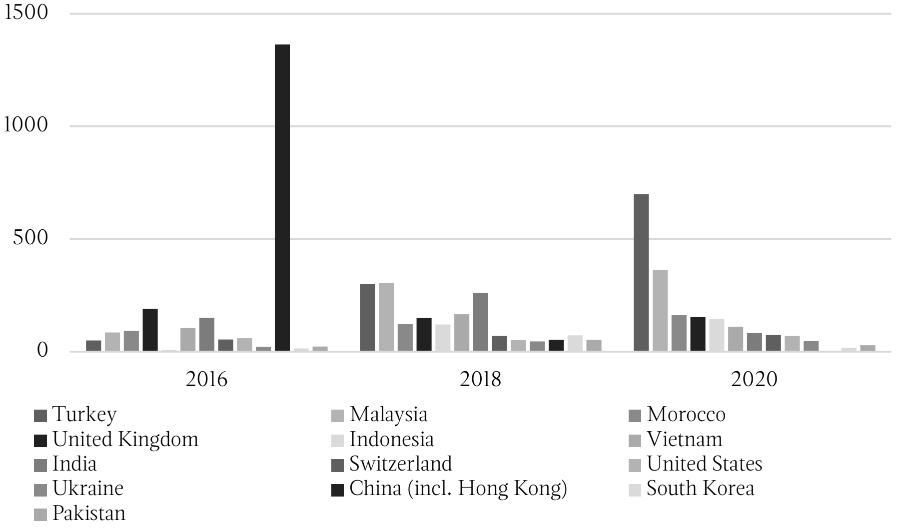
Source: Own preparation based on (Haarman et al., 2020; Material Economics, 2018; Plastics Europe, 2018; 2020).

Chart 1.
Plastic waste volumes in Europe (mt per year)



Source: Own preparation based on (Material Economics, 2018; Plastics Europe, 2018).

Chart 2.
Plastic waste exports by the EU–27 in 2016, 2018 and 2020 (largest destination, in 1000 metric tonnes)



Source: Own preparation based on Eurostat (2021).