PolyCE

Post-Consumer High-tech Recycled Polymers for a Circular Economy

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Introduction

This PolyCE deliverable, 8.3, presents the business case and benefits for dematerialisation and circular economy business models (CEBMs) for Electronic and Electrical Equipment (EEE) compared to traditional linear economy business models. EEE contains a complex mix of valuable metals, plastics and critical raw materials. While metals and electronic components are prioritized during recycling, plastics are often left in the background. Recommendations for changes in product design, and other operational issues, based on the dematerialisation trials, are compiled.

Circular economy business models offer the opportunity to manage valuable materials more effectively requiring a systematic transformation involving all actors in the value chain and encompassing the entire lifecycle of plastic materials. Key enablers and barriers to adopting CE business models were identified

The research findings stemming from PolyCE's Work Packages 1, 2,3, 7,8 and 9 indicate a slow but positive trend of transition from linear towards Circular Economy for businesses and consumers in the electronics sector and show positive economic and environmental benefits for adopting a more circular approach. The following research is the result of the cumulative work of the PolyCE project partners across all work packages. The findings from WP 1, 2, 3 and 9 along with supporting evidence from WP7 and the design and LCA findings from WP8 have been evaluated and used in presenting the advantages for a circular business case. Dematerialisation is delivering the same product or service using a percentage or none of the mass or material types. It is valuing what the product does rather than valuing the product itself. There are a few pathways to dematerialise a product:

- Digitise – sell the product electronically or virtually
- Servitise – sell the utility of the product as a service
- Reduction - absolute or relative reduction in the quantity or type of materials used and/or the quantity of waste generated in the production of a unit of economic output

Within PolyCE we have looked at the reduction element of dematerialisation. PolyCE developed demonstrators to show the benefits of using high quality polymers from Post-Consumer Recycled WEEE plastics. The demonstrators highlighted in this deliverable are those developed for SME's as WP1 (D1.2) identified that this was perceived as being the most difficult market to develop. The concept, design and function of the products were designed incorporating the guidelines developed by PolyCE, using mainly post-consumer recycled polymers (PCR) produced by PolyCE partner MGG, or post-industrial recycled polymers produced by Sitraplas, where use of PCRs was not possible. . The PolyCE project examined the potential economic, environmental, and social benefits, to make the business case for the adoption of a circular economy approach.

Consideration of Life cycle analysis LCA including carbon, water and raw material savings, cost benefit analysis, product lifetime (compared to previous use and industry average), transport costs and an evaluation of potential market penetration have been conducted. Both quantitative and qualitative learnings from the research in previous work packages have been assessed.

2 The Case for the Circular Business Model.

2.1 Introduction.

It is clear that the Circular Economy (CE) represents a radical and important shift in our society; both in consumption patterns and how business is conducted. However, views differ on how this shift will be monitored and the pace at which it can happen, but it is generally agreed that the pace will be determined by both the legislative framework and the commercial attitude to change. It is currently simpler for business to be conducted in a linear way, and the adoption of Circular Economy Business Models (CEBMs) will need to run in parallel with linear business practices before a paradigm shift is achieved (Colley-Jones et al., 2019). A circular business model (CEBM) is not a new concept: to not do things efficiently should be an anathema to businesses as waste equals money (Porter & Linde 2004). The challenge is to develop sustainable businesses that are compatible with the current economic reality. Circular business models ultimately aim to adopt an alternative approach to the value proposition (Teece, 2010). New business models are an opportunity to mitigate the risk of depletion of *at risk* materials, as they allow greater retention of materials along value chains.

Innovative business models and products must be financially viable, irrespective of how good they are ecologically and socially. Ellen MacArthur Foundation (2015) demonstrate that adoption of circular economy could deliver potential global benefits of €1.8 trillion p.a. by 2030.

The potential effectiveness of circular business models in delivering the circular economy is recognised by the EU and the Circular Economy package was launched in December 2015 (EU 2015). The package aims to further stimulate Europe’s conversion towards embracing circular business models with a view to boosting global competitiveness and fostering sustainable economic growth. EASAC (2016) identifies that linkages exist between the circular economy; human well-being and sustainable economic development.

In order to deliver a good circular business model, there is a need to identify the key resources and processes to deliver the value proposition to the customer (Johnson et al., 2008) as can be seen in figure 1. Those businesses operating in the circular economy should create value (EMF, 2013). A holistic approach to delivering circular business models for the electrical and electronic equipment has the potential to maximise resources and deliver a more effective solution to the wider sustainability of the sector.

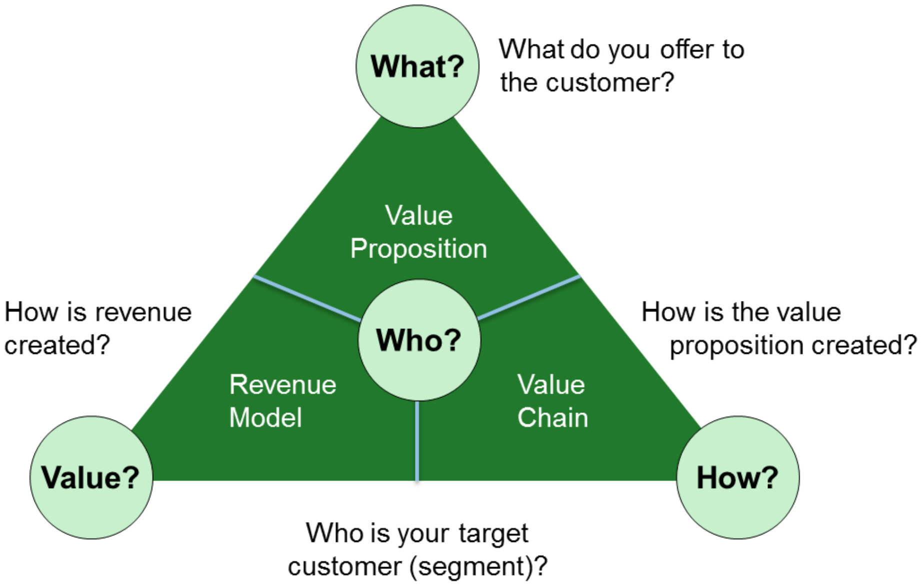


Figure 1 Considerations when developing a business model. (Source; eu.europa 2015)

The value proposition is the product or service for the customer (Teece, 2010) needs to be accompanied by a profit formula (Johnson et al., 2008) of key resources and processes which describe how that value will be delivered to the customer and the company.

2.2 Circular Economy Business Models used by the PolyCE project.

The concept of Circular Economy (CE) can provide companies with an opportunity to transform the way they create value. Circular business strategies can pave a way towards production and consumption patterns that enable long-lasting sustainability. In a CE, companies that implement circular business models (CBM) play an important role. In line with the PolyCE Project, five different types of dematerialization models that have been categorized to understand alternative business model types as developed in WP1:

- Long-life Model.
- ReValue Model.
- Modularity Model
- Access Model
- Service Model.

2.3 Adopting a circular business model approach.

Many of the organisations that were interviewed during the PolyCE project have a long history of embedded sustainability and resource efficiency goals. Increasingly though, these organisations are seeing added value in developing closed loop systems and other CEBMs, both from an economic and environmental perspective

A review of current indicators used by OEMS to measure environmental/ circularity performance show that there is a range of methods employed. While companies are encouraged to come together in a pre-competitive environment to share best practices for movement towards a circular economy it is clear that each organisations journey towards circularity is unique and therefore comparison can only be done in a meaningful context and in careful consideration. Companies such as Dell and HP, focus on the environmental impact of the company with Dell reporting “net benefits” (in terms of natural capital) and HP aligning itself with “three pillars of sustainability. All OEMS report on circularity in terms of improvements or goals achieved, set against pledges and internal bench marks, and in relation to Philips and Whirlpool, are keen to report in terms of individual products as well as the company as a whole. It is noted that none report in terms of economic benefits and tend to cite the impact, in terms of benefits to sustainability, thus aligning directly with UN Sustainability Goals. There is no current consensus approach for how companies should measure their effectiveness in moving towards more circular business models, the development of Circular Transition Indicators (WBCSD, 2018) aim to provide an objective, quantitative and flexible framework (Von Brunschot, 2020) and compliment a company’s existing sustainability efforts.

An interpretation of best practice, of the steps in developing the case and monitoring the development a circular product, has been collated and is shown in figure 2.

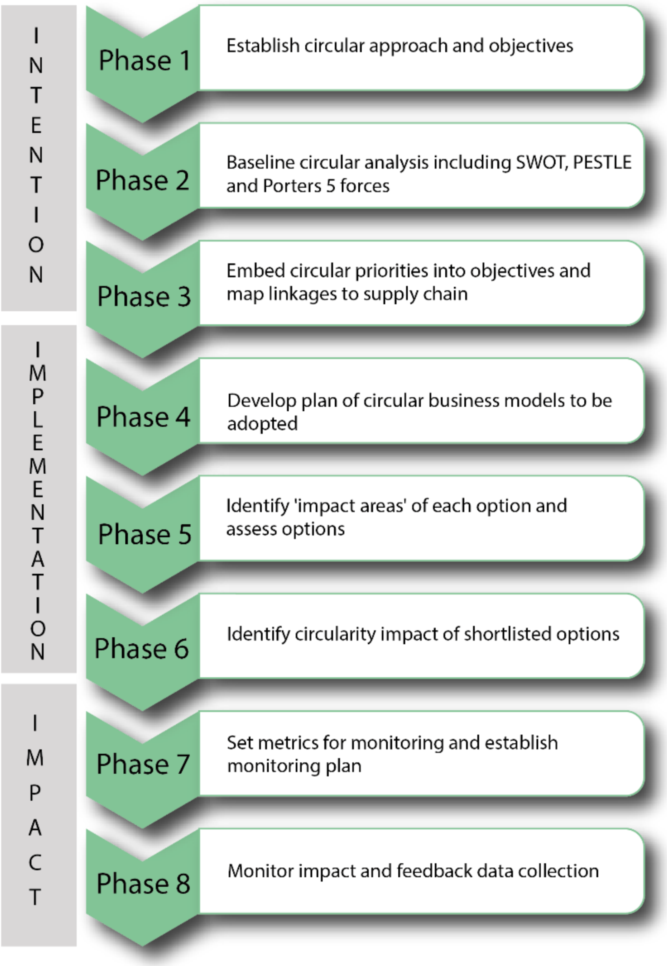


Figure 2 : Phased development towards circularity for products

3. PESTLE analysis

Two techniques are used to examine the business environment within which an organization is operating: PESTLE analysis and SWOT analysis. Using the PESTLE and SWOT techniques together help to provide a detailed picture of the situation facing an organization. Just using one technique may leave gaps in knowledge and understanding. Individual SWOT evaluation will be done for each of the case study demonstrators. The PESTLE analysis enables the identification of a list of potential issues within the business environment; this analysis is performed for the WEEE PCR plastic context and it is reported below.

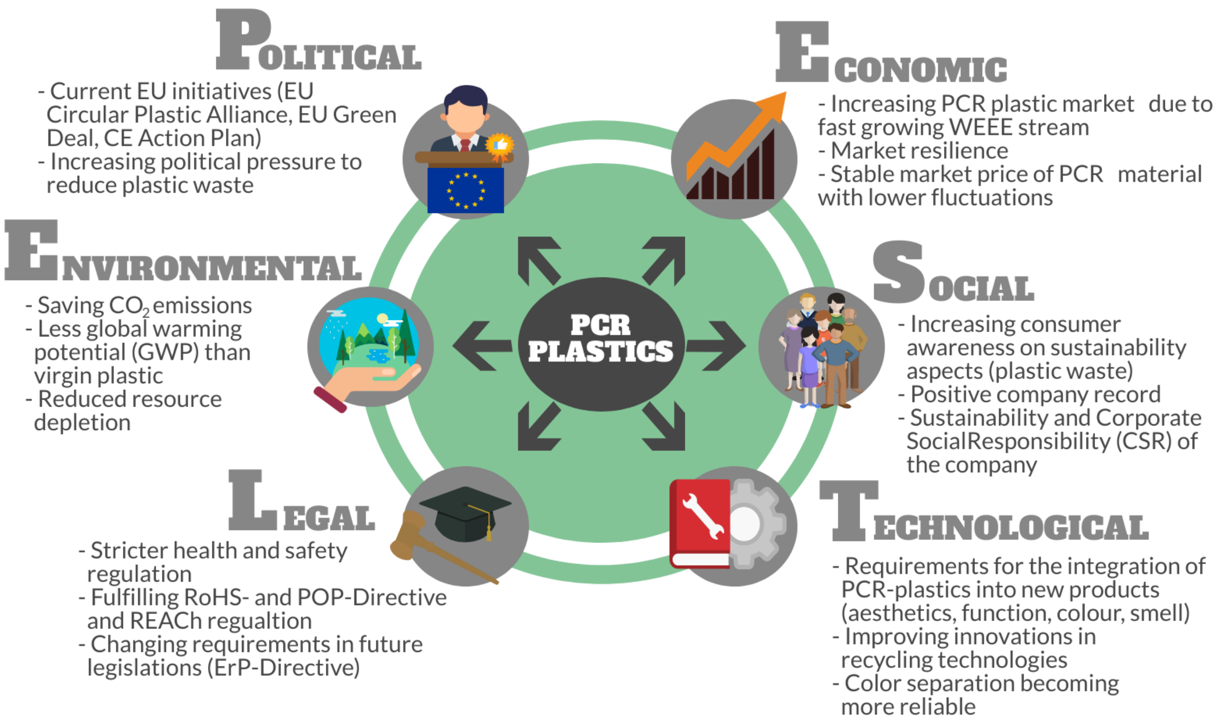


Figure 3 Influencing factors of PESTLE analysis regarding PCR-plastics

3.1 Political factors.

Many of the recent EU legislation and voluntary agreements, such as the various National Plastics Pacts and the Circular Plastics Alliance are a strong factor for driving industry sectors towards increased plastic recycling in Europe. The European Commission has claimed that by 2030 at the latest, plastics that cannot be recycled should no longer be used in the EU.

The European Commission has set higher collection and recycling targets to increase the amount of WEEE to be treated, therefore, more WEEE plastics are available for recycling. From 2019 the minimum collection rate rose from 45% to 65% (WEEE directive 2012). Since 1 January 2021, the revised Basel convention regulates transboundary shipments of secondary plastics and plastic wastes: in particular, sets a one-size-fits all 2% threshold of non-hazardous impurities/components in order to be classified under the new entry EU3011 (clean, non-hazardous waste that can be destinated for recycling to non-OECD countries only under specific conditions and for which intra-EU shipments for recovery are exempt from new controls).

The European Federation of Waste Management and Environmental Services is continuously advocating for concrete and strong policy measures, such as mandatory green public procurement, binding recycled content in certain products, reduced VAT for products composed of recycled content, and eco-design aspects. Vice Commission President Frans Timmermans argues that an EU-wide tax on virgin plastics will be extremely difficult to establish, pinpointing to the fact that some plastic use is indispensable. *However, through incentives and innovations, but also through prohibitions, Brussels wants to make plastics not only better: the only long-term solution is to reduce plastic waste by increasing its recycling and reuse.*

The **EU Plastics Strategy,** published in January 2018, aims to push the EU towards a circular plastic economy, to support more sustainable production patterns for plastics, reuse, repair and recycling of products as well as to reduce marine litter, greenhouse gas emissions and dependence on imported fossil fuels (European Commission, 2018). To push the uptake of recycled plastics, Annex III of this strategy includes voluntary pledges of 70 companies and business associations defining their contribution, with an overall goal that 10 million tons of recycled plastics find their way into new products by 2025 in the EU (European Commission 2018). This has led to the development of the industry Circular Plastics Alliance (CPA). The CPA is currently identifying limitations in existing standards that restrict the incorporation of high value recycled products being used in manufacture of new products.

In December 2019, the **European Green Deal** was announced which aims for zero emissions of greenhouse gases by 2050, and to decouple the economic growth from resource use (European Commission 2019). One of the main blocks of the Green Deal is a **Circular Economy Action Plan**, which was published in March 2020, and provides a future-oriented agenda for achieving a cleaner and more competitive Europe. The Action plan announces initiatives along the entire life cycle of products, targeting the design of sustainable products, promoting circularity in production processes, supporting sustainable consumption, and aiming to ensure that the resources used are kept in the EU economy for as long as possible. (European Commission, 2020). One of the strategies to increase the uptake of recycled plastics could be the requirement for minimum recycled content in new products as well as waste reduction measures. Current and future political initiatives are very much in line with the strategy that support the integration of recycled plastics into new electronics applications, thus manufacturers that choose this path are actively supporting the current political CE Initiatives in Europe.

Additionally, in December 2018, the European Commission launched the **Circular Plastics Alliance** to help plastics value chains boost the EU market for recycled plastics to 10 million tonnes by 2025. Currently 272 signatories have made voluntary pledges to produce or use more recycled plastics; among them there are several EEE producers (e.g., Whirlpool) and WEEE plastic recyclers.

3.2 Economic factors

If demand for quality recyclates increases, then in theory this will drive the value chain to collect sort and produce more recycled polymers. It is likely however, that the policy and fiscal changes will need to happen to fully realise the potential for recycled polymers. The different economic factors that can boost PCR plastic use in the EEE sector in the next years are presented below:

- **Economic Incentives from the Circular Finance Sector**: circular economy finance is growing. There has been a steep increase in activity in the past 2 years (EMF, 2020), as the financial sector allocates more capital to stimulate economic growth through the transition from a linear to a circular economy. Increasingly circular finance is being recognised as a critical factor in contributing to more sustainable consumption and production. Substantial financial resources are needed to induce structural change in production and consumption alongside technology change to enhance economic efficiency and optimize use of financial capital.

- **Financial Risk:** climate related risks are a source of financial risk and have the potential to threaten financial stability. **Environmental, social and governance (ESG) criteria** are increasingly becoming an important criterion for investors the emphasis has shifted from whether they matter to how they will be addressed, and the circular economy provides a crucial part of the solution (FinanCE 2018). They can measure circular elements such as product stewardship, eco-design and revenues from sustainable products.

- **Investment from EU/National Governments**: governments can directly invest in circular economy activities and innovation. EU H2020 programme has funding which enables innovative business models to be trialled through projects such as PolyCE. The European Investment plan has provided almost EUR 2.5 billion in lending for circular projects over the past 5 years (EMF 2020).

- **Fiscal Measures:** governments can set direction via policy and level the playing field through fiscal measures Extended producer responsibility and plastics taxes are increasingly likely to be implemented on national level and European level.

- **Cost of Recycled plastics:** an advantage for using PCR plastics is a more stable market price with lower fluctuations as demonstrated in Figure 7. The monthly data from "Kunstoff Information" over the past four years shows **less fluctuation** than virgin plastics and that recycled plastic equivalents **had a market price around 30-50 % below the price of primary plastics**. It remains to be seen whether a future increase in demand for plastic recyclates would result in rising prices, although recent drops in oil prices, during the pandemic, didn't change price advantages of recycled material.

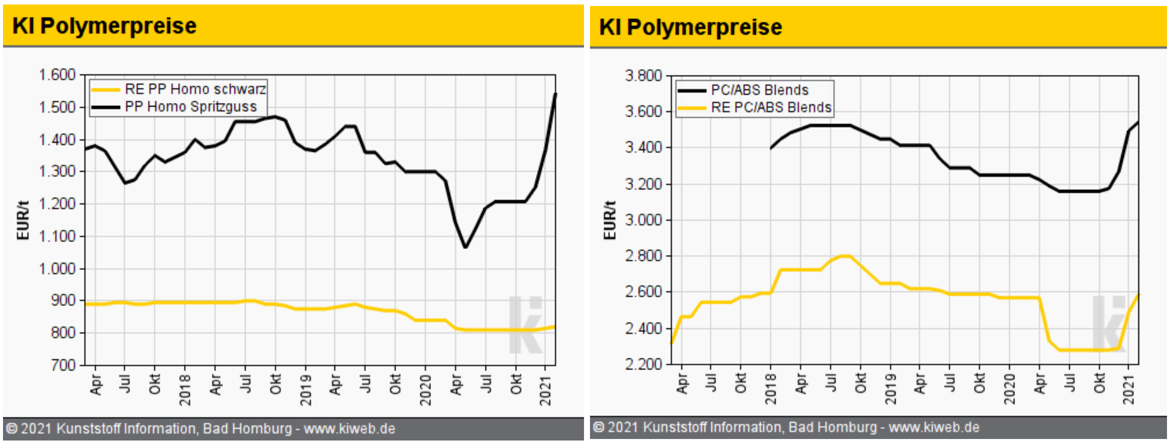


Figure 4 Polymer costs of recycled PP and PC/ABS and virgin equivalents (KunststoffWeb 2021)

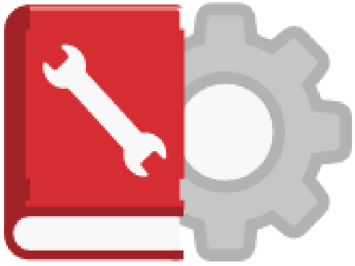
3.3 Social factors

Sustainable development requires the need for consideration of the interaction of economic, social, environmental and technological aspects of a sector (Ren et al., 2013). The underlying rationale (environmental, political, economic and business) of the Circular Economy (CE) attempts to reconcile all these elements (Ellen Macarthur Foundation, 2012). The very concept of the CE promotes the efficient and environmentally sound use of resources, new business models and innovative employment opportunities as well as improved wellbeing and positive impacts on future generations. Therefore, the very ethos of the CE aligns itself with UN Sustainable Development Goals.

Corporate Social Responsibility (CSR) is the voluntary contribution of a company to sustainable development. It goes beyond legal requirements and includes aspects such as environmentally responsible production and procurement (Sandberg und Lederer, 2011). The uptake of recycled plastics into new electronic products is not only a choice for sustainability but could provide a company with a competitive advantage over market players who remain linear. The use of such material acknowledges the heightened environmental awareness of the consumer and enhanced contributions to CSR.

The promotion of the CE and consumer responsibility/ awareness is vital in driving the development, purchase and use of more sustainable products and services (Ghisellini et al., 2016). A consumer survey conducted by PolyCE, as part of WP Deliverable 1.3, found that many EU consumers claim to frequently engage with CE practices in terms of recycling, retaining and repairing possessions etc. However, it was apparent that lower numbers of consumers are willing to engage with CEBMs. such as leasing. Respondents also reported that they frequently looked for information with regard to sustainability on products but often that information was difficult to find. It is imperative that information on products, relating to aspects of recyclability or sustainability, is easily identified and communicated to the consumer (European Commission, 2018). Consumers are found to be willing to engage in sustainable consumption driven by their concerns with regard to the environment, especially amongst young adults who are developing more environmental conscious behaviour. However, lack of knowledge, awareness and communication could potentially become a major barrier and result in a low demand for EEE containing recycled plastics in electronic devices.

3.4 Technological factors



PolyCE has shown that the recycling industry can meet quality requirements for many electronic applications, and certain plastic components can be replaced by recycled equivalents. However, when it comes to technological factors, it is important for manufacturers to understand the challenges and possibilities of PCR plastics for their specific products.

An important challenge, at the downstream stage, are the requirements for the integration of PCR-plastics into new products like aesthetics, functional properties, colour or smell. Plastics used in specific products have to fulfil target properties for the application which differ from one company to another. PCR plastics have to meet these technical requirements in order to enable its future uptake. When it comes to aesthetical challenges of PCR-plastics, a high-quality visual appearance, including colour and surface properties (gloss, matt, transparency, etc.), pose some of the major challenges for manufacturers and designers working with recycled plastics. Since the visual appearance is a key priority for electric and electronic goods, it is necessary to fulfil these requirements with recycled materials when utilised for visible parts (Mbarek et al., 2019). There are several factors which pose a challenge for recycled material returning from the WEEE stream. First of all, the broad variety of coloured PCR plastics is a limiting factor for specific colour requirements. However, it has been proven that the quality of recycled plastics is improving rapidly and compounders are able to produce a broad spectrum of coloured and high gloss products also with recycled materials. (Mbarek et al., 2019)

When it comes to material properties of PCR-plastics, the material does tend to change during recycling. The polymer itself, the conditions during its lifetime and processing, all determine which properties will be altered to a higher or lesser degree. Therefore, a good knowledge about the degradational effects of the individual polymer is crucial. As an example, ABS is one of the most effectively recycled polymers within WEEE recycling, however, it is sensitive to degradation. Impact strength and ductility are most affected in this instance. In this case, restabilisation through the addition of virgin material or additives, like impact modifiers, are promising solutions to obtain a good final product (Rageart et al., 2017). This holds true for most polymers, however, the type and amount of virgin material and additives varies dependent upon the polymer and the final product specifications. Regarding the material degradation, WEEE treatment operations claim that the quality of polymers (virgin plastic) used in EEE currently on the market is very poor (WEEE pre-treatment operators and plastic sorters noticed a reduction of polymers quality over time). This reduces the potential for recycling of WEEE plastic. Therefore, recommendation for compounders should be also elaborated.

Moreover, it is important to consider that manufacturers need material supply which is stable in terms of volumes, quality and properties. And this can be difficult to achieve from recycled sources of materials. In this regard, it should also be considered that suppliers of recycled materials are often smaller companies compared to the suppliers of virgin materials.

When it comes to the processing of PCR plastics in the production process, injection moulding represents the most important technique to produce polymer formed components. When the company progresses towards introducing recycled plastics in new products that still need to be launched, companies should ensure that the mould is optimized for material properties: ensuring good venting of the mould; avoiding very thin-walled mould design; considering texturing parts to mask visual limitations of recycled plastics.

In comparison to virgin plastics there are several crucial differences which can lead to defects in the final product. First, it is important to keep in mind that PCR plastics come with technical data sheets, however, these only show the general properties (this is the same for virgin). Specific material properties are requested by the manufacturer who will carry out material property testing at product level. During the process itself mild processing is the key for a good result. Whilst virgin material can be processed at higher rates, pressure, temperature etc. for high efficiency and still obtain the desired quality, PCR plastics are more sensitive. High screw shear forces, temperatures and pressure can further degrade the recycled polymers (Höggerl, 2019).

The production of odorous substances can stem from a variety of sources. External contamination of the plastic in its previous use is perceived as the main cause for smell but also the production of odours during processing poses a challenge. It is self-evident that a product cannot be sold holding these olfactory characteristics (Strangl et al., 2017). Presently there are several existing methods to counteract this problem and many more are in development. Known methods for odour reduction in recycled materials are contacting PCR plastics with hot gas under vacuum, the addition of further substances or stripping of volatiles (Wypch, 2013). Furthermore, a gentle re-processing could reduce smell of recyclates at least for PE (Bravo und Hotchkiss, 1993).

3.5 Legal factors

When it comes to legal factors, **several regulations are in place for EU actors, like the Restriction of Hazardous Substances (RoHS), the WEEE-Directive as well as the REACH and POP Regulation**. By this regulatory requirements, WEEE recycling facilities and EEE manufacturers are often faced with difficulties like dealing with plastics parts that contain brominated flame retardants (BFR). The EEE industry is generating a limited number of plastic products with BFR which have to be properly separated by pre-processors and recyclers to enable the re-use of PCR plastics in new products. However, recycling technologies today are increasingly being developed to detect and remove substances of concern (SOC) from the plastic waste streams, followed by a secure elimination to remove SOC from the value chain. Furthermore, pre-processors and recyclers are widely aware of the waste stream categories and even the plastic parts that need special handling to avoid SOC entering the mix of materials to be recycled. It is critical that there is a balanced interface between EU chemical and waste legislation.

Regarding the **design for recycling approach**, there are currently no significant considerations to use PCR plastics in the manufacturing of new products within the legal framework 2009/125/EC Energy-related Products (ErP) Directive (European Commission 2009). Focus of this directive is to reduce the environmental impact caused during the manufacturing, use and disposal of products as well as general requirements on energy consumption (Wagner, 2018). Nevertheless, discussions are ongoing whether a minimum recycled content for plastic should be introduced in new products to stimulate secondary plastic markets. Experts claim that it might only be a matter of time before recycled content is implemented in legislation e.g. in form of a minimum recycled content for new EEE products. 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.

Food contact approval remains a challenge for recyclers of materials other than PET. Since PCR WEEE plastics could contain certain impurities including a low percentage of substances of concern, applications for food contact, toys or medical devices are not suited for PCR plastic uptake (Berwald 2018). Within the PolyCE project there have been tests on HIPS recycled material coming from the treatment of refrigerators and the technical performances are evaluated in the project to be equal to a virgin material. But the material cannot be considered as food-grade qualified as the material generated does not have the food-grade certification. If this regulatory issue could be overcome, it could give a giant boost to recycling as food contact materials have a higher value on the market. In addition, the possibility of putting this material on the market at a higher price could further stimulate investment in WEEE plastic recycling with the objective of increasing quality and quantity of the available materials. In the HIPS case, the food grade approval was the only requirement that could not be fulfilled, during this project, for the use of PCR WEEE plastic in a new EEE application (more details are available in deliverable 7.7).

3.6 Environmental factors

The management of plastic waste has been identified by the European Commission as a key priority as part of its "Action Plan for the Circular Economy" (European Commission, 2015). Within the circular economy, it is essential the resource potential of materials is preserved either by looping them back into the economic systems (den Hollander et al., 2017) or by extending the lifetime of products.

Compared to virgin plastics, the recycling of plastics has the opportunity to save large amounts of CO_2 emission and energy (EERA, 2018) with an estimated CO_2 reduction around 2.5 million mega tonnes per year (compliant recycling of all plastics from WEEE in Europe according to the standard EN 50615-1) (EERA, 2018).

A study in 2015 concluded that PCR plastics have less than 20 % of the global warming potential (GWP), compared to virgin plastics from the primary production. (Wäger and Hischier 2015). An investigation by the PolyCE project of the life cycle assessment (LCA) of virgin and recycled plastics compared the environmental performance of post-consumer recycling of PP and PS from WEEE with a respective conventional approach. The environmental performance of the resulting PCR PP and PCR PS from the PolyCE approach show that the GWP of 1 kg PCR PP is 75 % lower compared to virgin PP (see Figure 8). Furthermore, the need of water for the production of PCR equivalent is 53 % lower and the abiotic resource depletion potentials (ADP) is 91 % lower than the virgin production. (Gaspar Martinez 2019)

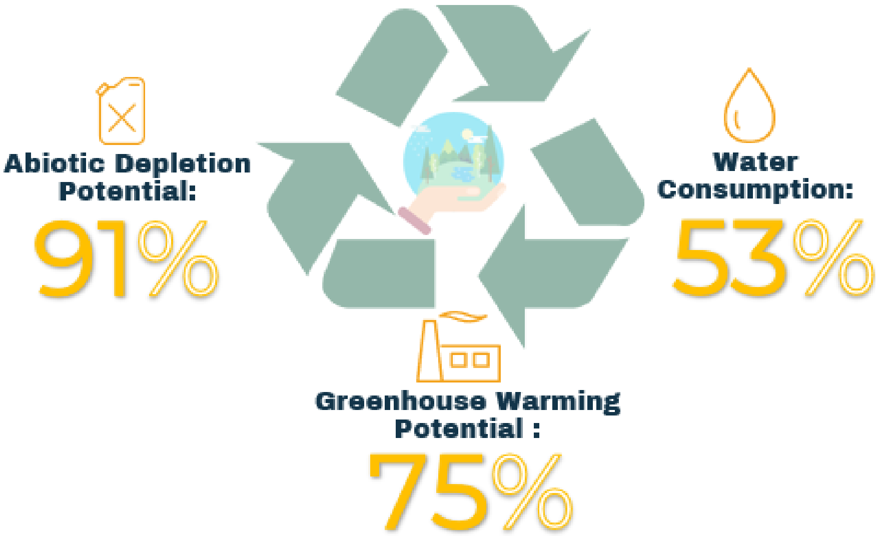


Figure 5 Saving potential of using recycled instead of virgin plastics from WEEE according to (Gaspar Martinez 2019)

4. PolyCE Circular Business Model Demonstrator Case Studies.

4.1 Overview of the LCA benefits of using high value recycled polymers

From the investigation of the life cycle assessment (LCA) performed by PolyCE project regarding virgin and recycled plastics (all the details are available in D8.2. *Resource efficiency studies and Life Cycle Assessments*), it resulted that the environmental impact of plastic in a circular supply chain is reduced by 27 to 38% compared to single use plastic depending on the plastic type. In addition, the results of the LCA show that the potential environmental impact of a plastic component produced by injection moulding with recycled feedstock is reduced by 24% compared to single use plastic. Overall, the study conducted within deliverable D8.2. demonstrates the potential environmental benefits of using recycled plastics compared to single use plastics. Moreover, it demonstrates the benefits of a closed-loop approach, according to which the recycled plastic is used for an application which is the same of the initial one: recycling of plastics in collected WEEE and use of PCR plastics could save 21% of primary plastics production for plastics in EEE. Figure 6 below identifies the key reductions in CO_2 savings in the production of the recycled high-tech polymers.

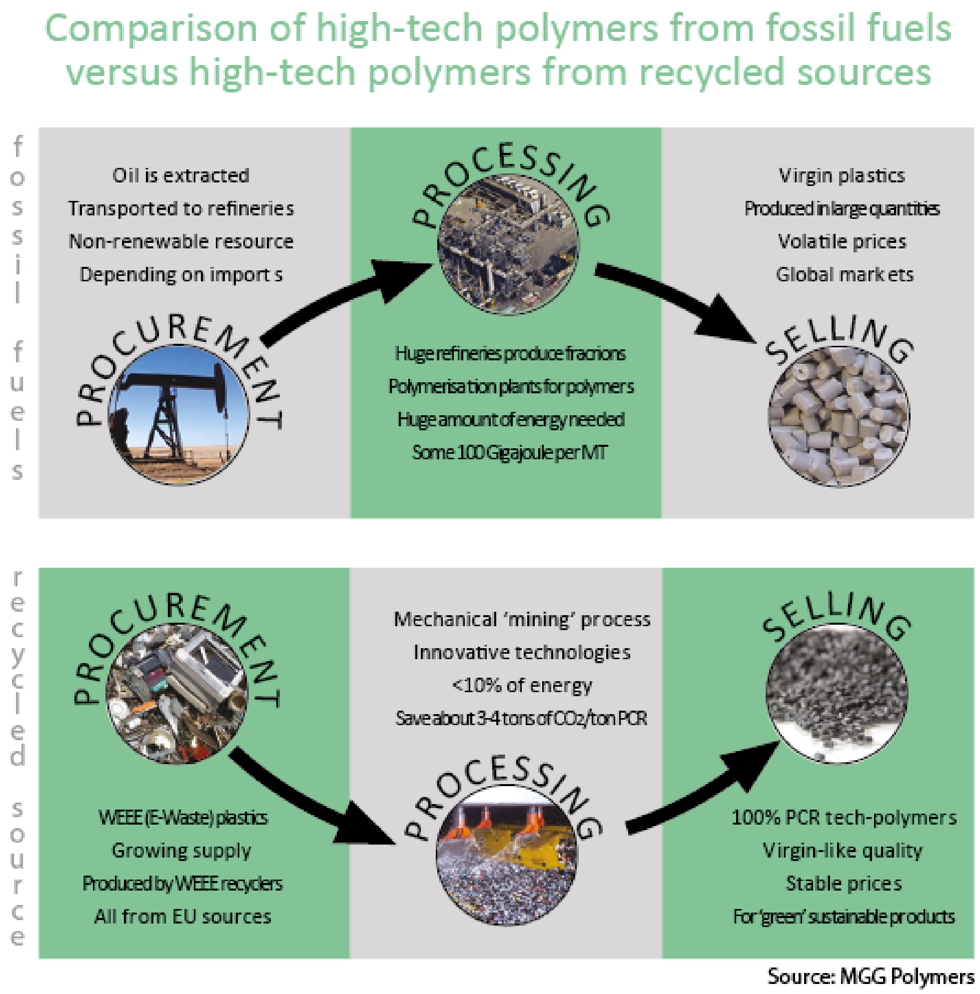


Figure 6 Comparison of high-tech polymers from virgin vs recycled (derived from MGG)

The description of the PolyCE demonstrators reported below aims to highlight two important aspects referring to the implementation of circular solutions: on one hand, the fact that the use of PCR plastic in new equipment brings advantages not only from an environmental point of view but also in terms of economic sustainability; on the other hand, that the dematerialisation trials demonstrated that the use recycled material can be associated with changes in product design, operational issues, relationship with stakeholders.

4.2 Demonstrator description – WiSensys

4.1.1 Application

Pezy were approached by a customer to primarily design a box to house sensors which are used for measurement data processing through wireless technology. Prior to approaching Pezy the customer had multiple designs of boxes for various purposes where keen to develop a design of box which could be readily identified as a corporate brand yet fulfilled the need for a range of functionality including for use outside. There was no intrinsic motivation from the company to design anything other than a box of appropriate, and varied dimensions which would fulfil the need of the customer by housing an array of sensors. Pezy suggested that the box itself could potentially be made from recycled material and the customer was guaranteed that in event that the recycled material would not meet the specifications detailed, virgin material could be used within the design. In essence the design would need to be applicable for both virgin and recycled materials and it would need to be economically feasible and desirable to the client.

In addition to the one originally developed for the client, Pezy have developed another product as a PolyCE *demonstrator* which has an antenna and it is larger than the original product.

4.2.2 The design

The design rules

The PolyCE design guidelines (as per D8.1) were used to develop and design the demonstrator. The only issue and discrepancy with the guidelines were the need to use glue for the vent. However, some options have been already explored such as the use of PTFE Gore-Tex membranes which eliminate the need to use glue as can be screwed. As previously mentioned, the product was designed to be made with either recycled or virgin materials. The only problem that was encountered was the need for a soft TPE in order to fulfil the sealing with a limited amount of pressure. (The use of elastomers is not within the design for recycling rules).

The material

One of the main drivers for the choice of recycled materials was that there should equity with financial costs so the choice had to be either equal to or less expensive than using virgin material. Once the concept box had been designed and the financial model for the concept presented, it became apparent that the design could feasibly be made using recycled material.

The first preference was to choose post-consumer recycled plastics and to assess whether it was technically and aesthetically possible to produce the required design. Post-industrial recycled plastics presented a further option and the use of virgin materials as a last resort.

Colour options using post-consumer plastics were very limited and black along with shades of grey were the only options. The customer had wanted to have more colour options and therefore post-industrial recycled plastics could be considered but, as the product did not require mass production the quantities required proved to be relatively expensive in terms of price per kg. (the cost for a black recycled ABS is 1.65 €/kg (from MGG); while the cost of coloured recycled ABS is 25 €/kg (from Sitraplas)) In addition, there are still elements of risk using post-industrial recycled materials in terms of a lack of research into e.g. degradation, stability and discolouration. In order to produce a functioning product which was fit for purpose, economically feasible and durable, the use of virgin materials presented the only option for some of the component parts.

The first version of the demonstrator was made of black ABS plastic with a ring of coloured plastic (virgin). The incorporation of the coloured ring was pivotal in terms of the design requirements from the customer, in distinguishing the different applications of the device. While using 100% recycled material was attractive in terms of a sustainability point of view, a balance between profitability, feasibility and desirability for the customer had to be achieved.

The end of life
The product Pezy designed is modular, therefore theoretically the sensor can be easily removed and replaced is the need should arise. In addition, the batteries are easy to replace or remove at end of life. Allowing a circularity to the product and the possibility of reuse and highlighting the need for a potential dedicated collection programme by the producers should be investigated. Likely, the devices will go to recycling after the first life cycle.

4.2.3 Key challenges

The selection of the proper PCR material has been one of the main challenge of the demonstrator implementation. As previously highlighted consideration to other materials was given but ABS was the preferred materials for this demonstrator for the following reasons;

1. The original concept box was also made out of ABS. therefore the functionality of the material was proven.
2. The recyclability of ABS is high
3. Economically desirable (per kg is cheaper than virgin material);
4. ABS is more stable material: recycled ABS is more similar to virgin ABS, than PP is similar to recycled PP.
5. It is readily available and obtainable on the market.

4.2.4 Key learnings

Financial incentive provided by the PolyCE was critical in driving this new innovative design and therefore the importance of governmental policy and support initiatives driving the CE are apparent, specifically with regard to SMEs who have limited ability to absorb additional financial expenditure, testing trials will have a cost implication of 30, 000-40,000€. During the design phase the customer became more enthused around the sustainability aspects of using recycled plastics and felt it could provide further dimension to their products and provide their customers with added value from such a product.

4.2.5 SWOT Analysis for WISENSYS

Strengths		Weaknesses	
S1	Design was developed in order to facilitate the use of both virgin and recycled material.	W1	Volumes of material (addressing the price per kg), in this case ABS, required can pose issues in terms of supply and demand and pricing regimes.
S2	Demonstrated the design stage can influence the use of materials	W2	While the design used recycled materials it was not possible, economically to use 100% recycled materials.
S3	A product which contained no recycled material has the option to contain > 50% of sustainability and therefore the potential for further substitution in other products could be assessed.	W3	Colour choice of post consumer ABS is limited and while post industrial plastics provide further colour options there is a need to explore the financial feasibility in line with virgin prices.
S4	A modular and multipurpose design ensure that devices can be reused or recycled after the first life cycle.	W4	Uncertainty around the stability of the product in terms of both degradation and discolouration.
Opportunities		**Threats**	
O1	Marketing and corporate brand could be associated with sustainability	T1	Financial risk in the development of new products without the support of R&D incentives
O2	Sustainability within government procurement incentives	T2	Support from governmental policy is crucial in driving forward research agendas to enable support for businesses particularly SMES
O3	Added value of distinctness of product in terms of sustainability	T3	Lack of research looking at polymer additions for longevity and sustainability of recycled plastics.
O4	Development of further application and use of recycled plastics with enhanced design guidelines		
O5	The ability to offer a product which does encompass CEBMs and aligns with sustainable development goals.		

4.3 FundWaste Demonstrator

4.3.1. Application

FundWaste, in partnership with The Imagination Factory, are developing an IoT sensor *"Smart Waste Management Sensor"* for use in commercial facilities that wish to optimise the financial viability of waste recycling. The device being developed gathers data on temperature, humidity, off-gassing and fill level and combines it all with an image uploaded to the Cloud. Machine learning is then used on the data to help the facilities manager to maintain the quality of the waste and get the best price possible on the market.

Fundwaste adopt a circular waste to wealth approach to their business, working closely with customers sharing the recycling revenue that customer's waste generates and using smart technology, artificial and business intelligence to support their waste to wealth infrastructure. The technology empowers businesses, community groups and schools to be smarter about their recycling and allows them to track carbon savings and revenue. The sensor will enable the businesses collecting waste materials to monitor contamination and therefore maximise the value of the materials being recycled, this is demonstrated in figure 4.

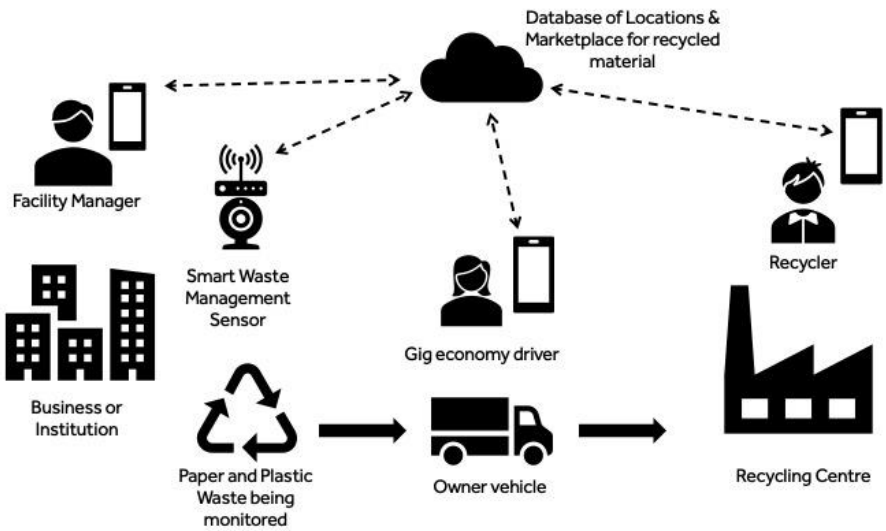


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Figure 7 Diagram of the FundWaste System employing the Smart Waste Management Sensor

FundWaste is a technology-led business combining the latest in sensing, IoT, Artificial Intelligence, a digital platform and an App. The combination of these technologies achieves the following:

- a facility manager can monitor the quality and quantity of the waste being stored through an intelligent IoT device that incorporates a camera with an "electronic nose" and an AI algorithm;
- the business owner or the head of an institution can find out the value of the waste their facility manager has collected in real time through the marketplace feature of the App which is connected to material recyclers and online materials trading websites;
- collection of the waste and distribution to recycling centres is decentralized through the App by leveraging the gig economy (think Uber for recycling collection).

FundWaste has carried out market research to understand the potential for their business model and having determined the feasibility of the commercial venture they approached IF to design a proof of concept device which was completed in January 2020. With the bare-bones technology proven the next step is to develop the device for pilot testing for which approximately 50 schools and businesses in the UK have expressed interest.

In keeping with the ethos of Fundwaste, it was important that the sensor was designed from post-consumer recycled (PCR) plastics using both Design for & from Recycling strategies. Using PCR plastics aligns with their brand message by demonstrating high value markets for recycled materials. The IoT connected sensor device is conceptualized with a special focus on product design as to facilitate upgrade-ability, disassembly and reassembly and thus enable longer lifespan and increase the material efficiency of the product.

4.3.2. The design

Each device uses a larger volume of plastic representing a significant opportunity to show how a product can be made from fully recycled plastic. The product required a functional and visually appealing plastic housing. The IoT market as such is already a multi-billion market and forecasted to grow further rapidly in coming years. There is a modular element to the product which is being designed so that a block of the electronics inside can be easily swapped over to change from a WiFi version to cellular.

Guidelines on Design from and for Recycling that The Imagination Factory has learned through the PolyCE project so far have been applied to the proof-of-concept work on the FundWaste device. The main components are the body (front and back cover) and a control knob. These three components were produced in the same material, black recycled PC/ABS see figure 5. The housing was screwed together (fig 5) enabling it to be broken up easily during the recycling process. The main areas for innovation relate to the use of recycled PC/ABS in the manufacturing process. The recycled polymer was produced by the PolyCE partner MGG polymers from post-consumer plastics from WEEE

Figure 8 The Smart Waste Sensor

4.3.3. Key Challenges

- The device requires an antenna on the inside for WiFi and Cellular connection to the IoT cloud. There is a technical challenge to make sure this works with recycled plastics especially if they are pigmented with Carbon Black.

- The "electronic nose" must be able to detect gases around the location of the waste without being skewed by any off-gassing from the recycled plastic in the case of the device.

- The product must maintain the performance characteristics of a device made from virgin injection moulded plastic (environmental stability, impact, appearance, etc).

4.3.4. Key Learnings

Financial incentive provided by the PolyCE was critical in driving this new innovative design and therefore the importance of governmental policy and support initiatives driving the CE are apparent, specifically with regard to SMEs who have limited ability to absorb additional financial expenditure. This enabled a smart waste sensor not only to drive circular economy by its design but also by its application.

4.3.5 SWOT Analysis for FundWaste

Strengths		**Weaknesses**	
S1	Design was developed in order to facilitate the use of PC/ABS recycled material however this could be replaced with virgin if recycled polymer was not available.	W1	Volumes of material (addressing the price per kg), in this case PC/ABS, required could pose issues in terms of supply and demand and pricing regimes.
S2	Design stage can influence the use of materials	W2	While the design used recycled materials it was not possible, economically to use 100% recycled materials as the lens cover had to be made using virgin PMMA
S3	Possible to design a high tech new product to utilise PCR plastics that is both functional and aesthetically pleasing		Uncertainty around the stability of the product in terms of both degradation and discolouration.
S4	A modular and multipurpose design ensures that devices can be reused or recycled after the first life cycle.		
Opportunities		**Threats**	
O1	Using PCR plastics creates a powerful brand message	T1	Financial risk in the development of new products without the support of R&D incentives
O2	Futureproofing for requirements for statutory recycled content	T2	Support from governmental policy is crucial in driving forward research agendas to enable support for businesses particularly SMES
O3	Added value of distinctness of product in terms of sustainability	T3	Lack of research looking at polymer additions for longevity and sustainability of recycled plastics.
O4	Competitive advantage for public procurement		
O5	The ability to offer a product which does encompass CEBMs and aligns with sustainable development goals.		

4.4 Clustering approach Demonstrator

4.4.1 Application

The demonstrator redesigned the collection phase and the treatment phase of the WEEE value chain evaluating the impacts of adopting a **clustering strategy** and suggesting adaptations/improvements during the pre-treatment step to improve the quantity and quality of the mixed plastics to be recycled.

During the demo, specific products or product groupings (e.g., printers, coffee machines, vacuum cleaners, washing machines, etc.) which are currently treated together because they are collected together in the same WEEE stream, have been treated separately. The obtained plastic flakes were first sent to an academic expert, at KU Leuven, to be characterized and then to industrial partner, MGG, that used them to produce a new compound. The final compound was tested by UL, a standardization body, that identified specific compound properties and compared them with current compounds performances.

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4.4.2 The design (of the clustering solution)

The cluster approach allows WEEE pre-treatment operators to obtain plastic mix which is **less heterogenous** (containing less type of different polymers) and **less contaminated** (plastic mix with low presence of contaminants such as iron, concrete, wood) than the current one.

This is beneficial:

- for the WEEE pre-treatment operators: adopting the clustering approach
    - they can obtain plastics with a higher value on the market. Today, WEEE plastic is the results of negative sorting (the target materials of WEEE pre-treatment activities are mainly metals) and, due to the high contamination, it is mainly downgraded. Consequently, the value of the current WEEE plastic flakes on the market is very low (something WEEE plastic is a cost because WEEE pre-treatment operators must pay to dispose the material that has a very low quality) and WEEE pre-processors are not interested in investing for plastic treatment improvements;

- for plastic recyclers: thanks to the clustering approach
    - they have the possibility of sourcing better quality plastics: this will increase the yield of recycling activities. Moreover, the input flow of materials will be more stable in terms of composition; therefore, it will be easier to determine (and maintain them constant) the parameters of recycling activities;

    - they can obtain plastics pellets with a higher value on the market. If manufacturers can rely on a stable and high-quality supply of recycled pellets, they will be more willing to use them in new equipment: the demand on the market will increase and the price of PCR plastic pellets will increase consequently.

- for EEE manufacturers: thanks to the clustering approach
    - they have the possibility of sourcing better quality PCR plastics granulates;
    - they have the possibility of using PCR plastic in several application meeting companies' sustainability goals and ESG criteria;
    - they can be less dependent on the price fluctuations of the virgin material (which are linked with oil price).

The listed stakeholders may also face also some disadvantages related to the clustering implementation:

- WEEE pre-treatment operators:
  - they have to bear the additional costs related to the labour work required to cluster the mixed WEEE at arrive at the WEEE pre-treatment plant.
    Possible solution: to implement the clustering strategy at the collection level (e.g., at municipal collection points or at retailer's collection points);

  - they require additional space to store the clustered products; in fact, to reach the minimum number of products that can be treated together in the same cluster it would require considerable time

  - they need to stop the plant to treat the clustered products in dedicated batches. In fact, to treated certain product separately, it is necessary to organize the treatment in batches; this means that additional time to stop the lines should be included (about 20 minutes are required to properly clean treatment machineries as shredders and convey belts). Thus, the volume treated during the separate batches should be considerable;
    Possible solution: if the profitability of the cluster approach is proved, it will be possible to invest in new treatment lines dedicated to the target clusters.

- Plastic recyclers:
  - they need to stop the plant to treat the input clustered plastic flakes in dedicated batches
    Possible solution: if the profitability of the cluster approach is proved, it will be possible to invest in new treatment lines dedicated to the target clusters.

Below an overview of the current WEEE collection and treatment approach (figure 9), as well as a schematic drawing referring to the PolyCE clusters approach tested during the demonstrator (figure 10).

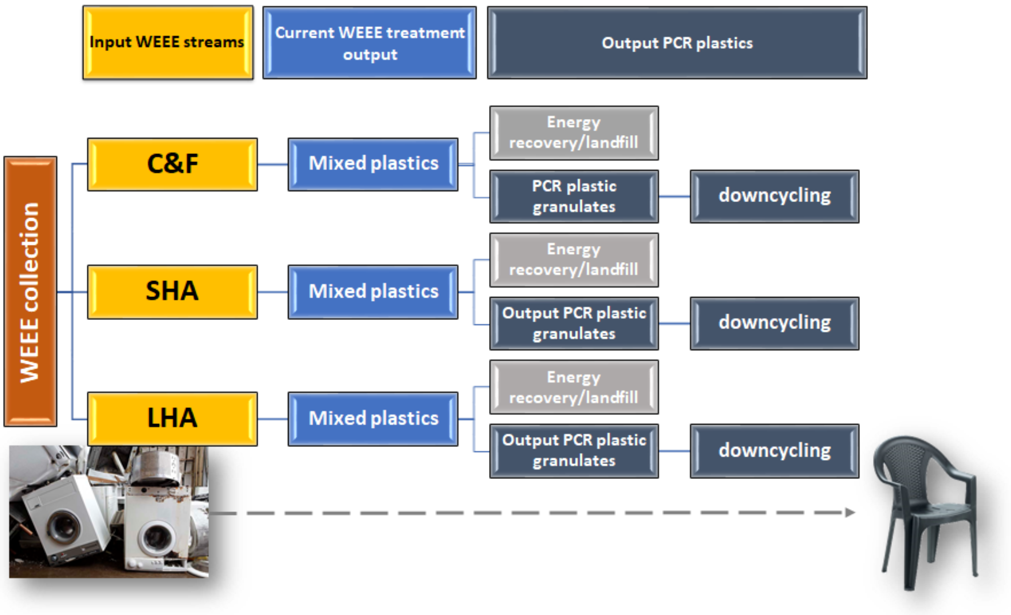

Figure 9 Current WEEE value chain: from WEEE collection to PCR WEEE plastics

Due to the challenges related to the current WEEE collection and treatment system, the quality of PCR WEEE plastic is low. Consequently, PCR WEEE plastic is mainly **downcycled**: this means that PCR WEEE plastics are reduced in quality and/or functionality (for example, PCR WEEE plastic are mainly used for applications such as external furniture and planters). Therefore, PCR WEEE plastics are reduced in terms of value with respect to the original material.

On the contrary, thanks to the PolyCE cluster approach, it is possible to **close the loop** of WEEE plastics because the quality of the output PCR plastic granulate is high and therefore suitable for EEE applications.

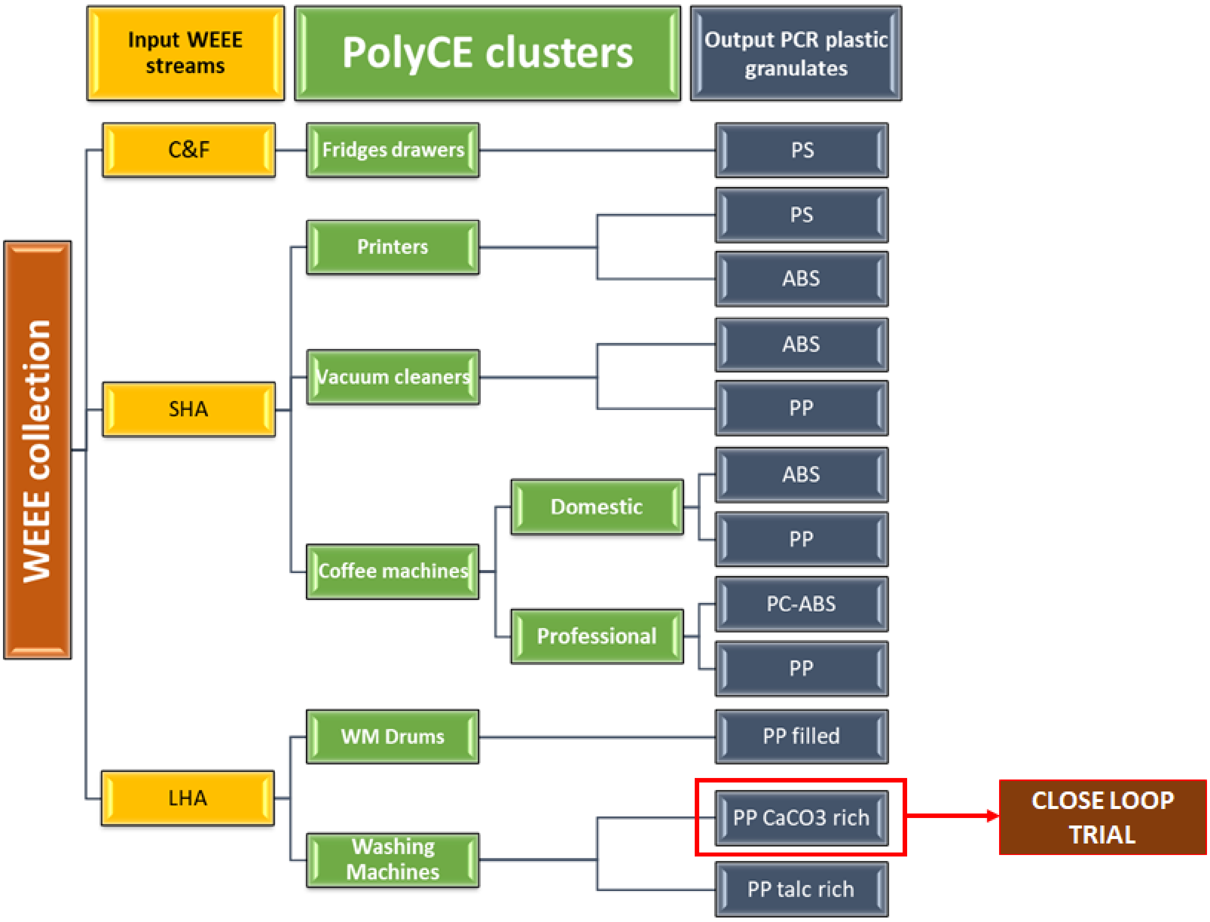

Figure 10 PolyCE cluster approach: from clustered WEEE collection to high quality PCR WEEE plastics

Along the demonstrator concerning the LHA cluster, the possibility of reintroducing into the moulds for the realization of the components of new equipment, closing the production cycle in accordance of circular economy principles, was also tested (the corresponding detailed results are reported in deliverable 7.7.). Overall, the PP $CaCO_3$ pellets obtained from the treatment of washing machine cluster have been successfully used by Whirlpool for the production of a component, the drum, of a new washing machine (figure 11).

Figure 11 PolyCE close loop demonstrator: from end of life washing machine cluster to new washing machine drum

The valorisation of the materials

As mentioned above, one of the fundamental benefits of implementing a cluster approach is the possibility of obtaining high quality materials (materials that can be used in close loop application) that have and **higher value on the market**. Within PolyCE the profitability of the clustering activities has been modelled adopting a mathematical approach (the results of this evaluation are presented in deliverable 3.2); however, at this stage is difficult to gather information from industrial stakeholders involved in the demonstrator activities regarding the potential price of this material. This is due to the fact that the implementation of the cluster approach at WEEE pre-treatment stage can be currently time consuming and costly (as reported in more details in the section *5.3.4 Key learnings).*

The graph below (figure 12) aims to give an overview of the additional value generation related with the production of high-quality PCR WEEE plastics.

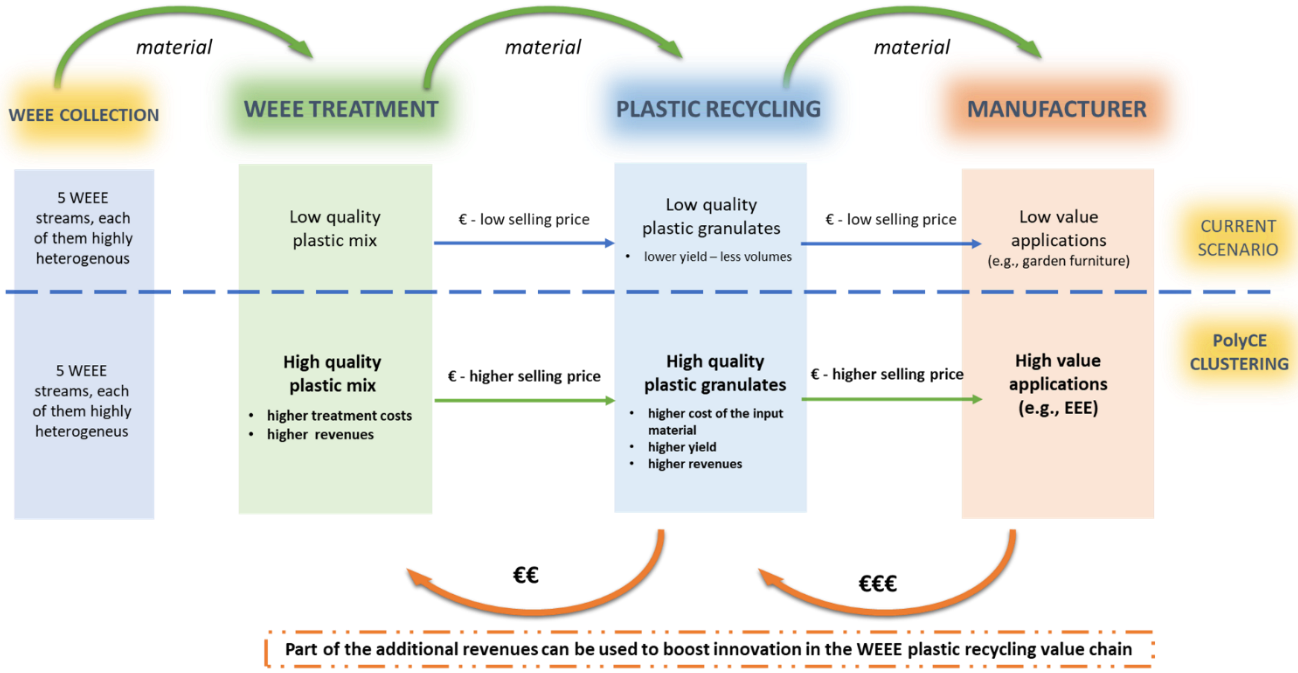

Figure 12 Profitability of the PolyCE cluster approach

To guarantee the profitability of the cluster strategy, particular attention should be given to **the maximum price that EEE manufacturer would be able to pay for PCR plastics** (some stakeholders claimed that PCR plastic price should stay below the price of the virgin material to be considered as a real alternative; however, also the positive externalities associated with the use of recycled materials, for example in terms of ESG ratings, should be included in cost/benefits and pricing considerations).

4.4.3. Key challenges

The demonstrator aimed to quantitatively and qualitatively improve the production of WEEE PCR plastic addressing the following challenges related to the WEEE collection and treatment steps:

- currently WEEE are collected and treated in different streams: cooling and freezing appliances, large household appliances, TV & screens, small household appliances and lamps. Products within the same WEEE flow (e.g., small household appliances) are shredded all together. Each WEEE stream contains different products and it can be highly heterogeneous. It is extremely complicated then to separate and recycle polymers coming from the treatment of mixed appliances composed by hundreds of different products;

- WEEE are unproperly disposed: products belonging to a certain WEEE streams end up in a different WEEE streams;

- manual sorting of products within a certain WEEE stream is time consuming and costly;

- small household appliances collection cluster contains several different products: on one hand, it is complicated do define a standardized process to remove certain components; on the other hand, the plastic mix obtained from the small household appliances contains a very large variety of polymers and contaminants.

PolyCE aimed to enhance collection and treatment of WEEE through redefined products group clusters based on material types and properties.

4.4.4. Key learnings

Key learning on feasibility of cluster approach at the *PRE-TREATMENT FACILITIES:*

- storage spaces are required to perform the products separation;
- additional manpower is needed to separate relevant products from the traditional stream;
- separation of selected products is a time-consuming activity;
- to obtain relevant quantities of a single products/cluster of few products takes long times;
- to avoid the presence of impurities in the plastic stream the treatment line shall be cleaned up; this mean that extra treatment time is required;
- to improve the purity of the plastic stream additional manpower is required along the treatment line.

Overall, the clustering approach is associated with some technical and infrastructural pre-conditions: for instance, additional space would be required to allocate different waste containers (additional space should be foreseen for each of the different products selected); additional storage space is required also for the different fractions obtained after the treatment steps.

Moreover, the output plastic fractions from the treatment of products/components within a certain cluster should be stored separately from other plastic fractions (output of different treatment activities) to avoid contamination.

Finally, the clustering approach at WEEE pre-treatment plant level is associated with specific training needs: at the treatment plant, personnel should be trained to perform waste sorting according to defined products clusters.

Key learning on COLLECTION

Considering the difficulties experienced in the implementation of the clustering approach at the WEEE pre-treatment level, it is fundamental to evaluate the possibility of implementing the clustering strategy already at the WEEE collection step. However, the clustered collection strategy could be difficult to implement at municipal collection points level due to space constrains, need of training the personnel, need of additional authorization, need of properly informing citizens.

The clustering approach is associated with some technical and infrastructural pre-conditions: for instance, additional space would be required to allocate different bins.
The clustering approach is associated with specific training needs: trained personnel should be dedicated for the product identification.

Moreover, personnel should be trained also to proper communicate to citizens: citizens in fact should be properly informed regarding the correct disposal of different products.

- **Collection at *RETAILERS***

  Clustered collection can be implemented at retailer level: it would be possible to take advantage of the fact that certain shops are selling specific products (e.g. coffee machines of

a certain brand) to have a clean stream of products collected (citizens can easily identify the shop as a place suitable for coffee machine disposal).
However, there are space constrains to consider for full implementation of the cluster strategy at the retailers' level; moreover, retailers should be incentivized to participate to this collection activities and consumers should be educated to use this disposal channel.

4.4.5. SWOT Analysis for the Clustering approach

Strengths		**Weaknesses**	
S1	For WEEE pre-processors: possibility of reducing cost associated to plastic incineration and landfill	W1	For WEEE pre-processor: additional costs, for example due to additional manual labour, space, processing time
S2	For WEEE pre-processors: possibility of selling PCR WEEE plastic at higher price due to increased plastic quality	W2	Formative needs of WEEE pre-treatment operators
S3	For plastic recyclers: reduction of time and cost for plastic sorting	W3	Need of increasing the amount of WEEE collected, filling in the gap between WEEE generated and WEEE collected, to increase the economic viability of the clustering strategy
S4	For plastic recyclers: increase of production yield	W4	Currently, it is not possible to obtain food grade approval for PCR WEEE plastic
S5	For WEEE pre-processors: possibility of reducing plastic quality variability	W5	Currently, it is not possible to obtain transparent PCR WEEE plastic
S6	The clustering approach does not require technological innovation or changes in the current WEEE treatment line	W6	For retailers: additional space required for clustering activities
Opportunities		**Threats**	

O1	Legislative changes (1): obligation for EEE manufacturers of using a certain amount of PCR WEEE plastics in new EEE	T1	Evolution of WEEE waste streams, in terms of products and in terms of products composition (for example, use of new plastic blends, increasing use of electronics…)
O2	Legislative changes (2): obligation for municipal collection point or retailers of implementing a clustered collection	T2	Reduction of cost of virgin plastic
		T3	Evolution of legislation regarding restricted substances (for example concerning banned flame retardants)
O3	Legislative changes (3): obligation for EEE manufactures of reducing the numbers of polymers used in new WEEE and the complexity of the product (eco-design) with the possibility to disassembling	T4	Emerging of conflictual clustering needs (for example, need of improving the recycling of certain CRM or need of segregating products containing batteries)
O4	Development of innovative sorting technologies (automation of clustering activities)	T5	Quality reduction of the virgin plastic used in EEE (for example, due to import of low-quality products from China), that makes recycling more complicated
O5	Possibility of engaging social workers (cost reduction)		
O6	China ban consequences: WEEE pre-processors' need of testing innovative strategies to effectively manage increasing flows of WEEE plastic		

4.5 Demonstrator description – ONA

4.5.1. Application

Ona's goal is to develop a high-end design fixtures for LED lighting with consideration of the Design for/from Recycling strategies and start implementing PCR/PIR plastics in future high-end lighting components. From the beginning ONA set out to design a product with a noble appearance. Normally metals, exotic woods and ceramics are referred to as noble and durable while plastics are commonly perceived as cheap and ugly. This goal formed the major challenge for ONA on top of not having any previous experience with using plastics on this scale. Normally it is advisable to start with the so called, low hanging fruit, parts and/or products which do not have any challenging requirements for recycled plastics like transparency/translucency or high gloss. However, for a company like ONA quality and aesthetics are at the core of their products, so the challenge was taken on with both hands.

4.5.2. The design

ONA during the demonstrator, substituted the material currently used for the production of its lamp, namely glass/crystal, with recycled plastic. For this particular case study, it is interesting to note that the use of recycled plastic material can be a beneficial option also in terms of economics, considering that crystal is particularly expensive material.

In this case the demonstrator proved that the recycled plastics can be used in an application currently made of crystal. Beside the economic advantages, the use of plastics allows the design of very particular shapes which is very difficult (or impossible) to realize using crystal. Additionally, the lamp made of plastic is much more durable compared to the lamp made of crystal.

The design challenge is related to the transparency of the plastic material.

Feasibility ONA will able to replicate the activities performed within PolyCE beyond the PolyCE project. To increase the production of the demonstrator lamp, ONA would buy the recycled plastic from Sitraplas. If the demonstrator developed during the project is accepted by the market, ONA is willing to increase its production.

The issue related to finding the proper material for the ONA lamp production (namely, transparent recycled plastic), was solved by Sitraplas using post-industrial polymers.

ONA aims to communicate to consumers that the products contain recycled material: ONAs clientele is a very small and concrete audience to which is easy to explain product characteristics and easily reassured regarding product quality and safety.

ONA is already producing lamps containing recycled post-industrial aluminium and wood: these products are not more expensive than lamps containing virgin materials. ONA expects that the same will occur for the lamps made of recycled plastics although, the recycled plastic materials will cost more than the virgin one. ONA expects to sell more products to cover the additional costs.

4.5.3. Key challenges

The main challenge experience by ONA during the demonstrator implementation was related to the mould design and production. The mould production is the most expensive phase of the product development.

This is a key aspect that should be carefully evaluated considering the application of the PolyCE learnings to other products. According to ONA feedback, it will possible to use recycled plastics in other products if these products will be made of modular and repetitive parts/components (for example a lamp made of several small round spheres; figure 15). The reason of this is that ONA is an SME that is not able to invest, at least 30.000€ for a new mould production, of the same dimension of the one used for the demonstrator; on the contrary, ONA would be able to invest less, about 5,000€, in the production of a smaller mould.

During the implementation of the demonstrator activities, the main challenges were around the mould development (it was necessary to change the mould design after a first injection trial that was not successful).

Additionally, ONA had to change the operator in charge of the injection moulding activity during the project, because the first one selected was not able to properly use the recycled material (specifically, the used machinery was not able to dry the recycled plastic material provided by Sitraplas). This highlights that for the ONA demonstrator, finding the most appropriate business partner was fundamental.

In ONA's experience, the negative perception of use of plastics by consumers presents another challenge. However, ONA has identified that the use of high-quality recycled plastics rather than the alternative virgin glass provides a competitive advantage. Today, ONA competitors already have products on the market made of recycled plastics. However, these products are mostly unrefined, characterized by low quality in terms of transparency and colour. ONA aims to produce products that have the same material perfection (the refining degree) appearance as those containing virgin materials.

Figure 13 Modular design of the ONA demonstrator

4.5.4. Key learnings

ONA is able internally to invest in development of new products in terms of design. However, they need the support of experts, such as the PolyCE partner Sitraplas or other technical institution, to find the proper recycled material for their needs.

Moreover, ONA aims to communicate its involvement in the PolyCE project to its consumers to make them aware that ONA is not just interested in the design of the products, but also their environmental impacts and they are conscientious about the selected materials.

Additionally, considering that ONA is SME, PolyCE was the opportunity to run the injection tests with a supplier that otherwise would be impossible to perform for such small company (in fact, this will be too expensive, considering that the supplier should stop its normal operational activities to allow ONA perform its tests on a very small quantity of materials and products). This is significant difference between ONA and larger companies such as Philips, that internally have the capabilities to source the material and perform the moulding activities. To perform the kind of research performed during PolyCE, ONA should find an ally that trust in the company and allow it to run the trials: it is not just an economic issue, challenges are also related to the fact that supplier should stop their normal production and change their working schedules to perform trials activities, and often they are not willing to do so.

4.5.6 SWOT Analysis for ONA

Strengths	**Weaknesses**
S1 Recycled plastics could result cheaper than the material currently used for the lamps production (crystal) S2 Recycled plastics could result more resistant than the material currently used for the lamps production (crystal)	W1 Currently plastics has a bad reputation among consumers
Opportunities	**Threats**
O1 Recycled plastics allow more design possibilities than one offered by the materials currently used for the lamps production (crystal) O2 ONA aims to obtain products that have the same appearance of the ones containing virgin materials O3 There are already companies that put on the market products made of recycled plastics. However, these products are mostly unrefined, characterized by low quality in terms of transparency and colour. ONA is able to obtain products that have the same appearance of the ones containing virgin materials	T1 Possibility of designing products that are made of modular and repetitive parts/components (for example a lamp made of several small round spheres) otherwise, it wouldn't be economically feasible for ONA to develop and produce a new mould to use recycled plastic T2 Find the right supplier/the proper business partner (moulder)

5. Conclusions

5.1 Key Conclusions Overall

The analysis of the demonstrator's implementation and results highlights some key learning of the trial activities:

- Learn by doing small steps: need to adopt a step change as too much at once is not possible. Changing an existing product can be used as a learning experience to advance adopting circular practices.
- External influences as highlighted in the PESTLE analysis can force change.
- Tolerance should not be too tight otherwise is becomes a design issue, there needs to be a willingness to tweak the design – look at tolerances, mould change etc.
- Need to consider material choices carefully as volumes needed can be an issue.
- Materials should be looked at business wide to assess opportunity. For production departments/ suppliers increasing production is their priority and changing material is the biggest obstruction.
- When looking at adopting a circular business model it is important to assess the environmental impact of a product quantitatively and qualitatively. This could be done via an LCA or other equivalent means

To effectively adopt dematerialization business cases (as the use of PCR plastics and the implementation of the clustering strategy), it is fundamental to also take into account the key aspects listed below.

5.1.1 Limitations of material sourcing

Considerations that need to be assessed when obtaining materials:

1. Availability can be influenced by several factors.

   As an example: there is more PP than ABS on the market, but it is more problematic to source PP. In fact, one of the main sectors that uses PP is packaging where there are 2 main barriers due to the high competition for material sourcing (plastic bottles – 300 tonnes so price and availability more important).In the EEE sector there is a higher use of ABS and overall, less material is needed. There is also less demand as a sector (3.000,000 tonnes annual of plastic in total (2016)

   Additionally, It is not simple to find supplier for PCR WEEE plastic and while there are very well-known companies (e.g. MGG, Galloo and Coolrec), it is difficult to identify and select other possible material suppliers.

2. Cost of recycled material can be higher than the virgin one

   It is important to understand what the market is willing to pay, looking at the right markets and taking advantage from economies of scale. For example, within the EEE sector there are many internal frames within products which can't be seen, which reduces the importance of aesthetics and this is potentially a large market for use of PCR plastic (looking at the drop-in approach, internal parts can have lower level of complexity)

Thus, if the recycled material is more expensive, the additional cost can be offset targeting larger volumes (so tends to be higher value products that are sustainable). The cost can be absorbed if there are very expensive components. For example, in electronics PCBs are extensively used and they are expensive: assuming that in a product 40€ is the cost of PCB and 5€ the cost for plastic housing, the increase of cost due to recycled plastic can be easily covered by a % of the product price; for device with a large plastic housing, the increase of cost due to the use of the recycled plastic represent a greater part of the total cost. If coloured parts are not economically feasible but only account for a small part then use virgin materials.

3. Quality

   It is complicated to verify the quality of the material as the technical factsheets are not always reliable, with long disclaimers explaining that the performance of the material can vary. This uncertainty surrounding performance implies that it may be beneficial to re-test the material before it is used. However, as Pezy have highlighted, when dealing with SMEs with little or no research and development capabilities and financial limitations, this is simply not a risk which makes business or economic sense. Moreover, during fairs and exhibitions WEEE plastic recyclers tend to show pellets as their final product; when in fact it would be much more effective and useful to show actual products made by PCR WEEE plastic, thus demonstrating the real quality of the pellets and the potentialities of the material.

5.1.2 Environmental Impact

In addition to sourcing, it is important that companies look at the environmental impact of replacing virgin materials with recycled polymers, through LCAs or other environmental impact assessment. Consideration of these environmental aspects will avoid unintended consequences and make sure that each step change is a positive one environmentally

5.2 Key Conclusions from the SWOT analysis

5.2.1 Strengths

Economic

- Recycled plastics could provide economic benefits as well as enhancing the resistant and stable nature of the product.
- Economic savings in terms of waste disposal and potential for income generation for WEEE pre-processors and plastic recyclers from selling PCR WEEE plastics at a higher price due to an increase in quality.
- Design can influence the use of material and can be developed to use either recycled or virgin material allowing the potential to rethink current material use within

existing designs and ensure that economic feasibility of a product is maintained in a fluctuating market.

Performance of the circular product (or solutions)

- Recycled plastics could result more resistant than the material currently used, as in the lamps production case (for which crystal is currently used)
- The clustering approach does not require technological innovation or changes in the current WEEE treatment line
- For new designs it is possible to design a high-tech new product to utilise PCR plastics that is both functional and aesthetically pleasing

Environment and circularity

- A product which contained no recycled material has the option to contain > 50% of sustainability and therefore the potential for further substitution in other products could be assessed.
- A modular and multipurpose design ensure that devices can be reused or recycled after the first life cycle

5.2.2 Weaknesses

Economic

- Volumes of material (addressing the price per kg), in this case ABS, required can pose issues in terms of supply and demand and pricing regimes.
- Often while designs can include recycled plastics it is not always in terms of economic and design options to use 100% recycled materials
- Potential additional costs (labour, space and processing time) are for WEEE pre-processor: additional costs, for example due to additional manual labour, space, processing time
- The economic viability of the clustering strategy needs to be addressed by increasing the amount of WEEE collected, at the moment there is a notable gap in the amount generated and collected for recycling.

Performance of the circular product (or solutions)

- Uncertainty still exists around the stability of the product in terms of both degradation and discolouration and hence lack of consumer confidence.
- Formative needs of WEEE pre-treatment operators

Environmental and circularity

- Currently, it is not possible to obtain food grade approval for PCR WEEE plastic nor is it possible to obtain transparent PCR WEEE plastics limiting the application within design.

5.2.3 Opportunities

Economic

- Marketing and corporate branding could be associated with sustainability which could provide competitive advantage and provide added value of distinctiveness in terms of product as well as aligning with the Circular Economy and UN SDGs
- Competitive advantage for public procurement and in particular sustainability initiatives.
- Providing the opportunity for businesses (including SMEs) to futureproof for potential requirements for statutory recycled content

Performance of the circular product (or solutions)

- There are already companies manufacturing products made of recycled plastics. However, these products are mostly unrefined, characterized by low quality in terms of transparency and colour. Demonstrators have shown that high quality products are achievable and could encourage other companies to examine the possibility of recycled materials within their product. ONA is able to obtain products that have the same appearance as the ones containing virgin materials

Environment and circularity

- The ability to offer a product which does encompass CEBMs and aligns with sustainable development goals.
- Development of further application and use of recycled plastics with enhanced design guidelines
- Potential to influence Legislative changes
    - obligation for EEE manufacturers of using a certain amount of PCR WEEE plastics in new EEE
    - obligation for municipal collection point or retailers of implementing a clustered collection
    - obligation for EEE manufactures of reducing the numbers of polymers used in new WEEE and the complexity of the product (eco-design) with the possibility to disassembling
- Development of innovative sorting technologies (automation of clustering activities and the possibility of engaging social workers (cost reduction)
- China ban consequences: WEEE pre-processors' need of testing innovative strategies to effectively manage increasing flows of WEEE plastic

5.2.4 Threats

Economic

- Support from governmental policy is crucial in driving forward research agendas to enable support for businesses particularly SMEs as without funding the development of new products brings financial risk
- Reduction of cost of virgin plastic reducing the attractiveness of recycled content and financial feasibility for SMEs

Performance of the circular product (or solutions)

- Lack of research looking at polymer additions for longevity and sustainability of recycled plastics.
- Evolution of WEEE waste streams, in terms of products and in terms of products composition (for example, use of new plastic blends, increasing use of electronics)
- Quality reduction of the virgin plastic used in EEE (for example, due to import of low-quality products from China)
- Evolution of legislation regarding restricted substances (for example, concerning banned flame retardants)
- Availability of correct suppliers and appropriate business partners to help support product development
- Find the right supplier/the proper business partner (moulder)

Environment and circularity

- Emerging of conflictual clustering needs (for example, need of improving the recycling of certain CRM or need of segregating products containing batteries)

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