PolyCE

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

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Executive Summary

One of the key characteristic of the PolyCE project is its ambition to investigate the entire EEE/WEEE value chain and to engage all the actors and stakeholders operating along it. Aiming to improve after use management of WEEE post-consumer plastics, WP3 is dedicated to the study of WEEE pre-treatment activities and of other related WEEE value chain nodes as collection, logistic and plastic recycling. Each WP3 task deeply analysed different aspects of WEEE PCR plastic management and developed specific solutions to overcome weakness of current system.

This deliverable presents WP3 findings in form of recommendations that directly address WEEE value chain relevant actors. Recommendations suggest to implement *technological innovations*, as the adoption of optimum shredding size of plastic flakes at WEEE pre-treatment level; *innovative procedures*, as the collection and treatment of WEEE according to new clusters of products and the adoption of *harmonized datasheet* by WEEE pre-treatment operators (to share information regarding mixed plastic flakes quality with plastic recyclers in a standardized way); *systemic innovations*, as the improved dialogue within stakeholders and the promotion of WEEE collection.

To validate PolyCE recommendations effectiveness and feasibility, feedback from relevant stakeholders have been collected. Consulted stakeholders consider particular relevant the recommendations applicable to collection level: *increase effort of all actors operating along the EEE/WEEE value chain in promoting WEEE collection and organize the collection in additional clusters, mainly at retailers level.* The proposed approach is considered potentially beneficial to increase the return rate of plastics and improve the recycling of post-consumer plastics.

Moreover, consultation results show that to guarantee the successful implementation of PolyCE recommendations specific aspects should be carefully taken into account: labour costs, space constrains, legislative requirements, scavenging risks, need of additional training for personnel.

Overall, stakeholders' answers clearly underline the need of elaborating a solid business case showing economic benefits of proposed solutions and highlighting new business opportunity arising from WEEE PCR plastics quality improvements.

1 Introduction

Within PolyCE project, WP3 is dedicated to identifying solutions for improving the after use management of Waste Electrical and Electronic Equipment (WEEE) post-consumer plastics. For this purpose, the value chain of WEEE post-consumer recycled (PCR) plastic has been scrutinized (task 3.1); then the main weaknesses of the current system have been studied; finally, the most effective methods (including technological improvements as well as innovative procedures) to support efficient business operations for collection and clustering (task 3.2), reverse logistics (task 3.3) and WEEE treatment (task 3.4) have been proposed. The overall aim of the work package is to increase the return rate of plastics and to increase the recycling of WEEE PCR plastics.

One of the key features of the PolyCE project is its holistic ambition to encompass all the relevant nodes of the WEEE value chain. As analysed in detail in task 3.1, key nodes of WEEE value chain include, for example, OEMs, consumers, WEEE pre-processors and plastic recyclers. Although the WP3 investigation mainly concerns WEEE pre-processing activities, it is not realistic to design a solution for this particular phase of the Electrical and Electronic Equipment (EEE)/WEEE value chain without taking into account the impact on the other value chain steps; or disregarding the contribution that other stakeholders can make.

Consequently, a multi-stakeholder network is strictly required to achieve the objectives of the PolyCE project. It is evident that to develop new innovative solutions as well as to test their feasibility, it is fundamental to include the expertise of people from various relevant backgrounds.

Collecting other WP3 tasks outcomes and experts' opinions, task 3.5 aims to review the revised EEE/WEEE value chain and refine it for maximum effect. This task will also deploy a review of current understanding of what is perceived to be best practice for the proposed circular economy solutions based on re-design of value and supply chains.

1.1 Aim and scope of the deliverable

The scope of this deliverable is threefold:

- To provide a **comprehensive overview** of the findings of other WP3 tasks. Each WP3 task has been devoted to the study of a particular aspect of the WEEE pre-treatment activities. Input and output materials have been studied in terms of quality and quantity within task 3.1. A new treatment procedure (*clustering*) which consists of treating certain products/products families together/separately has been investigated within task 3.2. A reverse logistic solution to take advantage of spare capacity currently in product end-of-life handling process has been designed in task 3.3; and an optimum size of WEEE plastics flakes, in terms of effectiveness of subsequent sorting activities, has been determined in task 3.4.

  As shown in figure 1, each WP3 task (and the corresponding deliverable) addressed specific issues related to one, or more, steps of the EEE/WEEE value chain.

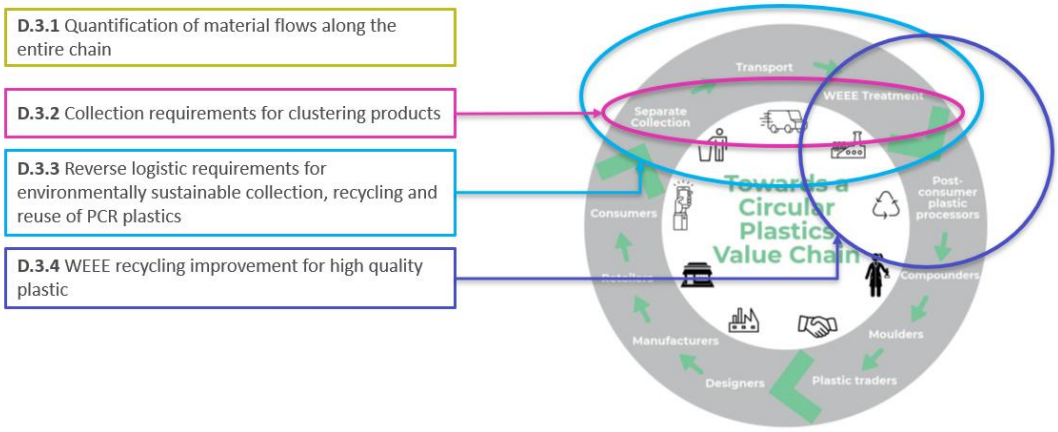

Figure 1. WP3 deliverables addressing key nodes of EEE/WEEE value chain

From this starting point, task 3.5 compiles a set of recommendations that corresponds to current value chain criticalities with a more systematic approach (figure 2);

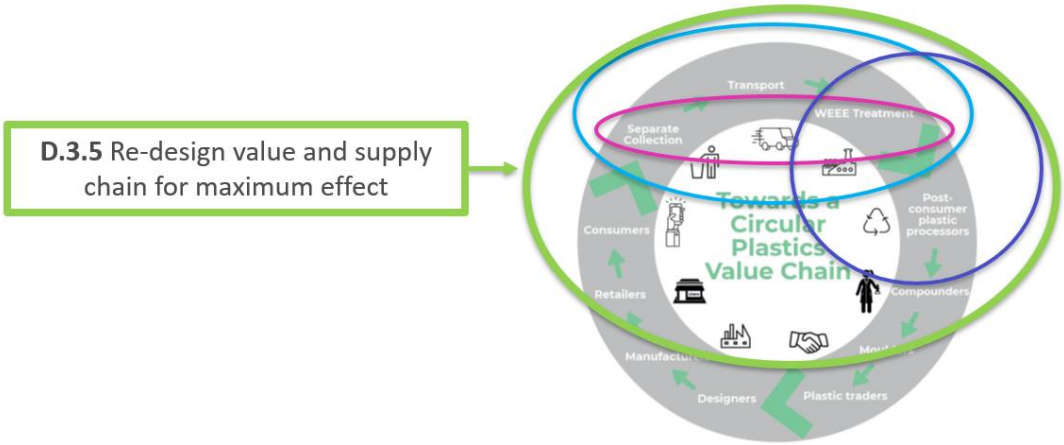

Figure 2. Deliverable 3.5 addressing key nodes of EEE/WEEE value chain

- to validate the **viability** of the methods identified:
  together with the relevant industrial partners this deliverable measures the potential benefits of the proposed solutions. The feasibility of the PolyCE strategy so far defined, is evaluated collecting final users' feedback. In line with the indication provided within the *Plan for a transparent consultation* (deliverable 2.3), the consultation with relevant stakeholders will allow for:

  - validation of WP3 methodology and outcomes;
  - evaluation of technical and economic feasibility of WP3 solutions;
  - alignment of the research to the actual needs of the industry;
  - identification of synergies with other existing research initiatives in industry environment.

Therefore, consultation performed during task 3.5 research activities, will ensure the effectiveness of the proposed measure; raise awareness of the project research among industrial stakeholders and effectively communicate PolyCE findings to professionals in the EEE/WEEE field. According to the feedback collected through the consultation activities, WP3 recommendations will be refined and improved.

- to provide **support to the demonstrators** trials of WP7:
  this deliverable contains an extended *checklist* that can be implemented during WP7 demonstrator activities. The main goal of WP7 is to bring together the knowledge gained from previous work packages into multiple large-scale demonstrators for the effective re-use of PCR plastics from WEEE. Specifically, task 7.1 is dedicated to demonstrators for the WEEE supply chain. Within task 7.1 the requirements identified in WP3 are applied, due to the direct involvement of distributors and retail shops, logistics providers and WEEE pre-treatment operators and plastic recyclers. This represents an extremely valuable opportunity to verify the feasibility of the proposed solutions in an actual working environment. The checklist furthermore allows collection of field data required to carry out cost-benefit analysis that contains considerations regarding the efforts (e.g. costs) required to implement PolyCE measures as well as an estimation of the achieved benefits (e.g. increased purity of the obtained plastic streams).
  According to the feedback collected through the checklist, WP3 recommendations will be refined and improved.

  Additionally, the checklist can be interpreted as a list of key aspects to which professionals operating along EEE/WEEE value chain should consider to improve WEEE PCR plastic quality.

The outcomes of the deliverables 3.5 will be used as input for tasks 2.2 (enlarging the list of external stakeholders involved in PolyCE activities) and WP7 (tasks 7.1, 7.6, 7.7, 7.8).

Moreover, task 3.5 is also correlated to the milestone MS10 Value and supply chain needs summarized. As mentioned before, task 3.5 represents a relevant decision point: according to the feedback collected from relevant industrial stakeholders WP3 recommendations will be refined and improved.

2 Methodology

To achieve the objectives listed above, task 3.5 has been carried out in several subsequent activities. The adopted approach is shown below:

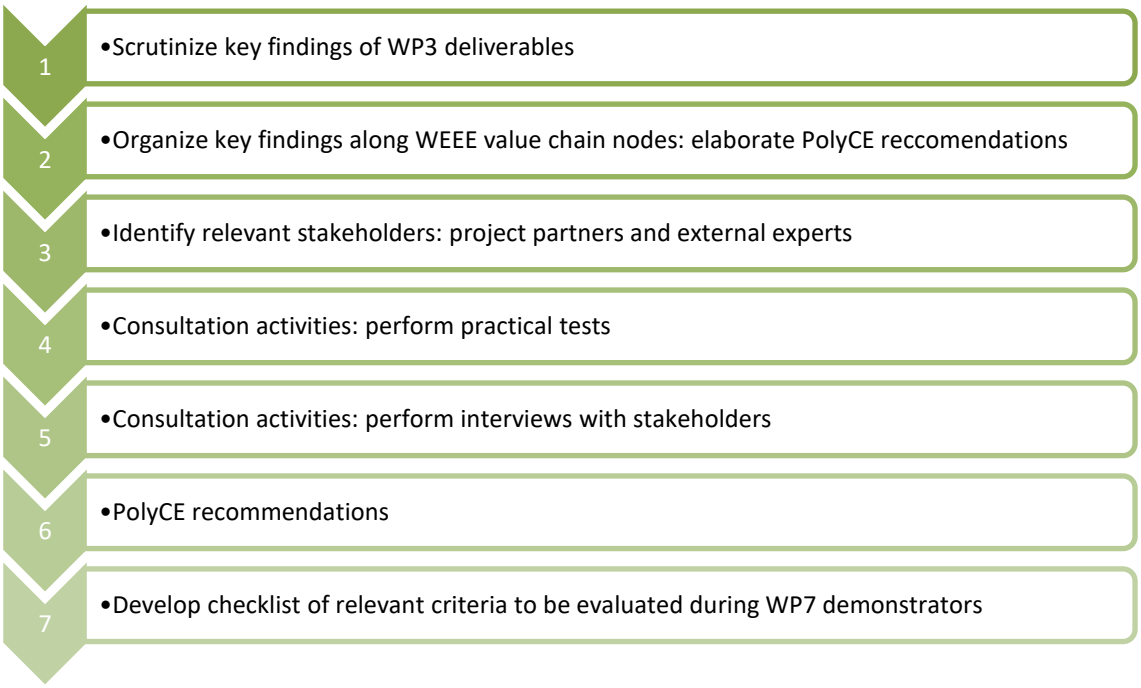

Figure 3. Task 3.5 methodology

3 PolyCE recommendations

PolyCE recommendations are presented in following subsections. For each recommendation the expected type of benefit is indicated:

Table 1. Expected benefit types of PolyCE reccomendations

Expected benefit type	Symbol
Environmental	
Economic	
Costs savings for the society	

Recommendations are categorized along WEEE value chain. PolyCE recommendations apply to collection, logistical, treatment and communication levels.
In the following, all the recommendations from the tasks of WP3 are listed and classified.

3.1 Collection level

Problem: operators not working within the official WEEE system are likely not interested in WEEE plastic recovery. Currently, only about 35% of WEEE generated in Europe is collected through official schemes [1]. Therefore, a large amount of WEEE generated and the related plastic is treated with non-circular solutions (informal channels).

State of the art: citizens have the possibility to dispose of WEEE in *local municipal collection points* free of charge; citizens have additional possibilities to dispose WEEE: *1) one for one system*: which obliges the distributor to collect, free of charge, the WEEE which the customer hands over when buying a new piece of equivalent equipment. This also includes distributors that work in teleshopping and electronic sales, and they are obliged to inform consumers of the free collection; *2) one for zero system*: free collection of small WEEE under 25 cm in stores of at least 400m^2. In some municipalities *door-to-door* collection is also available for WEEE large appliances (by appointment).

Recommendation:

Promote WEEE collection and reduce the gap between WEEE generated and WEEE collected		**R.1**
Input	**Implementation**	**Innovation type**
Deliverable 3.1	Long term goal	Systemic

Objective. Increase the amount of PCR WEEE plastic potentially available in Europe:

Benefits

- increasing the amount of WEEE collected and properly treated would enable greater amounts of PCR to be reprocessed and provide a higher share of the European EEE sectors plastic demand (according to the findings of deliverable 3.1, WEEE plastic potentially available for recycling represents almost 65% of the EEE sector plastic demand that accounts for 3.1 mt annually [2])

- increasing the amount of WEEE collected would make it possible to take advantages of economies of scale benefits in logistic as well as WEEE pre-treatment steps.

Problem: it is extremely complicated to separate and recycle polymers coming from the treatment of mixed appliances composed by hundreds of different products

State of the art: WEEE are collected (and transferred then to WEEE pre-treatment plants) in 5 different streams: cooling and freezing appliances, large household appliances, TV&screens, small household appliances and lamps. Each WEEE stream contains different products. The small household appliances waste stream is the most heterogeneous one and is composed of a very large variety of products.

Recommendation:

Enhanced collection of WEEE through redefined product group clustering based on material types and properties		**R.2**
Input	**Implementation**	**Innovation type**
Deliverable 3.2	Long term goal	New procedures

Objective. Increase the efficiency of the subsequent treatment steps and improve PCR WEEE plastic quality

Benefits

- smart clustering strategies implemented at collection level can facilitate the processes of material separation in WEEE pre-treatment facilities

- smart clustering strategies implemented at collection level can increase the output and quality of PCR plastics as well as enhance the availability of high-quality PCR plastics at the market.

3.2 Logistic level

Problem: there are inefficiencies in current WEEE transport operations. Inefficiencies arise where, to transport WEEE from collection points to treatment plants, the logistic system relies on single-lane transportation where vehicle load factors may not be optimal.

State of the art: tack back schemes put in place logistic activities through authorized transport operators that use trucks for tipping containers (if the served collection point is managed by a container) or trucks with tail lift (if the served collection point is managed by manual picking). Logistic operators transport WEEE form Collection Points to Treatment Plants. Municipal collection points and retailers communicate that a collection service is needed; the municipal collection point and the retailer can require a collection service only for amount equal or above certain threshold previously defined (depending on the WEEE typology). By contract, logistic operators have a maximum interventions time. Collection sites and WEEE pre-treatment facilities can be located far away.

Recommendation:

Introduce a new node within the transportation network: a Consolidation centres that functions as an intermediary destination where goods of identical streams and destination can be stockpiled until such a point that transportation to the relevant destination can be performed at a more optimal load-factor.

R.3

Input	Implementation	Innovation type
Deliverable 3.3	Medium term goal	New procedure/Systemic

Objective. Remove inefficiencies in transport operations of end-of-life goods from collection points to treatment plants

Benefits

- consolidation centre can reduce logistic costs reducing km, steam mileage (*i.e. the amount of miles it takes for a truck to drive to a specific delivery route area*), and therefore reduce number of vehicles and fuel consumption. The use of a consolidation centre located in the gravity centre (point that is *equidistant* to WEEE collection points located within a specific area) of collection volumes for a determined area permit less trucks kilometres per trip. This is achieved by reducing the need for vehicles to always route to a treatment centre

- consolidation centre can reduce social costs reducing CO_2 emissions and, due to the shorter mileages for collection vehicles (eradication of stem mileage), the overall investment, depreciation and day-day operational costs is reduced, therefore, delivering cheaper services to the various stakeholders from consumer to local authority

- consolidation centre can increase trip efficiency: by vehicles staying local, better use of driver operator and vehicle time can be made with collecting waste product, rather than the wasteful practice of stem mileage

- consolidation centres can create business opportunities: having a consolidation centre allows to pull together smaller volumes (that do not fulfil adequately the container/the truck to justify a long trip to the treatment plant) to get greater economies with line haul vehicles that operate from consolidation centre to treatment plant and permit greater volume to be transported.

3.3 Treatment level

Problem: it is extremely complicated to separate and recycle polymers coming from the treatment of mixed appliances composed by hundreds of different products. It should be taken into account that mixed plastic particles have a lower resale value than a pure plastic stream.

State of the art: WEEE pre-treatment plants put in place ad hoc treatment processes according to the specific characteristics of the treated waste stream. However, some main treatment steps can be identified as common for all WEEE streams: manual sorting of certain products/components, shredding, mechanical sorting. Often plastic is the outcome of a negative sorting activity, meaning that the target fraction of the sorting is another material (e.g. copper), likely more valuable, and that plastic is a contaminant that needs to be eliminated through the sorting process.

Recommendation:

Treat separately specific product categories and/or specific product components with the aim to increase the concentration of specific plastic types.

R.4

Input	Implementation	Innovation type
Deliverable 3.2	Medium term goal	New procedures

Objective: improve the quality and quantity of output materials of WEEE pre-treatment facilities, thereby improving the WEEE plastics recycling rate

Benefits

- proper clustering strategies can limit the degree of contamination in output streams

- proper clustering strategies can limit the mixing of difficult to separate and incompatible materials.

Problem: there are a high number of different polymers in WEEE. Especially the WEEE stream of small household appliances is problematic for pre-processors, because of the heterogeneous and complex composition (up to 20 or 30 different polymers). Every sorting technology needs a specific particle size range to

provide an efficient separation performance. If a sorting technology cannot separate plastics properly due to the wrong particle size, the target fraction may get into the fraction to be disposed of and thus be lost. If a wrong or undetected particle gets into the target fraction, the quality of the plastic fraction is reduced. If this particle gets into the fraction which is disposed of, the plastic is not recycled.

State of the art: WEEE pre-processors obtain mixed plastic fractions; plastic recyclers treat mixed plastic fractions putting in place several activities (as sorting, washing, compounding and finally extrusion) to transform mixed plastic flakes in plastic granulates. Although there are similarities regarding the WEEE pre-treatment plant layouts, there are differences regarding adopted shredding technologies, particle size and composition of the materials sent to plastics recycling.

Recommendation:

Production of plastics mixed fractions that can be easily sorted at downstream facilities (implementation of a standard particle size range - Optimum particle size 10 to 20 mm)

R.5

Input	Implementation	Innovation type
Deliverable 3.4	Short term goal	Technological

Objective: Increase quantity and quality of the plastics processed in post-consumer plastics recycling facilities by improving particles sortability

Benefits

- the suggested particle size would allow to effective application of different sorting techniques such as magnetic and eddy current sorting, XRF, XRT, S/F, NIR

- the suggested particle size would allow to effective application of different technologies such as air table, wet shaking table, triboelectric sorting, centrifugal sorting; the suggested particle size would allow as well to effective extrusion operation performing only one shredding step;

- the suggested particle size would avoid the risk of forming a *composite*, namely a flake containing two different materials, as plastic and metal (that might happen with large particle size). The presence of composites leads to loss of plastic particles in other material streams. For example, during metal separation, plastic parts can attach to the metal and get into the metal fraction. These particles are lost and not transported to the recyclers, which is reducing the volume of potentially recyclable fraction

- the suggested particle size increases the bulk density and reduces transport costs and transport emissions.

Recommendation:

Keep the production of fines low by reducing the number of shredding steps

R.6

Input	Implementation	Innovation type
Deliverable 3.4	Short term goal	Technological

Objective: Increase quantity and quality of the plastics materials delivered to post-consumer plastics recycling facilities increasing particles sortability

Benefits

- by reducing shredding steps it would be possible to reduce losses: in each shredding step losses of recyclable materials in form of dust and fines, occur

- reducing shredding steps reduces CO_2 emissions and energy costs through less energy consumption of shredding equipment.

Recommendation:

Find suitable recyclers with appropriate sorting technologies for the fine fraction, instead of discarding

R.7

Input	Implementation	Innovation type
Deliverable 3.4	Short term goal	Systemic

Objective: Increase quantity and quality of the plastics materials delivered to post-consumer plastics recycling facilities

Benefits

- identify suitable recyclers that use sorting technologies appropriate for fine fractions allows to keep the losses as low as possible. There are different sorting technologies that work efficiently in a size range of 2 to 10 mm (common sorting technologies already exist, and most effectively sort in 2 to 6 mm and 6 to 10 mm sizes).

Recommendation:

Dedicated removal and pre-sorting of certain plastic fraction, (e.g. pure plastic fraction/plastics containing BFR/POP substances dangerous or not) at the point of pre-processor

R.8

Input	Implementation	Innovation type
Deliverable 3.4	Short term goal	New procedures

Objective: Improve the quality of the output fraction from WEEE pre-treatment facilities:

Benefits

- pre-sorting at WEEE pre-treatment plant level would allow to remove large plastic parts manually resulting in a more homogenous plastic input for recycler 
- pre-sorting at WEEE pre-treatment plant level would allow the reduction or elimination of the proportion of plastics containing brominated flame retardants: brominated fractions can be sorted out by XRF or XRT even with large particle sizes. This approach makes the output fraction of the pre-processor more valuable 
- pre-sorting at WEEE pre-treatment plant level would allow the reduction of transportation costs and related CO_2 emissions. 

3.4 Communication level

Problem: WEEE pre-processors hardly know which sorting technologies the recycler operates and what particle size is needed

State of the art: every sorting technology needs a specific particle size range to provide an efficient separation performance

Recommendation:

Improve the communication between pre-processors and recyclers. **R.9**

Input	Implementation	Innovation type
Deliverable 3.4	Short term goal	Systemic

Objective: Improve the quality of output plastic fraction coming out from the WEEE pre-treatment facilities

Benefits

- applying the proper particle size has the potential to decrease transport costs and emissions due to optimised use of space during logistics (increased bulky density and consequently better filled bags etc.), if smaller particle size are required by sorting operators 
- applying the proper particle size has the potential to reduce additional shredding steps, if smaller particle size are required by sorting operators. 

Problem: it is difficult to compare different mixed plastic quality and characteristics in terms of size distribution, colour composition and the plastic composition. It is consequently difficult for recyclers to select the most appropriate sorting technology to be adopted as well as to proper valorise different materials.

State of the art: currently datasheets of plastic properties are similar but with slight differences, depending of WEEE pre-treatment facility and recycling company procedures.

Recommendation:

Harmonization of technical datasheets of the produced plastics fractions;

R.10

Input	Implementation	Innovation type
Deliverable 3.4	Short term goal	New procedures/Systemic

Objective: To facilitate information flow along the WEEE plastic value chain

Benefits

- harmonized technical datasheets would facilitate the comparison (in term of obtained plastic quality) of treatment processes applied by different WEEE pre-treatment facilities and by different recycling plants

- harmonized technical datasheet would allow WEEE pre-treatment plant to understand plastic recyclers requirements

- harmonized technical datasheets would allow WEEE pre-treatment plants and recyclers to define plastic price according to quality evaluation.

4 Stakeholder consultation

The interviews were designed to explore the key themes of PolyCE recommendations in more details and to give experts and stakeholders, along the value chain, the opportunity to elaborate on the topic of WEEE PCR plastic supply and value chain improvements. A series of semi-structured interviews were conducted. In preparation for these interviews, the recommendation were organized as presented in chapter 3 (collection level, logistic level, treatment level, communication level). This allowed specific questions to be asked to stakeholders according to their main field of expertise.

Therefore the questions were individually adapted according to the type of operations conducted.

The interviews were conducted in the language of the country. It was agreed with the interviewees that the results would be aggregated and anonymized before publication.

Semi-structured interviews were conducted. The framework of themes to be explored during the interviews are reported in the in Annex I.

4.1 Identification of stakeholders

In total, 27 interviews were conducted. Respondents where representatives of different nodes of the WEEE value chain:

- 4 EEE producers;
- 12 WEEE pre-processors;
- 1 logistic operator;
- 1 producer of producer of shredding systems and machinery;
- 1 national Clearing House;
- 4 WEEE plastic recyclers;
- 3 take back schemes;
- 1 European take back schemes association.

4.2 Practical tests

Through the collaboration of WEEE pre-treatment operators, the effectiveness of the recommendation **R5, *reduction of plastic flakes size to increase bulky density***, has

been tested. Specifically, it has been investigated if it is possible to reduce emissions and costs due to material transport increasing plastic flakes bulky density.

Output mixed plastic flakes from WEEE treatment could present the following characteristics:

- 500 kg/m^3 → **fine shredded** plastic flakes (flakes dimension about 10mm – 20mm)
- 300 kg/m^3 → **coarsely shredded** plastic flakes (flakes dimension about 30mm – 50mm)

Mixed plastic flakes are transported by truck. According to road codes, permissible maximum gross weight of loaded trucks in Europe is 40 tonnes [3]; considering the truck weight, this means that permissible maximum net weight of truck load is about 24 tonnes. Truck main characteristics are reported in table 2 [4].

Table 2. Truck characteristics

Parameters	
	Truck (Case)
Length [m]	13.60
Width [m]	2.48
Height [m]	2.65
Volume [m³]	89.38
Weight [t]	up to 24 tons loading weight

Mixed plastic flakes can be allocated in the truck with or without big bags. The two scenarios are presented below.

1. Mixed plastic flakes transported *using big bags*

Assuming the following common big bag size [5]:

- big bag medium dimension: 2.15 m x 0.91 m x 0.91 m ≈ 2.0 m³

it results that:

- big bag containing fine shredded plastic flakes: ≈ 2.0 m³ x 500 kg/m³ = 1 tons
- big bag containing coarsely shredded plastic flakes: ≈ 2.0 m³ x 300 kg/m³ = 0.6 tons

The calculation of the transport quantity is evaluated by considering the storage slots of the big bags. This is done because the big bags cannot be stacked on top of each other (due to load securing); therefore the calculation cannot be carried out with the total volume of the loading area of the truck (the space above the big bags remains empty).

Considering truck and big bags dimension, it results that a maximum number of 28 big bags (2 on the wide side and 14 on long side) can be allocated on the truck. In terms of weight, this means that:

- big bag containing fine shredded plastic flakes TOTAL weight: 1.0 tons x 28 = 28 tons
- big bag containing coarse shredded plastic flakes TOTAL weight: 0.6 tons x 28 = 16.8 tons

It is evident that the optimal load of the truck can be achieved filling in 24 big bags with fine shredded plastic flakes: this would allow to transport 24 tons of plastic instead of just 16.8 tons.

Therefore, according to the calculation reported above, filling in big bags with small flakes, more material can be transported at once, resulting in fewer transports, which saves on emissions and costs.

2. Mixed plastic flakes transported *without big bags*

Often mixed plastic flakes are transported without big bags. This is due to the fact that additional costs (10-15 €/tons) occur when big bags are used. The additional costs are related to:

- cost of big bag (unit price about 7-8 €)
- extra time to load and unload big bags.

Therefore, big bags are actually used only to transport highly valuable materials as plastic flakes from cooling and freezing appliances and for short distances travels.

Considering that a large truck volume is about 89.38 m^3 and that the load limitation is 24 tons, also implementing recommended shredding size it would not be possible to completely fill in the truck. From calculation it results that:

- full truck containing fine shredded plastic flakes: ≈ 89.38 m^3 x 500 kg/m^3 = 44.69 tons
- full truck containing coarsely shredded plastic flakes: ≈ 89.38 m^3 x 300 kg/m^3 = 26.81 tons

Thus, considering the density of fine shredded plastic flakes, it would be possible to fill in only about 50% of the available truck volume.

Therefore, it is not relevant that the suggested particle size increases the bulk density in terms of transport costs and emissions reductions if plastics is not transported in big bags.

5 Consultation results

PolyCE recommendations listed above have been organized in figure 4 according to their estimated *implementation timeframe* and according to the *innovation type* that each proposed solutions can potentially introduce in the current EEE/WEEE value chain.

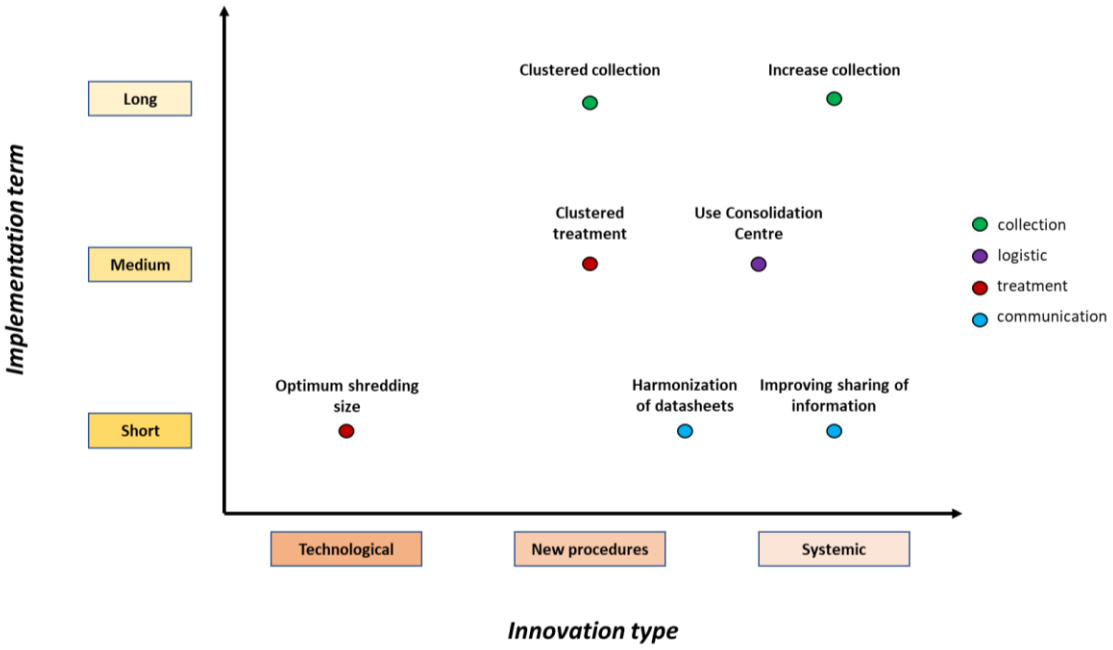

Figure 4. PolyCE recommendations

As mentioned in chapter 4, PolyCE recommendations have been brought to the attention of relevant stakeholders. The consultation results are reported in the following sections.

5.1 Collection level

The results of consultation regarding PolyCE recommendation to be implemented at WEEE collection level are reported below.

R.1 To promote WEEE collection and reduce the gap between WEEE generated and WEEE collected.

Interviewed stakeholders consider this recommendation extremely relevant.

- Good results in improving collection performance can be achieved by **increasing citizens awareness through dedicated communication activities.**

  A good example of communication campaign effectiveness is provided by the Italian Clearing House. In Italy, designed by EEE producers and put in place by the Italian Clearing House, a communication campaign focused on the promotion

of WEEE collection started in 2019 (and it is still ongoing). The campaign uses different channels (television, radio and web) and aims to communicate the importance of WEEE collection as well as the proper disposal methods and opportunities to a wide audience. The initial results of the campaign are very promising: during the first 5 months of the campaign (from January 2019 to March 2019) the amount of small household appliances collected increased by 19% in comparison to the same period in the previous year; the collection of other WEEE streams, as cooling and freezing appliances, large household appliances, TV and screens and lamps increased on average about 10%.

The effectiveness of communication efforts is strongly related to the availability of a dedicated **budget** (in the Italian case, the investments are about 2 Million euros). Moreover, the communication should be **constant, widespread** and **well planned in the short as well as in the long term.**

- Collection performance of small equipment (small household appliances and lamps) can be achieved adopting **collection methodologies that better meet citizen's habits**, for example designing collection systems for:
  - municipal collection points, e.g. prolonging opening hours;
  - **highly frequented areas**, as schools, offices, shops…
  - **retailers**; currently, retailers collect mainly cooling and freezing appliances and large household appliances, that represent about 90% by weigh of the total retailers collection. Consequently, aiming to assign a key role in the small household appliances collection to retailers, new attitudes should be promoted. Thus, behavioural change toward WEEE collection should be encourages not only within citizens, but also within retailers.

  To implement this suggestion, it is fundamental to reduce current legislative barriers.

- Good results in improving collection performance can be achieved simplifying current regulation:
  - there are particular actors, as installers of EEE, that currently manage significant WEEE flow. However, due to legislative barriers (e.g. installers need to be formally authorized by the EEE producer to perform WEEE collection), they are discouraged to be involved in the formal collection system.
  - there are particular products that can be managed in a simplify way: e.g. consumers can directly send back to producers exhausted toner cartridges. One of the stakeholders interviewed has seen an increase in uptake of its cartridge replacement service which has led to improved design. For the customer their needs are better met.

- There is also a role for incentivised collection of WEEE especially through take back schemes. This has worked well in schemes in the US where customers are given a 10% off a new product when bringing their old one in.

- **All the actors operating along the EEE/WEEE value chain (EEE manufacturers, municipalities, retailers) and legally obliged to manage WEEE collection should be committed** in achieving the objective of WEEE collection performance improvements. This means that all mentioned key actors should make greater investments to increase WEEE collection and WEEE treatment quality, for instance providing stronger economic support to

stakeholders in charge of these activities along the EEE/WEEE value chain. Also National Governments need to be committed to a long-term strategy in terms of capture rates. This will give treatment facilities the confidence to invest in better treatment facilities.

R.2 Organization of the collection activities in clusters, namely products (or components) families defined taking into account material composition

Interviewed stakeholders consider this recommendation interesting and potentially beneficial. However, some implementation constrains should be taken into account.

- It is suggested to investigate further the hypothesis of performing the **WEEE sorting step as a dedicated activity**. Namely, it is proposed to consider another node, exclusively devoted to sorting, within WEEE collection and WEEE pre-treatment step. For instance, this dedicated sorting step will be in charge of collecting all the different WEEE streams together and of clustering the products according to specific requirements (e.g. material composition, product type…). This approach can potentially improve the quality of product delivered (obtaining more homogenous flow) to WEEE pre-treatment plants and consequently the quality and the valorisation of recovered materials. However, this additional activity, performed at professionals level, should be properly valorised (e.g. by EEE manufacturers) and it will be implemented taking into account legislative constraints and safety issue (e.g. dangerous and not dangerous WEEE should be keep separated).

- Clustered collection is **difficult to implement at municipal collection points level**. This is due to several reasons:
  - additional **space** would be required to allocate different bins (in this regard, it should be taken into account that often highly frequented collection points have a small space available and different bins will have different filling rate);
  - **trained personnel** should be dedicated for the product identification; this is related to additional costs;
  - municipal collection points can place a certain number of containers in an authorized space; therefore, the position of new bins would require **additional authorization**;
  - **citizens should be properly informed** regarding the correct disposal of different products;
    currently, it often occurs that municipal collection points (due to citizens and collection points operators error) are not able to deliver to WEEE pre-treatment plants material properly segregated (e.g. monitors arrive in WEEE treatment plant in the same container as the small domestic appliances)

- 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).
  - retailers in general have better sorted WEEE streams and have less contamination than Municipal sites, however space can be limited.

5.2 Logistic level

The results of consultation regarding PolyCE recommendation to be implemented at WEEE collection level are reported below.

R.3 To introduce a new node within the transportation network: a Consolidation centres that functions as an intermediary destination where goods of identical streams and destination can be stockpiled until such a point that transportation to the relevant destination can be performed at a more optimal load-factor.

Interviewed stakeholders consider this recommendation not extremely relevant and difficult to implement.

- Consolidation centres are associated with **high costs** of management:
  - WEEE treatment plants are not prepared to pay additional costs to be able to use consolidation centre; it is not evident for them if it would be possible to cover the additional costs through savings due to logistic optimization;
  - WEEE treatment plants consider the approach proposed in the recommendation economically feasible only if they were owners of the Consolidation Centre. However, this would require high investment costs;
  - the business case associated with Consolidation Centre management seems weak. There is in fact the risk that it would be underused by WEEE treatment plant (only when the load of the transportation is not already optimized and the distance appropriate). The fee associated with the Consolidation Centre should be then accurately defined.

- Currently, Consolidation Centres are used as little as possible, only for journeys greater than a certain distance (100km – 150km). This is due to the fact that Consolidation Centres are associated with:
  - **very high risk of scavenging**
  - additional costs due to loading/unloading time
  - additional work safety risks
  - legislative requirements (e.g. it is compulsory to avoid mix of waste collected in different municipal collection points)

- **It is extremely difficult to obtain authorization** (especially in certain location) to use an area as Consolidation Centre, namely a place where WEEE are stocked and handled.

- Rather than introducing a Consolidation Centre, it is suggested to investigate further the hypothesis of performing the collection *on call*. Currently, municipal collection points request collection service when they need to be emptied; after the request, logistic operators should respect specific deadline to provide the service. The service then cannot be optimized in terms of load and route. Alternatively, it is proposed to test the effectiveness of a different procedure, according to which it is the logistic operator that contacts municipal collection points within a certain area. The logistic operator verifies collection points needs and consequently optimally organize the collection service. This seems beneficial for different reasons:
  - travelled distances would be reduced

- collection points would be served promptly

- Consolidation Centres can be potentially designed as the place where *clusterization* activities are performed: operators of Consolidation Centre that currently optimize input WEEE in terms of quantity, can optimize them also in terms of quality, sorting products according to homogeneous flows.

5.3 Treatment level

The results of consultation regarding PolyCE recommendation to be implemented at WEEE collection level are reported below.

R.4 To treat separately specific product categories and/or specific product components with the aim to increase the concentration of specific plastic types.

Interviewed stakeholders consider this recommendation difficult to implement. However, they consider the challenge of obtaining homogeneus plastic flake as output of WEEE pre-treatment activities relevant.

- To sort products **from professional WEEE** (this term indicates the waste coming from EEE intended for administrative and economic activities, the supply of which is quantitatively important or the characteristics of which are for professional use only, that is to say equipment which are not used in the house) **collection is easily feasible**, because products arrive to WEEE pre-treatment plant already organized in homogenous flows;

- To sort products **from domestic WEEE collection is extremely difficult**. This is due to the fact that:
  - at the treatment plant, **additional trained personnel** should be employed to perform manual sorting (at least one operator should be added to the current treatment line; this corresponds to an additional cost of 30.000€/year);
  - at the treatment plant, materials arriving from certain municipal collection points are in bad condition: for instance, if bins at municipal collection points needs to be filled in from the top by citizens, it is likely that the collected materials will be broken and more difficult to sort;
  - even if the sorting activity is performed directly at the collection phase (e.g. at municipal collection points), treatment plants should cover the **additional costs and the additional effort to purchase and logistically manage new containers** (considering that WEEE treatment plants usually provide containers for the collection to collection points);
  - the variety of the products are high, especially within small domestic appliance waste flow; this makes it more **difficult to identify a standardized process** as has been done for other product type (e.g. fridges parts are manually removed for depollution; however, fridges from WEEE domestic collection are considerably standardized products);

- Where stakeholders have invested in sorting lines for small household appliances, they are seeing a good return on investment. The outputs are cleaner

and have reduced contamination. In addition this is often a more economical option that sorting post shredder material;

- It seems more feasible to perform the cluster activity in small treatment plants rather than in large plants, where it results in more difficult to coordinate additional work;

- Within the small household appliances WEEE stream, cluster activities could be feasible, targeting products such as computers or printers that are:
    - pretty homogenous (in terms of shapes and composition);
    - very much present in waste collected (e.g. there are a lot of printers in the current small domestic appliance waste flow);
    - made of few components;
    - easily and quickly identifiable by WEEE treatment operators;
    - already removed from the flow (e.g. fridges and CRT TVs manually remover to perform depollution activities);

  However, stakeholders suggest to focus on already segregated professional WEEE streams of mentioned products, because **it is not evident yet if the cost of additional sorting activities for domestic WEEE can be covered by treatment output fractions added value.**

- 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). Therefore, the volume treated during the separate batches should be considerable;

- To reach the minimum number of products that can be treated together in the same cluster it would require considerable time. Collection from municipal collection points are not constant: products collected as well as quantity collected are not always the same throughout the year:
    - additional storage space (additional space should be foreseen for each of the different products selected);

- To commercialize output plastics form WEEE pre-treatment activities it is necessary to reach certain production amount. Applying the cluster strategy, to obtain sufficient quantity of pure plastics more time would be required. This is related to:
    - additional storage space (additional space should be foreseen for each of the different plastic type selected), the additional space will be occupied until a sufficient amount of output material is produced;

- Strategies similar to the one proposed in the recommendation have been already tested as pilots certain WEEE treatment plants. Specifically, the effectiveness of fridge drawers and printer clusters has been investigated. In the mentioned pilots, although the quality of the obtained plastic improved, it was impossible to find commercial channels to be able to economically benefit from the obtained fractions;

- It is necessary to develop a clustering strategy that takes into account WEEE flows variations in terms of collected products as well as in terms of product material composition. Otherwise, WEEE pre-treatment operators would risk to

change their plant layout or to made investments that are not beneficial in short term.

Feedback received on recommendation about plastic flakes size have been grouped together.

R.5 Production of plastics mixed fractions that can be easily sorted at downstream facilities (implementation of a standard particle size range).

R.6 Keep the production of fines low by reducing the number of shredding steps

R.7 Find suitable recyclers with appropriate sorting technologies for the fine fraction instead of discarding

R.8 Dedicated removal and pre-sorting of certain plastic fraction, (e.g. pure plastic fraction/plastics containing BFR/POP substances dangerous or not) at the point of pre-processor

Interviewed stakeholders consider these recommendations difficult to implement.

- Currently, the size of mixed plastic flakes from small household appliance treatment is about 50mm (higher than the optimum size recommended). This is due to the fact that:
  - to obtain small flakes, plastics should stay in the shredders longer. This is related to overheating risk (and consequently to fire risks) and wear and tears for the machineries: the material inside the shredder is not pure plastic; rather it contains metals as well as other impurities;
  - smaller particle size would slow down the production, due to additional shredding steps;
  - smaller particle size causes additional costs, due to additional shredding steps;
  - recyclers that use optical sorting prefer to receive larger flakes as input material to their sorting plants.

- Currently, the size of mixed plastic flakes from small household appliance treatment is about 50mm (higher than the optimum size recommended). However, when market conditions are particularly unfavourable, some WEEE treatment plants produce smaller plastic flakes to increase plastic value on market. Namely, when the market is particularly poor then some WEEE pre-treatment operators will shred more so they can sell more easily output material;

- Currently, the size of mixed plastic flakes from cooling and freezing appliances treatment is about 10mm-20mm. This size is selected because:
  - it ensures the separation of polyurethane foam residues from plastic parts;
  - it avoids the production of dusts;

- Currently, the size of mixed plastic flakes from cooling and freezing appliances treatment is about 10mm-20mm, however the trend is to increase plastic flakes size to speed up production; this applies both at WEEE treatment level and at the plastic recyclers level;

- The suggested particles size (10mm-20mm) is appropriate for densiometric sorting technologies; while optical sorting technologies require larger particle size (about 50mm-60mm). Often those plants which produce a larger particle size are producing for the Asia market and have sensor technology. Whereas those with density separators produce a small plastic size. Would require substantial investment to change sorting technologies;

- Manual removal of big plastic parts is feasible (and it is a procedure currently adopted) for specific products as TVs and screens. This is due to the fact that TVs and screens are approximately standardized products; this is not feasible for other small household appliances products, considering the considerable product variety;

- WEEE pre-treatment plants are interested only to certain extent in knowing what plastic recyclers need in terms of size of mixed plastic flakes size. This is due to the facts that WEEE pre-treatment plants and plastic recyclers have two different points of view. WEEE pre-treatment plants have the requirement of increasing the amount of produced materials: therefore, they usually shred the material small enough to allow recycler to use it; however, they do not shred the material below a certain threshold to avoid of slowing down plant operation;

- WEEE pre-treatment plants have only limited interest in plastic recyclers needs in terms of mixed plastic flakes size. This is due to the facts that WEEE pre-treatment plants and plastic recyclers have two different points of view. To meet plastic sorters needs, WEEE pre-treatment operators should do relevant investments (e.g. on average a metal detector to obtain a clean plastic flow costs 250.000€/300.000€; on average an additional shredder to obtain smaller plastic flake costs 150.000€). It should be bear in mind that WEEE pre-treatment and plastic recyclers are two very different businesses;

- WEEE pre-treatment plants have the requirement of increasing the amount of produced materials: therefore, they usually shred the material small enough to allow recycler to use it; however, they do not shred the material below a certain threshold to avoid of slowing down plant production.

5.4 Communication level

R.9 Improve the communication between pre-processors and recyclers.

R.10 Harmonization of technical datasheets of the produced plastics fractions.

Interviewed stakeholders consider this not relevant.

- Currently, WEEE pre-treatment plants share with recyclers waste characterization information and material composition analysis: this is a legislative requirement. Additionally, WEEE pre-treatment plants share material pictures and samples with recyclers. This results in an effective procedure;

- Where OEMs have engaged with the supply chain via roundtable discussions this has resulted in process innovations. Those who have done this have seen it as a positive step and a worthwhile investment which has led to increased recycled content in products and also designing for recyclability. Increasing connectivity in the supply chain and data sharing gives a better quality of plastics;

5.5 Additional consideration

- According to interviewed stakeholders, the **quality of polymers** (virgin plastic) used in EEE currently put 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. Specifically:
    - compounders should produce polymers that are as pure as possible;
    - compounders should avoid polymers mix;
    - compounders should ensure polymers recyclability.

  Consequently, EEE producers should select suppliers that are compliant with these recommendation. For example, EEE producers can introduce in their material specification, beside requirement referring to mechanical and chemical properties of the materials, an ad hoc *polymers recyclability requirement*;

- **EEE producers can influence the market** by choosing high quality compounds. They should **use less polymer types in their products** and they should select **suppliers that produce high quality compounds**. **Legislation** can play a key role in these regards: for instance, producers that put on the market products containing a large number of polymers can be penalized, by law, correlating visible EEE fee (EEE producers have the obligation of displaying visible environmental management costs of generated WEEE on the price displays for each product put on the market) with the amount of different types of used polymers. According to this mechanism, some products would be less competitive than others on the market.

  However, in this regard, it should be taken into account that EEE production facilities are located in several different countries within Europe and outside Europe. This means that to be effective, legislation should be harmonized within the current global market;

- Some stakeholders believe there is a role for EU legislation on regulation of quality of recycled plastics for export. However, More effort needs to be placed on enforcing current WEEE legislation, many of the stakeholders interviewed believe this a vital step in maintaining a level playing field.

6 Analysis of the results

6.1 Checklist for demonstrators

In the following, a possible set of criteria to be evaluated during the WP7 demonstrator implementation is presented:

During collection phase

Attention points	Unit	Value
1. Additional space required for clustered collection	m^2	
2. Additional labour cost	€/ton	
3. Additional costs due to communication efforts	€/ton	
4. Amount of WEEE collected	ton	
5. Share of WEEE disposed in the improper cluster	%	
6. Time needed for collection	h/ton	
7. Others		

During logistic operation

Attention points	Unit	Value
1. Additional labour cost	€/ton	
2. Additional scavenging losses	ton	
3. Additional loading/unloading time	h/ton	
4. Additional revenues	€/ton	
5. Others		

During treatment

Attention points	Unit	Value
1. Additional labour cost	€/ton	
2. Additional storage space required	m^2/ton	
3. Additional treatment time required	h/ton	
4. Cost due to additional equipment (e.g. shredders, containers)	€	
5. Share of WEEE treated in the improper cluster	%	
6. Additional revenues	€/ton	
7. Others		

During communication

Attention points	Unit	Value
1. Cost due to analysis of plastics	€/ton	
2. Additional revenues	€/ton	
3. Others		

7 Future work

From the consultation results, it became clear that additional attention should be devoted to the quality of polymers currently used in new EEE. As mentioned in section 5.5, at this stage the role of EEE manufacturers is pivotal as well as designers and compounders decisions are fundamental. Therefore, bearing in mind these considerations, inputs will be provided to PolyCE task dedicated to **eco-design issues**, i.e. task 8.1, where design for recycling aspects will be further investigated.

Key results of this deliverable will be presented to partners involved in WP3 and to external stakeholders during future PolyCE consultation activities (according to the plan and the consultation objectives reported in deliverable 2.3). This will allow the promotion PolyCE recommendations, and the collection of additional feedback on the proposed solutions and on proposed checklist.

Checklist effectiveness and usefulness will be also tested during demonstrator activities (WP7) and through the consultation of industrial stakeholders.

Moreover task 3.5 findings will be further evaluated in the light of environmental and economic considerations elaborated in task 8.5 regarding PolyCE approach benefits.

Additionally, stakeholders involved in the interviews will be kept informed regarding consultation results and feedback will be provided to the network of experts to highlight barriers, obstacles and success of the PolyCE solutions implementation testes during WP7 demonstrators activities.

8 Conclusion

Within the listed recommendations mainly new procedures have been proposed (e.g. implementation of a *clusterization strategy*, introduction of a *consolidation centre*); while only few of the listed solutions involve the implementation of new/different technologies (e.g. definition of optimum shredding size).

Overall, all the stakeholders interviewed during the consultation expressed high interest towards the PolyCE approach: the critical nodes of the EEE/WEEE value chain identified and scrutinized in WP3 tasks are considered relevant and the problem raised is widely acknowledged.

In particular, from the analysis of the feedback collected through stakeholders' consultation, some recommendations could lead to significant improvements. This is the case of the two recommendations: *increase effort of all actors operating along the EEE/WEEE value chain in promoting WEEE collection* and *organize the collection in additional clusters, mainly at retailers level*. These two approaches are considered potentially beneficial. The recommendations resulting promising from stakeholders' consultation address some of the pillars of PolyCE approach: this means that they will be further investigated during the project (e.g. during demonstrators activities in WP7).

Looking at the feedback provided on other PolyCE recommendation, it is evident that to ensure the feasibility of the proposed solutions, particular attention should be dedicated to key aspects. Specifically:

- additional **manual labour** should be avoided, considering that it is associated with high costs and it requires also redefinition of WEEE treatment plant layout;
- **space** constrain is a very relevant issue in WEEE treatment plant; this means that material storage (WEEE as well as WEEE treatment output fractions as plastic) should be avoided;
- **processing time** variation should be taken into account; this means that the introduction of additional sorting steps as well as the reduction of plastic fraction size (associated with additional shredding phase) should be avoided to not slow down production rate;
- **scavenging** is a criticality that affects different nodes of WEEE valued chain (collection and logistic steps). At this regard, it emerged that there is low trust between different stakeholders managing WEEE; therefore, the introduction of additional intermediate steps (as consolidation centre) should be avoided;
- **education** can play a key role to increased WEEE collection performance; investments should be done to increase citizens awareness and spread information regarding WEEE collection and related environmental benefits. PolyCE stakeholders clearly claim that consumers' education is a priority; this is also in line with the findings of other researches addressing the WEEE collection problem [6];
- **legislative constrains** should be taken into account; legislative barriers currently apply at different level (new collection, new area for consolidation centre…) discouraging innovation.

Finally, stakeholders answers clearly underline the need of elaborating a **solid business case** showing economic benefits of proposed solutions and highlighting new business opportunity arising from WEEE PCR plastics quality improvements. Therefore,

stakeholder considerations will be used as input of task 8.5, where environmental and economic sustainability benefits of the PolyCE approach will be evaluated.

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Annex I

Themes of the semi-structured interviews.

Please elaborate on:

ECONOMIC

- **the proposed strategy do not requires additional investment costs (e.g. to increase current WEEE treatment plant capacity; to buy new equipment/vehicles; to manage additional storage space…)?**
- **the proposed strategy do not requires additional costs due to additional manual work?**
- **the proposed strategy do not requires additional costs due to current changes in plant layout?**
- **the proposed strategy is expected to generate additional revenue (e.g. higher selling price for plastic)?**

ENVIROMENTAL

- **the proposed strategy do not requires additional energy use?**
- **the proposed strategy do not requires additional transports?**
- **the proposed strategy is not expected to increase CO_2 emissions?**
- **the proposed strategy is expected to increase plastic recycling?**
- **the proposed strategy is expected to increase other material recycling?**

WEEE VALUE CHAIN

- **the proposed strategy do not influence your relationship with stakeholders operating after you along the WEEE value chain?**
- **the proposed strategy do not influence your relationship with stakeholders operating before you along the WEEE value chain?**
- **the proposed strategy do not requires additional information exchange with other stakeholders operating along the PCR WEEE plastic value chain?**

IMPLEMENTATION

- **the proposed strategy is expected to be implemented in a short term?**
- **the proposed strategy is expected to be implemented in a medium term?**
- **the proposed strategy is expected to be implemented in a long term?**
- **the proposed strategy do not requires technological development to be fully implemented?**
- **the proposed strategy do not requires internal training (e.g. to learn new procedures, to learn the use of new equipment…) to be fully implemented?**

OVERALL EVALUATION:

- **the objective of the proposed strategy is relevant?**
- **the proposed strategy sounds appropriate to reach the objective?**
- **the proposed strategy is not completely new compared to current practices?**
- **the proposed strategy sounds feasible?**
- **the proposed strategy sounds beneficial from an environmental point of view?**
- **the proposed strategy sounds beneficial from an economic point of view?**
- **there are not legislative constrains to implement the proposed strategies?**

Do you already implement your own strategy to achieve the proposed objective? Please, describe.
Do you already implement a strategy similar to the one proposed that has been successful? Please, describe
Do you already implement a strategy similar to the one proposed that has not been successful? Please, describe