PolyCE

Post-Consumer High-tech Recycled Polymers

for a Circular Economy

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Disclaimer

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Contents

1. Introduction

At present, the quality of post-consumer recycled (PCR) plastic recycled from waste electrical and electronic equipment (WEEE or e-waste) is rather low. Consequently, PCR WEEE plastic is mainly downcycled, meaning that they are reduced in quality and/or functionality. The amount of PCR WEEE plastic put back into the electrical and electronic equipment (EEE) value chain has been estimated below 1%[1]. Therefore, PCR WEEE plastics are reduced in terms of value with respect to the original material. This is due to several economic, technical, regulatory and social factors, such as the limited demand for recycled plastic, the necessity to meet certain technical, security and safety requirements, and more generally the negative perception from market actors.

The WEEE (plastic) recycling value chain consists of many different market players, embedded in a complex environment. In order to be recycled at its end of life, WEEE and its components need to go through a variety of consecutive processes that are often managed by different actors (further information in deliverable 3.1). Figure 1 shows a simplified linear representation of the WEEE value chain and waste treatment alternatives (deliverable 2.2):

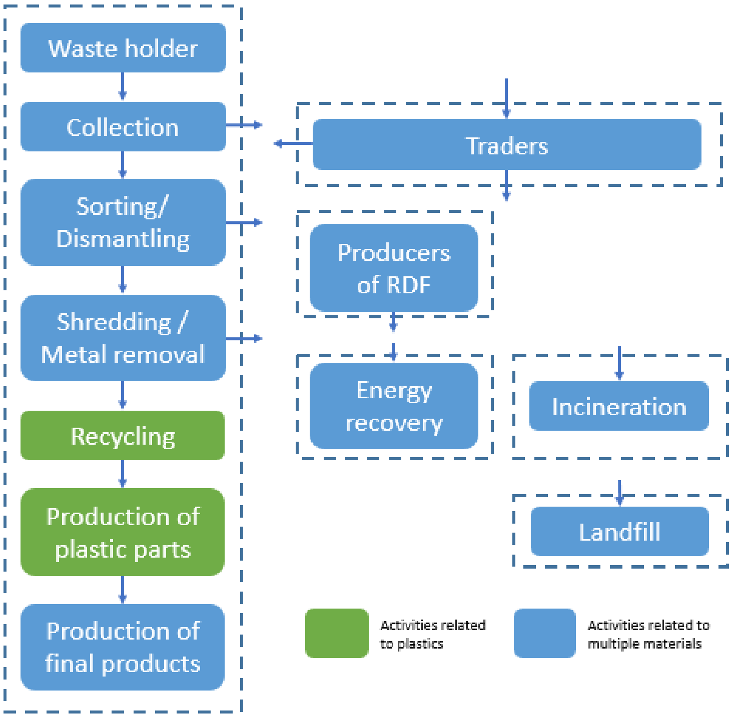

Figure 1: Simplified linear representation of the WEEE recycling chain[2]

The **Original Equipment Manufacturer** (OEMs) have several responsibilities along the studied value chain. First of all, they decide, based on technical specifications and functionality requirement of the product, on the design and materials used in the EEE placed on the market. At this stage, they can already adopt a "design for recycling approach" and "design from recycling"

[1] RDC Environment. (2017). Material efficiency by marking in EU Ecodesign. https://www.rdcenvironment.be/wp-content/uploads/2017/11/2665-Ministrie-Infra-Milieu-Ecodesign-1.pdf.

[2] Adapted from ADEME. (2015). Analyse de la chaîne de valeur du recyclage des plastiques en France. Trois grands axes d'actions pour développer la filière . https://www.ademe.fr/analyse-chaine-valeur-recyclage-plastiques-france.

approach, by promoting the use of recycled instead of virgin material. Then, when the EEE becomes WEEE, OEMs (and importers of EEE) are responsible for the end of life of their products, as per the extended producer responsibility (EPR) principle applied by the WEEE Directive[3], which makes the "design for recycling" important. In Europe, the WEEE Directive is implemented differently by different national authorities. OEMs may either setup their own system, or assign a third party to execute these regulations. In practice, OEMs often work collectively to exert their responsibility by setting up Producer Responsibility Organisations (PROs) which help collectives of manufacturers fulfil their legal requirements with respect to waste management. The organisation on WEEE takeback is organised differently per country.

After the EEE is used and discarded by **consumers,** WEEE is collected, sorted (identifying also the equipment that can be refurbished), transported, dismantled and treated. The role of the **WEEE treatment operator** is particularly crucial for the effective capture of plastic materials. WEEE treatment plants deploy different treatment processes according to the specific characteristics of the treated waste stream, especially depending on the presence of hazardous substances and the composition of the product belonging to a certain waste flow. Plastic is just one of the several output fractions of the WEEE treatment process and is often the outcome of a negative sorting activity, where another more valuable material (such as copper or other metals) was targeted. After depollution, WEEE is usually shredded into pieces smaller than 50 mm and processed in order to sort the largest part of the metals. The plastic-rich residue which is left after shredding is known as Electronics Shredder Residue (ESR) and serves as feedstock for plastic recyclers. At the end of the treatment process, mixed plastic flakes are recovered from ESR. **Plastic recyclers** put in place several activities (as sorting, washing, compounding and finally extrusion) to transform the mixed plastic flakes in plastic granulates. The plastic granulates are used then by moulders to produce plastic components of new products.

The current linear material flows for plastics is a consequence of the limited alignment and cooperation among the various actors in the supply chain. Circular economy business models (CEBMS) offer the opportunity to capture the value in the raw materials (including metals, plastics and critical raw materials) contained in EEE more effectively and has the potential to enhance resource management and material flows within the entire supply chains (see CEBM case studies in deliverable 1.3 Chapter 4). Fulfilling a circular economy requires new processes for closing the value chain, that extent the process of creating and capturing value in the forward value chain to the entire life cycle.

Figure 2: Circular Economy[4]

1.1 Aim and scope of the deliverable

The aim of task 2.3 is to assess the needs, financial and technical possibilities and limitations of actors in the value chain. Producers of plastics, EEE manufacturers including the purchasing departments and product designers, collectors and treatment operators of WEEE, and recyclers of plastics each have different priorities and requirements that do not necessarily match the ones

[3] Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE) Text with EEA relevance. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32012L0019.
[4] European Commission (2015) – Circular economy: the importance of re-using products and materials: http://www.europarl.europa.eu/news/en/headlines/economy/20150701STO72956/circular-economy-the-importance-of-re-using-products-and-materials.

of the other actors. Enabling the realignment of the value chain towards a circular economy model requires finding common interests of the actors in the value chain, identifying win-win situations, and finding solutions where the benefit of the one or few actors in the value chain has adverse impacts other actors.

The objective of this report is to describe the current framework situation in the plastic value chain by summarising the main economic and technical challenges that are preventing the various actors in the WEEE plastic value chain to transition from a linear to a circular economy, and by highlighting the existing opportunities for each actor to favour such transition. The report then illustrates the conditions for addressing the “missing link” between the recycling sector and the designers/manufacturers part of the circular value chain. It showcases an accumulated set of recommendations targeting governments and businesses on actions needed to close the e-plastics loop and to make the circular plastics value chain and the current business environment more appealing for all stakeholders involved. The ultimate aim of this deliverable, is to exemplify in tangible terms a scenario for addressing e-plastic waste generation looking into the following three key conditions for adopting circularity: (1) technical, (2) environmental, (3) economic and (4) legal.

This document targets all actors of the WEEE (plastic) value chain who can all benefit from a better understanding of the challenges faced by each other in the transition to a circular economy and the possible measures and actions to overcome them, as well as policy makers who can take the legal measures to support and favour this transition.

Polymers abbreviations used in the report	
Acrylonitrile Butadiene Styrene	BS
High Impact Polystyrene	HIPS
Polycarbonate	PC
Polycarbonate / Acrylonitrile Butadiene Styrene Blend	PC/ABS
Polyamide	PA
Polyoxymethylene	POM
Polystyrene	PS
Polyvinyl Chloride	PVC

1.2 Methodology

The current deliverable provides the main results and conclusions of the stakeholders consultation carried out through various activities of the PolyCE project, including:

- The organisation of face-to-face workshops and webinar

1 IERC 2020 workshop => 30 participants, incl. EEE producers, take back schemes, WEEE pre-treatment plants, plastic recyclers.

Essen PolyCE workshop => 7 participants, incl. 1 policy makers, 1 plastic recycler, 1 WEEE pre-processor, 4 research centers

Webinar => 25 participants, mainly WEEE pre-processors

- Bilateral expert interviews carried out with 127 key stakeholders of the WEEE plastic value chain – including OEMs, designers, collectors, pre-treatment operators, reprocessors, business representatives organisations, EU-funded projects representatives, and charity retailers – as well as policy makers;

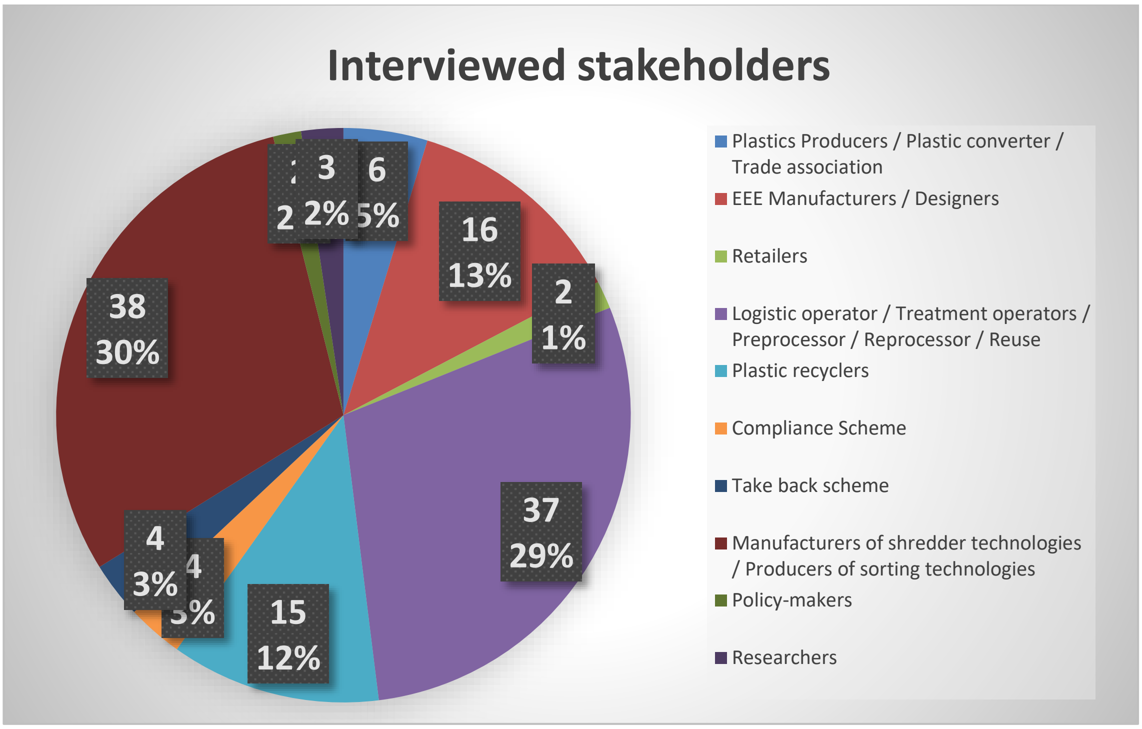

Figure 3: Overview of the types of stakeholders interviewed

In addition, the deliverable builds on the following sets of information:

- Findings from previous deliverables (especially D1.1, 1.2, 1.3, 2.1, 2.2, 3.1, 3.4, 3.5, 6.1 and 6.2) and articles published in the framework of the project;
- Conclusions made in Work Package 8
- Inputs from the consumer campaign and survey launched in Work Package 9; and
- A literature review carried out to confirm and complement the preliminary findings.

Results from the expert interviews showcase that the biggest barrier for CEBM is that "businesses as usual (i.e. linear models), are still economically feasible and perceived as more convenient" (deliverable 1.2). Economic and technological challenges and limitations both play a fundamental role in obstructing/hampering the capacity and willingness of the actors of the WEEE plastic value chain to engage into CEBMs. They are thus the two main aspects to be scrutinized and considered in order to find out current possibilities and opportunities towards more sustainable business models. In addition, regulatory and social factors have to be taken into account. Many of the economic, technical, regulatory and social factors hampering or contributing to a CEBM in the EEE plastic value chain are interdependent, and one change by one actor of the value chain might have positive or negative impact on one or several other actors. Examining the current roadblocks and existing solutions thus requires a holistic approach.

2. Economic limitations and possibilities

2.1 Costs and investments in shifting to recycled plastics

One of the key overarching barriers for the uptake of CEBM by OEM is the costs associated with the move from virgin to PCR plastics. Small companies in particular might lack the resources (e.g. finance) and access or knowledge of where to access post-consumer recycled plastic. Given their small size, they may also simply lack the capacity to require larger quantities of post-consumer recycled plastics (deliverable 1.2) thus making it more expensive. Most importantly, the design approach and processing technology required to produce high-tech recycled polymers are different – and potentially more complex - than for virgin plastic and may require additional investment through research and development activities that small and medium-sized enterprises

(SMEs) might find harder to access. However, according to a recent report by the Nordic Council of Ministers (2019)[5] this represents “only one R&D challenge amongst others; when there is a company-level commitment to using recycled plastics, required know-how can be built along with required changes in the processes to ensure a high quality of plastic”.

From the WEEE plastic treatment operators and recyclers side, the key challenge is to maximize the recycling yield (extract a maximum of recycled plastics for a minimum of waste) and quality (minimal contamination) of recycled plastics, while minimizing costs[6]. For the WEEE pre-processor, reducing contamination and increasing plastic purity enable them to produce plastic with higher value, which can potentially put on the market at higher price. But whether this additional value can balance additional treatment cost is still to be assessed. Investment in advanced technologies is necessary to increase efficiency, yield, product quality and revenues but is less likely to be deployed by smaller recyclers/WEEE treatment operators with limited capacities.[7]

2.2 Price and fluctuations of virgin vs. recycled polymers.

The price of virgin plastics is mainly determined by their cost of production, which depends largely on the crude oil price, along with other factors, such as grid energy price, cost of additives, supply and demand, and commercial agreements between seller and buyer. On the opposite, the price of recycled plastics is not determined by the marginal costs of production but by the competing alternatives of virgin materials, coupled with other factors, including consumer demand, environmental policy, or availability of technology (deliverable 6.1).

Prices of plastic raw materials are linked with crude oil price variations in the global markets and thus suffer high fluctuation. This has an impact for the OEM in term of costs and planning security (resilience), and similarly for plastic recyclers who have to keep competitive price compared to virgin plastic.

When looking at 2019 market price of commonly used types of plastic (PC/ABS and PP), the current recycled plastic equivalents are around 30-50% below the price of primary plastics and show fewer fluctuations, which is of interest for OEMs, both in term of costs and planning security (deliverable 1.3). Lower raw material costs consequently result in lower production costs and thus an increased profit rate.

[5] Raudaskoski, A., Lenau, T., Jokinen, T., Velander Gisslén, A. and Metze, A-L. (2019). Designing plastics circulation – electrical and electronic products. Nordic Council of Ministers.

[6] Hesselink, T. van Duuren, E. (2019). The plastic recycling Opportunity An industry ready for consolidation: Realizing value series. KPMG International. https://assets.kpmg/content/dam/kpmg/xx/pdf/2019/10/the-plastic-recycling-opportunity.pdf.

[7] Dimitrova, G., Berwald, A., Feenstra, T., Höggerl, G., Nissen, N. F., Schneider-Ramelow, M. (2020). Design For and Design From Recycling: The Key Pillars of Circular Product Design.

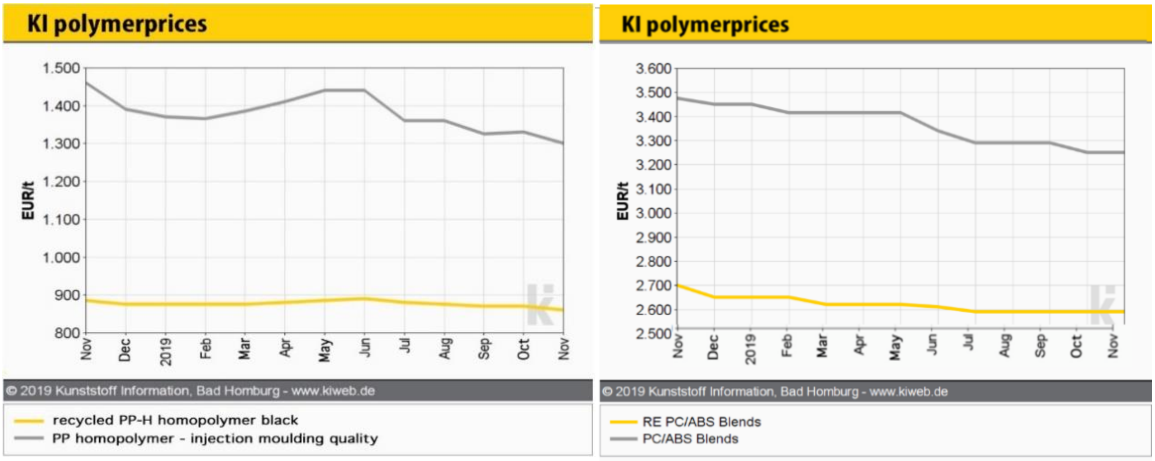

Figure 4: Polymer costs of recycled PP and PC/ABS and virgin equivalents (KunststoffWeb 2019[8])

However, the price and fluctuation trends of virgin vs. recycled plastic are subject to the market dynamics, and an increased demand for PCR plastic might reverse the current situation (price rise for recycled materials and price reduction for primary plastics), with virgin plastics becoming more competitive and stable in price. Similarly, a drop in oil prices could change the price advantages of recycled material.

2.3 Availability of material: from WEEE plastic to recycled plastics

An important challenge for WEEE plastic recyclers is to retrieve enough material and ensure feedstock volume. Research and analysis carried out by PolyCE (see deliverables 3.1 and 1.3) have proven that a large quantity of WEEE plastic is potentially available but the material (i.e. WEEE containing WEEE plastic) is not always properly collected through formal channel[9].

According to (Huisman et al, 2016) [10], the plastic component of EEE has increased from 14% in 1980 (Buekans & Yang 2014)[11] to 25 % in 2015. Based on this latter figure, the total amount of plastic potentially available in the EU from all WEEE is 3.08Mt (Huisman et al, 2016). However, only 1.08Mt (approximately 35%) is actually collected through compliance schemes. Similarly, EERA[12] reports that 1,2 Mt mixed WEEE plastics arises from the separated collection of WEEE and only about 0.3Mt of these plastics are delivered to specialized recycling facilities in Europe and recycled as PCR plastics. According to PolyCE calculations (see deliverable 3.1), at the European level, the treatment of more than 3 Mt of WEEE actually collected through official channels make available more than 717,000 tons (0,7Mt) of WEEE plastic. However, considering that an estimated 9 million tons of WEEE are generated in Europe, then more that 2 million tons of WEEE plastic would be potentially available for recycling (assuming that all the generated WEEE would be managed by the official channel).

[8] KunststoffWeb. (2019). Polymerpreise. KunststoffWeb. Online verfügbar unter https://www.kunststoffweb.de/polymerpreis-news/.

[9] When WEEE are collected through informal channels, operators are mainly interested in more valuable materials, as metals, while plastic is managed in a non-circular way.

[10] Huisman, J., Habib, H., Brechu, M.G., Downes, S., Herreras, L., Løvik, A.N., Wäger, P., Cassard, D., Tertre, F., Mählitz, P. and Rotter, S. (2016). September. ProSUM: Prospecting Secondary raw materials in the Urban mine and Mining wastes. In Electronics Goes Green 2016+(EGG), 2016 (pp. 1-8). IEEE.

[11] Buekens, A. and Yang, J., (2014). Recycling of WEEE plastics: a review. Journal of Material Cycles and Waste Management, 16(3), pp.415-434.imer, Chelsea Green Publishing.

[12] European Electronics Recyclers Association. Responsible recycling of WEEE plastics containing Brominated Flame Retardants- BFR's. https://www.eera-recyclers.com/files/eera-bfrs-folder-online.pdf.

The availability of PCR WEEE plastic is correlated with the WEEE collection dimension. Indeed, as highlighted by the 2020 United Nations University Global E-waste Monitor, in Europe, the total e-waste generation in 2019 was 12 Mt, out of which 5.1 Mt (42.5%) was documented to be collected and recycled[13].

While European WEEE collection rate is the highest in the world (see Global E-waste Monitor 2020 for the collection rate of the other regions), it could be further increased thanks to several measures and actions along the chain. E-waste collection should be promoted and the gap between WEEE generated and WEEE collected should be reduced. In particular, the collection of WEEE from small household appliances should be improved, as this product category has the largest plastic content (36.4%) and at the same time the lowest return and collection rate. In addition, organizing the collection in clusters (e.g. products families defined taking into account the plastic content of the products) can increase the efficiency of the subsequent treatment steps (deliverable 3.1). External event, such as the China plastic ban, might also serve as an opportunity for collectors to increase the collection rate, since additional material will stay in Europe and could thus be treated and used in Europe.

Consumers have also a key role to play by bringing their WEEE to certified collectors or via take-back systems. Awareness-raising campaign and educational campaigns improving the level of understanding and engagement of consumers in sustainable consumption practices (reuse, reduce, recycle, etc), as well as facilitated and innovative collection means (such as the possibility to bring WEEE in supermarket or the use of mobile App to facilitate the collection) are useful means that should be further promoted. OEMs themselves can strengthen their tack-back schemes, as instructed by the WEEE Directive, by promoting or incentivising such system.

In March 2020, the European Commission released a new Circular Economy Action Plan “which provides a future-oriented agenda for achieving a cleaner and more competitive Europe in co-creation with economic actors, consumers, citizens and civil society organisations. It aims at accelerating the transformational change required by the European Green Deal, while building on circular economy actions implemented since 2015”[14]. The Action Plan specifically requests for “improving the collection and treatment of waste electrical and electronic equipment including by exploring options for an EU-wide take back scheme to return or sell back old mobile phones, tablets and chargers”.

According to interview with EC representative, the European Commission is planning a review of the WEEE Directive and the conditions for effective consumer collections and take back incentives and industry take back schemes are to be revised and improved. Possible obligations for industry (EPR) and being discussed.

Despite the material availability, the reintroduction of recycled WEEE plastics into the EEE value chain is obstructed by losses and difficulties in different steps of the studied WEEE value chain (see Chapter 3 on technical limitations). New treatment technologies (e.g. innovative sorting equipment) or treatment procedures (e.g. manual dismantling additional steps) should be introduced by treatment operators to reduce plastics mix and to implement the treatment of batch of products collected according to certain clusters. At the level of plastic recyclers themselves,

[13] The remaining non-formally collected WEEE is either discarded with other wastes, informally recycled and scavenged for valuable parts and materials, exported for reuse, or illegally exported. Source: Huisman, J., Botezatu, I., Herreras, L., Liddane, M., Hintsa, J., Luda di Cortemiglia, V., Leroy, P., Vermeersch, E., Mohanty, S., van den Brink, S., Ghenciu, B., Dimitrova, D., Nash, E., Shryane, T., Wieting, M., Kehoe, J., Baldé, C.P., Magalini, F., Zanasi, A., Ruini, F., Männistö, T., and Bonzio, A. (2015). Countering WEEE Illegal Trade (CWIT) Summary Report, Market Assessment, Legal Analysis, Crime Analysis and Recommendations Roadmap, August 30, 2015, Lyon, France. https://www.cwitproject.eu/wp-content/uploads/2015/09/CWIT-Final-Report.pdf.

[14] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions A new Circular Economy Action Plan For a cleaner and more competiCOM/2020/98 final. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN; and European Commission. (2020). Circular Economy Action Plan- For a cleaner and more competitive Europe. Brochure. https://ec.europa.eu/environment/circular-economy/pdf/new_circular_economy_action_plan.pdf.

innovative recycling solutions should facilitate the separation of mixed plastics (see deliverable 3.1).

Thus, even if reaching the targeted collection rate, PCR plastic quantities that are currently on the market do not provide a substitute for primary plastics as a mass scenario and would require a significant increase in production. The ability for plastic recyclers to produce such quantity would necessitate enough material and investments in better separation technologies, such investment being feasible only with a sufficient demand for recycled plastics by manufacturers. However, OEMs themselves require stability in material volume availability in order to invest a specific market but PCR plastic quantities are not yet stable and it is thus difficult for OEMs to agree with suppliers on price for large amount of material and on a long-term basis (chicken-egg situation).

Thus, a shift from virgin to PCR plastics will remain difficult as long as demand and supply remain unstable and policy or ecolabels do not provide enough incentives to increase the amount of products containing recycling plastics on the market. For example, in the UK, the current WEEE system impose to manufacturer to pay an amount of money based on weight of EEE placed on the market, but there is no award in case of positive initiative taken to incorporate recycled material, to improve recyclability of the product at the end of like, to make capture of critical raw materials easier, etc. However, the government is looking creating a scheme introducing modulated fees for WEEE recycling (source: stakeholder interview).

2.4 Market opportunities for recycled plastics

According to the latest statistics, the European plastic demand is around 51.2 Mt (2019) of which 6.2 % (~3.17 Mt) is in EEE sector[15]. As mentioned above, 0.7Mt of WEEE plastic are potentially available from the WEEE treatment in Europe, representing roughly between 23% of the actual EEE plastic demand (deliverable 3.1). Yet, currently, only 1% of PCR from WEEE is used in new EEE product (RDC Environment, 2017)[16], which demonstrates the preference of OEMs for virgin plastics (for economic and technical reasons, as explained in this report). In addition, where recycled content is used, on average this constitutes around 35% of the product (see deliverable 1.2). Such limited market opportunities accentuates the dependence of certain recyclers from their (mostly larger) clients.

The current legal framework might also influence negatively the recycled plastic market. There are legal barriers to obtain PCR WEEE plastics with food contact grade, which reduces the possibility of WEEE pre-processor of obtaining high value plastics to put on the market. From a sourcing perspective, there is a lack of open market due to the cumbersome bureaucracy necessary to move recycled plastics along the supply chain. Plastic waste needs to become first a compounded product before being allowed to move like virgin material and to cross (EU) borders. Transport and shipping legislations limit the number of recycling plants.

> The European Commission is currently reviewing the EU rules on waste shipments and intends to “simplify and reduce burdens linked with the Waste Shipment Regulation’s implementation in general, and in particular to ensure a smooth functioning of the EU internal market for waste destined for recycling or re-use, and support its transition to circular economy models” (Inception impact assessment[17] published in March 2020)

[15] Plastics Europe. (2019). The Facts 2019. Analysis of European plastics production, demand and waste data. https://www.plasticseurope.org/application/files/9715/7129/9584/FINAL_web_version_Plastics_the_facts2019_14102019.pdf
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[16] RDC Environment. (2017). Material efficiency by marking in EU Ecodesign. https://www.rdcenvironment.be/wp-content/uploads/2017/11/2665-Ministrie-Infra-Milieu-Ecodesign-1.pdf.

[17] European Commission. (2020). Inception impact assessment. Ref. Ares(2020)1505101 - 11/03/2020. https://pracodawcy.pl/wp-content/uploads/2020/06/Inception-impact-assessment-Ares20201505101.pdf.

Despite those challenges, more and more companies decide to integrate PCR plastic into new EEE products, driven by legislation, financial considerations, sustainability targets and customers' desire for environmentally-friendly products[18]. For example, Electrolux uses 55% recycled PP in vacuum cleaners (Electrolux Ultra Silencer vacuum) with savings over 2 liters of crude oil and 80 liters of water per unit as well as reduced manufacturing energy consumption by 90%[19]. The German brand Grundig designed a vacuum cleaner made of 90 % recycled plastics originated from WEEE[20]. Philips designed a steam iron made of 30 % recycled plastics, a vacuum cleaner with 25-47 % recycled PP and a coffee machine with 13 % recycled plastics, while 90 % recycled ABS is in the baseplate and 40 % PP in the frame[21] (see deliverable 1.3 for further information). Samsung Electronics' business monitors are made of up to 30% recycled plastics and around 20% for mobile phone and the brand plan to increase this percentages in the future. Arçelik/Beko have used their WEEE recycling facilities to produce a vacuum cleaner made entirely from 90% recycled materials[22]. At end of 2019, HP was using 9% post-consumer recycled content plastic (25,560 tonnes) in personal systems and print products, and they plan to raise this amount to 30% by 2025[23]. As an example, one of HP's printer now contains 30% closed-loop recycled plastics (i.e. plastic from a previous printer)[24].

At the end of 2019, the Commission adopted 10 ecodesign implementing Regulations, setting out energy efficiency and other requirements for some household appliances, such as refrigerators, washing machines, dishwashers and televisions. For the first time, the measures include requirements for repairability and recyclability, contributing to circular economy objectives by improving the life span, maintenance, re-use, upgrade, recyclability and waste handling of appliances.[25]

In March 2020, the EC published the "Categorisation system for the Circular Economy: approach for activities contributing to the circular economy"[26]. This document provides a commonly accepted and inclusive definition and circularity measurement methodology to facilitate the transition to a more circular economy.

Discussions are also ongoing to introduce a minimum recycled content for plastic in new products, including EEE, to stimulate secondary plastic markets. Experts claim that it might only be a matter of time before recycled content is implemented in legislation. Companies that deal early with the integration of PCR plastics in new products would be well prepared for this change and can deal with the implementation of the new recommendations more easily and quickly. As part of the Action Plan, the EC adopted in January 2018 a European Strategy for plastics in a circular

[18] Hesselink, T. van Duuren, E. (2019). The plastic recycling Opportunity An industry ready for consolidation: Realizing value series. KPMG International. https://assets.kpmg/content/dam/kpmg/xx/pdf/2019/10/the-plastic-recycling-opportunity.pdf.
[19] MBA Polymers (2013). News. Vac for the future: Electrolux get to grips with recycled plastics. https://mbapolymers.com/news/news-electrolux-vac/.
[20] Grundig. (2018). PRESSEMITTEILUNG Plastik in neuer Mission: Recycelte Materialien für nachhaltige Haushaltsgeräte. https://www.grundig.com/fileadmin/Export/Content/News/Product/2018/08_August/Grundig_Haushaltstechnologien_fuer_eine_Umwelt_mit_Zukunft.pdf.

[21] Philips's webage Our approach to recycling. https://www.philips.com/a-w/about/sustainability/sustainable-planet/circular-economy/recycle.htm.

[22] Beko's webpage Waste & Recycling. https://www.bekoplc.com/sustainability/waste-and-recycling/.
[23] HP. (2019). Sustainable Impact Report 2019 Executive Summary. http://h20195.www2.hp.com/v2/GetDocument.aspx?docname=c05179523.
[24] Plastic Technology. (2019). HP Talks New Recycled Content Plastics Goal & Sustainability in 3D Printing. https://www.ptonline.com/blog/post/hp-talks-new-recycled-content-plastics-goal-sustainability-in-3d-printing-
[25] European Commission. (2019). New rules make household appliances more sustainable. Press release. Brussels. 1 October 2019. https://ec.europa.eu/commission/presscorner/detail/en/IP_19_5895.
[26] European Commission. (2020). Categorisation System for the Ciruclar Economy. A sector-agnostic approach for activities contributing to the circular economy. Independent Expert Report. https://op.europa.eu/en/publication-detail/-/publication/ca9846a8-6289-11ea-b735-01aa75ed71a1.

economy[27] aimed at transforming how plastics and plastics products are designed, produced, used and recycled with ambitious targets for the coming years, including: "ensure that by 2025, ten million tonnes of recycled plastics find their way into new products on the EU market" and "Changes in production and design enable higher plastics recycling rates for all key applications. By 2030, more than half of plastics waste generated in Europe is recycled."

2.5 Perceived quality of PCR plastics by consumers

From the consumer side, there is currently a rather low demand of EEE containing recycled plastics. This may be due to a lack of awareness of the existence of such option or to a perceived lower quality of recycled plastics from certain consumers which might impact their willingness to buy products containing such material and their willingness to pay equal or more that products containing virgin plastics. A recent behaviour study by the European Commission on consumers' engagement with the circular economy indeed reveals that product quality and price are the two most important factors influencing their product choice[28].

However, with growing concerns about the environment and increasing awareness and willingness for sustainable consumption, PCR plastics represent an opportunity to address the needs of consumers that are interested in products' sustainability performances. Indeed, the 2019 PolyCE consumer survey revealed that, when made aware of the positive effects on the environment and human health, 95% of the respondents confirmed they would buy an electronic product clearly labelled as containing recycled plastics (see additional results of the consumer survey in deliverable 1.3). On the business-to-business (B2B) side, bigger customers, especially in Nordic countries, are asking to implement closed loop project with IT brands and are specifically requesting the amount of recycled material used in products (source: stakeholder interview).

The PolyCE project highlighted certain environmental benefits of using PCR plastics: 91% abiotic depletion potential; 75% reduction of greenhouse warming; 53% decreased water consumption. These can serve to improve product marketing to environmentally conscious consumers, but also to improve a company's sustainability ranking (deliverable 1.3).

If, for the moment, consumer behaviour is not a strong push factor for companies to get into CEBMs, the increasing awareness and willingness of consumers and consumers' associations to contribute to a circular economy could, in the future, become a key factor. As a first step to overcome this issue, OEMs may consider starting to implement CEBMs in B2B markets (deliverable 1.2). Indeed such service models are usually easier to implement and sell as a concept when the relationship between producer and customer is more direct and can therefore be tailored to meet their needs.

3. Technical limitations and possibilities

[27] European Commission. (2018). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A European Strategy for Plastics in a Circular Economy. Brussels. 16.1.2018. COM(2018) 28 final. https://ec.europa.eu/environment/circular-economy/pdf/plastics-strategy.pdf; and European Commission. (2018). A European Strategy for Plastics in a Circular Economy. Brochure. https://ec.europa.eu/environment/circular-economy/pdf/plastics-strategy-brochure.pdf.
[28] European Commission. (2018). Behavior Study on Consumers' Engagement with the Circular Economy. Final Report Prepared by LE Europe, VVA Europe, Ipsos, ConPolicy and Trinomics. https://ec.europa.eu/info/sites/info/files/ec_circular_economy_final_report_0.pdf.

3.1 Consistent material quality: safety and technical requirements

A number of challenges and practical considerations are associated with the recovery of PCR plastics[29], including:

- Electronics Shredder Residue may contain a wide variety of plastic types (in terms of polymers and colours), such as PS, ABS, PC/ABS and PC, PA, POM, PVC, HIPS, etc. This material heterogeneity also needs to be assessed in light of the products' lifecycles evolutions and the evolution of the products composition, as well as of the composition of the WEEE flows. In addition, the different types of plastic are often difficult to separate because of similar density. Different plastic types are marked but the marking is not always correct and the marking is often not an effective tool considering that WEEE are not manually dismantled (products are shredded together, and the obtained mixed fractions sorted);
- ESR contains a significant amounts of non-plastic, and the ratios of the different plastics can be variable. Currently, non-plastic fractions are the main target materials of WEEE pre-processors activities;
- Presence of paints and coatings;
- Presence of impurities and hazardous substances or components, in particular Brominated Flame Retardants and heavy metals;
- End users are looking for specific property (in terms of aesthetics, function, colour, smell or stiffness) and requires recycled plastic to have equal or similar properties to virgin plastics;
- Many plastics have similar densities, which makes separation more difficult, especially when materials have been moulded together or enclosed permanently;
- Some plastics are extremely sensitive to moisture, acids, and bases, which can catalyze their degradation in the compounding step;
- Some plastics or additives can catalyze the degradation of other plastics or harm their properties;
- Virgin grades of these plastics are highly engineered for use in specific applications, so end users will require recycled plastics to have similar properties;
- Reduction of the quality of the virgin plastics used in new EEE to reduce the product prices makes plastic recycling activities more complex and may reduce the PCR plastic quality.

Technical

	Virgin Plastic	Recycled plastic
Quality	Constant	Quality variation based on used source
Availability	High	Limited PCR (PP, PE, HIPS, ABS, PET)
Surface	Good surface finishing quality	High gloss surfaces difficult to reach
Colour	Flexibility in colouring	Transparent natural color barely available, mainly black and grey colours
Olfactory performance	Good	Can be very smelly, depending on the source

"Achieving the same target properties can be very challenging with recycled plastics, since the collected material can suffer from limitations with respect to mechanical properties, colour or purity. These limitations can reduce the area of applications for recycled plastics. Since it cannot be categorically ruled out for certain waste streams that they contain impurities (incl. substances of concern), they cannot be used in products with food contact, toys or medical devices."

29 Built from D2.2; D1.3; Dimitrova, G., Berwald, A., Feenstra, T., Höggerl, G., Nissen, N. F., Schneider-Ramelow, M. (2020). Design For and Design From Recycling: The Key Pillars of Circular Product Design; and Schwesig, A. and Riise, B. (2016). PC/ABS Recovered from shredded waste electrical and electronic equipment. Technical paper. https://read.nxtbook.com/wiley/plasticsengineering/june2016/technicalpaper.html.

Figure 5: Technical attributes for virgin and recycled plastics[30]

A number of technologies are available and increasingly being developed to overcome these challenges (including air classification systems, water-based density sorting systems, electrostatic separations, melt filtration, additives, etc.) and pre-processors and recyclers are widely aware of the waste stream categories and even the plastic parts that need special handling to avoid substance of concern entering the mix of materials to be recycled.

PolyCE, in collaboration with the innovative plastics recycling industry have developed systematic sorting and separation concepts in order to produce PCR plastics from these complex mixes of plastics from WEEE that are compliant with RoHS Directive[31] and REACH Regulation[32]. The separated plastics containing the restricted persistent organic pollutants (POP) brominated flame retardants (BFRs) are eliminated in appropriate incineration processes, in line with the relevant Basel Convention guideline documents[33].

But not all players have the capacity to invest in such technologies nor are applying similar standards. Indeed, PCR plastic market is characterized by many suppliers on the market with huge quality variation. Thus, the consistency of PCR plastics quality cannot be always easily ensured, limiting their use in products. The differences in plastic composition depends on the WEEE categories, and on the origin of the material (especially EU vs. non-EU, but also within the EU). Technical factsheets of PCR Plastics are not always reliable and the OEM need to retest the material before using it to make sure it reaches the minimum quality requirements, which imply additional costs. The variability in methodology and internal standards within Europe in preparing for reuse (especially, the liability of producers for reused appliances that may not reach quality standards and may pose a hazard to second life users) is perceived to influence all the subsequent nodes of the PCR plastic value chain and is impacting on the achievement of high rates of recycling. Moreover, it currently represents a barrier for an appropriate valorisation of the plastic itself. The solution was felt to be the development of a EU high-quality standard system/methodology in preparing for reuse or the use of established trustworthy partners (deliverable 1.2, see also WEEE Forum, 2017[34]).

For lowering the cost of the recycling process and ensuring a high quality sorting, it is necessary not only to improve sorting technologies, but also to enhance the quality of the collection in the first place. Due to concerns of plastic miscibility and content of hazardous substances, mixed plastics require careful separation and clustering before their reprocessing. Thus, both the collection and sorting activities are having a high effect on the quality and supply reliability of recycled plastics (deliverable 6.1 and 3.5).

[30] Dimitrova, G., Berwald, A., Feenstra, T., Höggerl, G., Nissen, N. F., Schneider-Ramelow, M. (2020). Design For and Design From Recycling: The Key Pillars of Circular Product Design.

[31] Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32011L0065.

[32] Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32006R1907

[33] PolyCE project. (2019). PolyCE's Workshop on Circular Design: Making a Business Case for Recycled Plastics. https://medium.com/@PolyCE_EU/polyces-workshop-on-circular-design-making-a-business-case-for-recycled-plastics-ac143449bcd3.

[34] WEEE Forum. (2017). WEEE plastics and chemical, product and waste legislation. Response to the stakeholder consultation paper on the chemical, product and waste interface. p.3. http://weee-forum.org/wp-content/uploads/2019/06/Plastics_Issue-paper_v6_Final.pdf.

There is a general opinion that the use of PCRs, both currently and in future, would be determined by OEMs who set the material requirements for their products and product parts. OEM and designers have indeed a key role to play to homogenise the ESR composition and improve its recyclability, including by choosing common and easily recyclable plastics while avoiding plastics releasing toxic elements during the recycling process, opting for easy separable solutions, or optimizing mould for recycled plastics ("design for recycling approach"). In complement, OEM and designers can decide to incorporate recycled plastics in new EEE, thus contributing to closing the loop of the plastic value chain ("design from recycling" approach).

In order to facilitate plastics recycling at the product's end of life, PolyCE developed a priority plastics **Guide** for non-FR plastics to be used by designers of electrical and electronic equipment at the conception stage (see deliverable 2.2).

PolyCE also developed the **Drop-In Approach**™ which can help designers to mitigate different risks related to the use of recycled plastics by first building up material knowledge and then using this knowledge in new products and projects (see Dimitrova et. al. 2020).

The EC Circular Economy Action Plan 2020[35] specifically calls for "regulatory measures for electronics and ICT including mobile phones, tablets and laptops under the Ecodesign Directive so that devices are designed for energy efficiency and durability, reparability, upgradability, maintenance, reuse and recycling. The upcoming Ecodesign Working Plan will set out further details on this."

3.2 Legal complexities and uncertainties related to hazardous substances

The multiple layers of regulation, the difference of perception and interpretation of "risk" among countries and the lack of operation standards all create a certain degree of complexity and uncertainty for the actors of the WEEE value chain.

Indeed, WEEE plastic recycling is subject to several regulation in the EU, including the WEEE Directive, RoHS, REACH, and POP regulations, aimed at restricting and monitoring the use of hazardous substances. Although all EU countries have implemented the legal requirements to national law there are still considerable differences in classification of certain substances of concern (e.g. not listed, Annex IV, Annex III of the WEEE Directive, hazardous or non-hazardous waste), such as brominated flame retardants (BFR) contained in WEEE plastic[36].

WEEE Plastics	
ABS	24 %
HIPS	27 %
Polyolefines	7 %
PC and PC-ABS	7 %
BFR containing plastics	5 %
Other plastics	24 %
Other contaminants	6 %

Today, the majority of the WEEE plastics does not contain Brominated Flame Retardants (BFRs) and of the approximately 5-10 % that do contain BFRs, only approximately 30 % consists of POP BFRs.

[35] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions A new Circular Economy Action Plan For a cleaner and more competitive Europe. COM/2020/98 final. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN; and European Commission. (2020). Circular Economy Action Plan- For a cleaner and more competitive Europe. Brochure. https://ec.europa.eu/environment/circular-economy/pdf/new_circular_economy_action_plan.pdf.

[36] IMPEL. (2018). WEEE Directive Implementation and Enforcement Brominated Flame Retardants in WEEE plastic . https://www.impel.eu/wp-content/uploads/2016/12/WASTE-Report-BFRs-in-WEEE-plastic-2018-def.pdf.

Table 1: Average composition of WEEE plastics[37]

A number of European standards, such as the CENELEC EN 50625, have been developed to "improve the way WEEE is collected and treated and help actors meet the Directive's requirements in a clear and unambiguous way"[38].

In the Circular Economy Action Plan 2020[39], the European Commission announced the "review of EU rules on restrictions of hazardous substances in electrical and electronic equipment and provide guidance to improve coherence with relevant legislation, including REACH and Ecodesign."

Another legal challenge relate with conflicting targets between the various regulations. Whilst there are targets set by the WEEE Directive (Directive 2012/19/EU) to achieve a certain recovery rate, other legislations such as POPs, RoHS or REACH Regulations may prevent the achievement of such targets due to the recovery of certain hazardous substances contained in plastics being banned (deliverable 6.1).

With reference to the potential classification of WEEE plastic as hazardous waste, the PolyCE project issued a paper[40] highlighting that such decision would risk making EU recycling of WEEE plastics impossible due to the lack in Europe of WEEE plastics recycling facility permitted to take in hazardous wastes. These plastics would thus risk to be traded before leaving Europe through ports that have virtually no controls on BFRs specifically.

4. Conclusions from the stakeholder consultation

The research and consultations carried out in the framework of the PolyCE project revealed a number of economic, technical, as well as legal and social challenges hindering a more mass implementation of PCR plastics from WEEE (currently less than 1% of new EEE contains PCR plastics from WEEE). On the other hand, the consultation highlighted opportunities and enabling factors that speak of an emerging trend towards adopting sustainable components such as PCR plastics into new EEE products. The below points summarises the main conclusions from the stakeholder consultation:

BARRIERS

- Wide variety of plastic types, not all of them being easily recyclable, and some of them suffering degradation.
- PCR plastic market is characterized by many suppliers with huge variations in quality. Having many small suppliers makes it difficult for large OEMs to buy a big amount of material at lower price.

[37] Slijkhus, C. (2016). Circular Economy ELV and WEEE Plastics - an Industry Wish List -. MGG Polymers. Brussels, Belgium. Further information on the issues related to the classification of WEEE plastics as hazardous wastes is available in: Dimitrova, G. et. al. (2019). Roadblocks for the Circular Economy of WEEE Plastics: A Call for Informed Classification Practices. https://medium.com/@PolyCE_EU/roadblocks-for-the-circular-economy-of-weee-plastics-a-call-for-informed-classification-practices-9fc8d2da90dd.

[38] WEEE Forum. (2018). Compliant WEEE recycling. Why making EN 50625 standards legally binding is part of the solution. http://weee-forum.org/wp-content/uploads/2019/06/WEEE-compliant-recycling_QA.pdf.

[39] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions A new Circular Economy Action Plan For a cleaner and more competitive Europe. COM/2020/98 final. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN; and European Commission. (2020). Circular Economy Action Plan- For a cleaner and more competitive Europe. Brochure. https://ec.europa.eu/environment/circular-economy/pdf/new_circular_economy_action_plan.pdf.

[40] Dimitrova, G. et. al. (2019). Roadblocks for the Circular Economy of WEEE Plastics: A Call for Informed Classification Practices. https://medium.com/@PolyCE_EU/roadblocks-for-the-circular-economy-of-weee-plastics-a-call-for-informed-classification-practices-9fc8d2da90dd.

- Full removal of impurities and hazardous substances or components in order to obtain recyclable plastics from WEEE remains challenging. As OEMs are responsible for the product safety, they may be reluctant to use recycled plastic in their product.
- While manufacturers are looking for equivalent properties to virgin plastic, recycled plastics still have limitations in terms of mechanical properties, colour or purity, which reduces the areas of applications (e.g. for food contact, toys, medical devices).
- "Chicken-egg situation": on one side OEMs require stability in recycled plastic volume to invest, and on the other side plastic recyclers require sufficient demand by manufacturers to invest and produce enough PCR plastic.
- There are still some evident limitations in recycling and treatment technologies and procedures. Investments in advanced technologies are less likely to be deployed by small recyclers and treatment operators.
- The costs associated with the shift from virgin to PCR plastics by manufacturers are high, especially for smaller companies, due to the lack of resources, access and capacity.
- The price of the recycled plastics is not determined by the marginal costs of production, but by the competing alternatives of virgin materials.
- The limited quantities of WEEE-plastics are mainly due to low WEEE collection rates and the lack of clustering. And the WEEE collection rate is still low, due to various factors such as improper sorting by consumers, low rate of return of WEEE, illegal export, etc.
- The current legal framework limits the recycled plastic market due to the cumbersome bureaucracy necessary to move recycled plastics along the supply chain.
- There is still a high level of legal complexity and uncertainty related to the issue of hazardous substances in WEEE. This includes the variation of legal reference in the different national contexts, the lack of EU standards, conflicting targets among legal instruments such as the WEEE Directive, POPs, RoHS, REACH Regulations.

<u>ENABLERS</u>

- Investments in advanced technologies for WEEE collectors and treatment operators could bring further improvement, also in plastics recycling from WEEE. The innovative plastics recycling industry in collaboration with the Horizon 2020 financed project PolyCE have developed systematic sorting and separation concepts in order to produce RoHS and REACH compliant Post-Consumer-Recycled plastics from these complex mixes of plastics from WEEE.
- Investment in R&D promises to enable design for and from recycling, which is key for the success of circular design and the uptake of EEE containing recycled PCR plastics
- The price of recycled plastic is usually lower and less fluctuant than the virgin plastics. More flexibility in material choice increase company resilience when virgin prices are high
- Improvement in e-waste collection and clustering can increase the efficiency of the subsequent treatment steps. Several models exist to boost the collection rates.
- Market-driven, participatory and business-led legislation including economic instruments can incentivise businesses to fulfil concrete objectives of reaching sustainability targets and can bring more OEMs to decide to integrate PCR plastic into new EEE products The EC Circular Economy Action Plan of 2020 can help boosting innovative initiatives.
- General increase in consumers' awareness and a willingness to adopt circular consumption practices can increase demand for more environmental-friendly products, including buying electronic products clearly labelled as containing recycled plastics.
- There are certain environmental benefits of using PCR plastics according to PolyCE: 91% abiotic depletion potential; 75% reduction of greenhouse warming; 53% decreased water consumption. These can serve to improve product marketing to environmentally conscious consumers, but also to improve a company's sustainability ranking.

Barriers towards the success of the post-consumer recycled market are related to the complexity of the PCR value chain and an inherent lack of communication and collaboration between the actors of the plastic value chain, especially between manufacturers (buyers) and plastic recyclers (sellers), and between plastic recyclers and WEEE treatment operators.

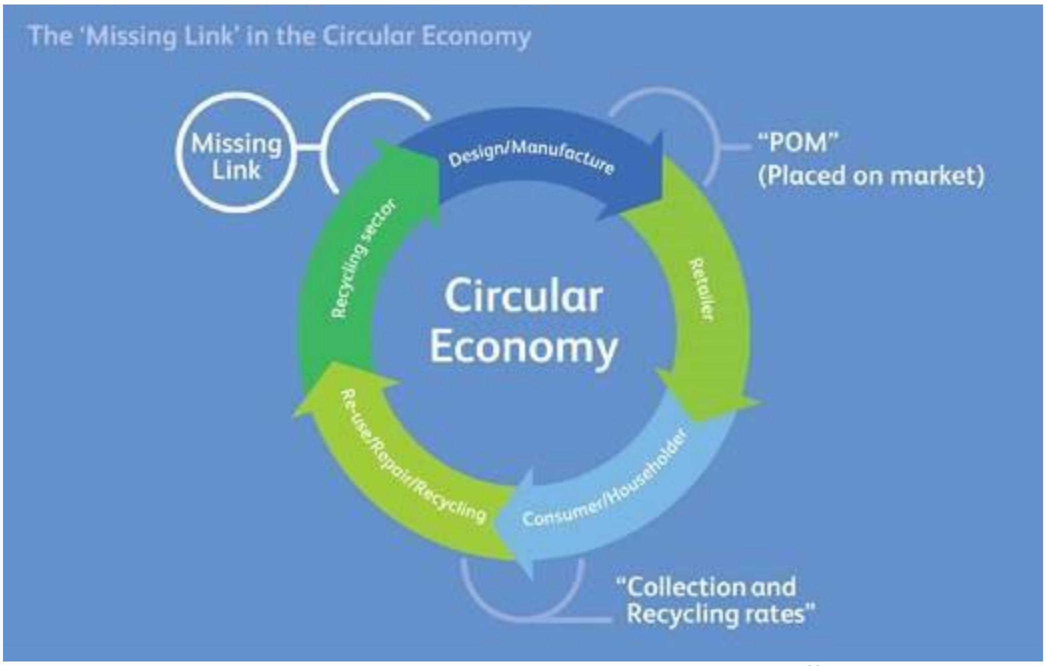

Figure 6: The 'Missing Link' in the Circular Economy[41]

Finding the right partners all along the value chain, creating a long-term business relationship would help to stabilize the price and the market, but also to ensure a constant material quality. In addition, applying a certain level of harmonization and standardisation at all stages of the plastic value chain (e.g. in terms of polymers used in EEE products, clustering of products and components for pre-processing, particle size, technical datasheet, etc.) would improve the quality and quantity of recycled plastics.

5. Conditions for adopting circularity across the plastics value chain.

Based on the barriers and enablers identified above, the following infographic is showcasing a set of short-term key - technical, environmental, economic and legal - requirements for overcoming hurdles on the way towards the circular plastics value chain. The suggested actions are future-oriented recommendations for the wider adoption of PCR plastics on the European market.

[41] MGG Polymers.

TECHNICAL

More takeback collection systems for EEE at end of life, throughout the EU and UK would encourage reuse and recycling and will result in a better quality plastic.

Design from and for recycling: the use of PCRs, both currently and in future, would be determined by OEMs who set the material requirements for their products and product parts.

OEM and designers play a key role in homogenising the ESR composition and in improving its recyclability.

ENVIRONMENTAL

Raising awareness amongst consumers and businesses on the environmental benefits of adopting PCR plastics, namely:

- 91% abiotic depletion potential;

- 75% reduction of greenhouse warming;

- 53% decreased water consumption.

These can serve to improve product marketing to environmentally conscious consumers, but also to improve a company's sustainability ranking.

ECONOMIC

Harmonized price on CO2 would incentivize the use of PCR plastics and avoid complex product regulations going down to the component level.

Financial incentivisation/fiscal measures either by taxing virgin products or rewarding use of PCR plastics.

The price of recycled plastic is usually lower and less fluctuant than the virgin plastics. More flexibility in material choice increase company resilience when virgin prices are high.

Investments in advanced technologies for WEEE collectors and treatment operators could bring further improvement, also in plastics recycling from WEEE.

LEGAL

Establishing end of waste criteria for plastic recycling and quality standards for secondary raw materials.

Policy measures on ecodesign of new products such as specifying a minimum recycled content.

Introducing incentives and securities to stimulate investments in collection and treatment facilities.

EU Standards for export of reuseable EEE or plastics from WEEE would encourage investment at EU level.

Figure 2: Conditions for enabling the circular plastics value chain

6. Recommendations.

In order to ensure the above listed conditions for change are met for all actors in the value chain, the PolyCE project has been in charge of compiling concrete recommendations from practitioners in the EEE industry sector (plastic producers, recyclers, EEE manufacturers and WEEE collectors). The below infographic presents these recommendations in a systemized manner. The ultimate recipient of these are government officials, in charge of utilising the appropriate political and economic instruments that would enable the uptake of PCR plastics amongst EEE businesses and their pool of stakeholders (supply chain partners, consumers, and other customers).

Plastic Producers

Matching quality requirements without affecting the final product.

Communicate with manufacturers about reliability of supply and predicting costs.

Meet regulations such as ROHS, REACH.

Specify properties of recycled plastics before production: mechanical, optical, processing.

EEE Manufacturers

Raising awareness amongst consumers and businesses on the environmental benefits of adopting PCR plastics, namely:

- 91% abiotic depletion potential;

- 75% reduction of greenhouse warming;

- 53% decreased water consumption.

These can serve to improve product marketing to environmentally conscious consumers, but also to improve a company's sustainability ranking.

Recyclers

Harmonise plastics use: marking of plastics, coupled with identification.

Use polymers with known high recyclability rates.

Harness platform design approach, where parts are standardised so that they can be used in several products.

WEEE Collectors

Involving consumers into circular consumption models.

Promote collection of WEEE from small household appliances – they have the largest plastic content (36.4%) and at the same time the lowest return and collection rate.

Clustering plastics types to facilitate the role recyclers.

New technologies (innovative sorting equipment) or treatment procedures (manual dismantling additional steps) should be introduced by treatment operators to reduce plastics mix and to implement treatment of batch of products collected according certain clusters

Figure 3: Recommendations for meeting the conditions for enabling the circular plastics value chain

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