PolyCE

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

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Introduction

PolyCE intends to introduce feasible innovations, both technologic and systemic, showcasing, through several demonstrators at industrial scale, circular economy solutions engaging all actors across the value and supply chain.

The focus of Task 7.1 is to demonstrate on large scale the improvements achieved by redesigning the End of Life value chain of post-consumer plastics from WEEE (Waste Electrical and Electronic Equipment). Task 7.1 mainly validates in practice the findings obtained in WP3 and WP4 that proposed recommendations on the EOL (EOL) value chain, including optimized collection, clustering, pre-treatment, sorting and re-processing of WEEE. Specifically, Task 7.1:

- puts into practices the recommendations of Task 3.2 (*Product clustering for improved collection, sorting and reprocessing and optimized re-cycling economics, high purity PCR plastics streams and uptake*) on products clustering, verifying the operative **feasibility of the theoretical findings** in an industrial environment;
- allows to evaluate the **applicability of the testing procedures** developed in Task 4.3 (*Development of standard and systematic testing procedures for the different types of PCR to determine the PCR grade and to control quality consistency across the material value chain*) on WEEE plastic flakes and to assess the relevance of the test results to the industrial stakeholders operating along the WEEE value chain;
- provides inputs to Task 7.7 (*Whirlpool Large domestic Appliances demonstrator*): the activities performed within Task 7.1 can be considered as preliminary to the Whirlpool’s demonstrator focusing on components for the washing machine. The Whirlpool Large Domestic Appliances demonstrator will further validate Task 7.1 results taking advantage of one of the plastic outputs from the *clusterization* test to **produce injection moulded parts** and potentially extruded parts looking at both aesthetical and/or structural application;

Additionally, Task 7.1 results gave the opportunity to evaluate the possibility of obtaining **food grade** approval from PCR WEEE plastic (from fridges’ drawers cluster) and to test the **stage gate approach** developed by UL for managing material quality and controlling processes across the value chain.

Overall, through several industrial trials, the task investigated the extent to which the recycling rate and the quality of PCR plastics can be enhanced, if the EOL value chain is redesigned.

1 Approach

Currently, in Europe WEEE collection is organized in every collection facility in 5 groups: cooling and freezing appliances (C&F); large household appliances (LHA); TV and screens; small household appliances (SHA); lamps. After the collection, WEEE is transported to dedicated WEEE pre-treatment plans that put in place ad hoc treatment processes according to the specific characteristics of the treated waste stream.

As opposed to standard WEEE treatment, Task 7.1 followed a new approach that included the following information and innovations:

1. **Information on WEEE streams, mass balance and WEEE plastics amount and types**

   As preliminary activity, the physical nodes of the current WEEE value chain have been investigated (*Deliverable 3.1: Quantification of the material flows along the entire chain*) on one hand, mapping how the current chain in Europe is managed, paying particular attention to flows and quantity of WEEE and WEEE plastic treated (and more in detail in terms of polymers); on the other hand, providing materials and know-how for further investigation within the project framework and for other research in the field (performing for example sampling campaigns on WEEE products currently collected and providing actual and reliable data on Italian WEEE system functioning and materials flows).

   OUTPUT: for each current WEEE stream, quantitative and qualitative information regarding the total amount of plastic available and the corresponding polymers mix have been elaborated. For specific products, material composition data have been gathered through sampling campaigns.

2. **Definition of new clusters of WEEE streams**

   The results of this background study have been combined with the findings of the clustering exercise (*Deliverable 3.2: Determination of collection requirements for clustering products*) performed by KU Leuven. Through a statistical model, KUL developed an effective product clustering strategy aiming to increase the quality of the plastic in output from the WEEE pre-treatment step, optimizing the separation of the involved plastics and improving the separation efficiency.

   OUTPUT: guidelines for the joint treatment of distinct product (or product component) categories prevalent in WEEE to limit the degree of contamination in output streams and the mixing of difficult to separate and incompatible materials have been elaborated.

3. **Trial execution**

   The technical and economic feasibility of the identified clusters solutions have been tested through demonstrator trials. The demonstrator activities managed by ERION investigated different WEEE flows (C&F, LHA and SHA).

<u>OUTPUT</u>: two main objectives have been achieved through the trial implementation:

- the possibility of adopting clusters to obtain high quality plastic from WEEE pre-treatment activities (increasing the efficiency of the subsequent treatment steps) has been verified;
- a first evaluation of economic feasibility of the clustering strategy has been performed consulting the industrial stakeholders involved in the demonstrator activities. Further evaluations are foreseen after the end of the project.

2 Description of the demonstrator

The demonstrators realized during the PolyCE project intended to obtain high quality PCR (post-consumer recycled) WEEE plastics. Specifically, the target of this research is to achieve output plastic from WEEE pre-treatment step that can be easily and profitably recycled. 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, is additionally tested (the plastic leaving the plants continues its journey until it is recycled, mixed with additives and reintroduced into original equipment manufacturer moulds for the manufacture of new equipment components, thus closing the production-use-reuse cycle).

During the demonstrator, in a real industrial environment, WEEE is collected and classified to optimize the subsequent treatment operations, which are implemented in specialized WEEE treatment plants. The WEEE pre-treatment activities are performed using currently adopted technologies and mainly implementing traditional treatment steps. PolyCE demonstrators aim to test the effectiveness of the following innovation:

- **at the waste collection level** - organization of the collection in clusters to increase the efficiency of the subsequent treatment steps, avoiding, for example, contamination owing to the presence of other materials (e.g., glass, rubber. . .);
- **at the WEEE treatment level** - trial of new treatment procedures (e.g., manual dismantling additional steps) to reduce complexity owing to plastics mix and to implement the treatment of a batch of products collected according to certain clusters;
- **at the plastic recycling level** - testing if processing clustered material facilitates the separation of mixed plastics.

The collection and pre-treatment operations of CFAs, LHAs and SHAs have been selected as case studies. The plastic flakes obtained through demonstrator activities are sent firstly to academic experts such as KU Leuven, to be characterized, and then to industrial partners such as MGG to produce plastic granulates. The final compound is tested by UL, a laboratory that identifies specific compound properties and compares them with current compounds performances. Finally, the obtained pellets have been used by OEMs such as Whirlpool in new components moulds (this last activity is outside the scope of Task 7.1 and it has been performed within Task 7.7; more details are available in deliverable 7.6. Whirlpool Large domestic Appliances demonstrator).

An overview of the practical activities of the demonstrator is shortly provided in the graph below (fig. 1).

Each step of the demonstrator implementation is described in detail in the following sections.

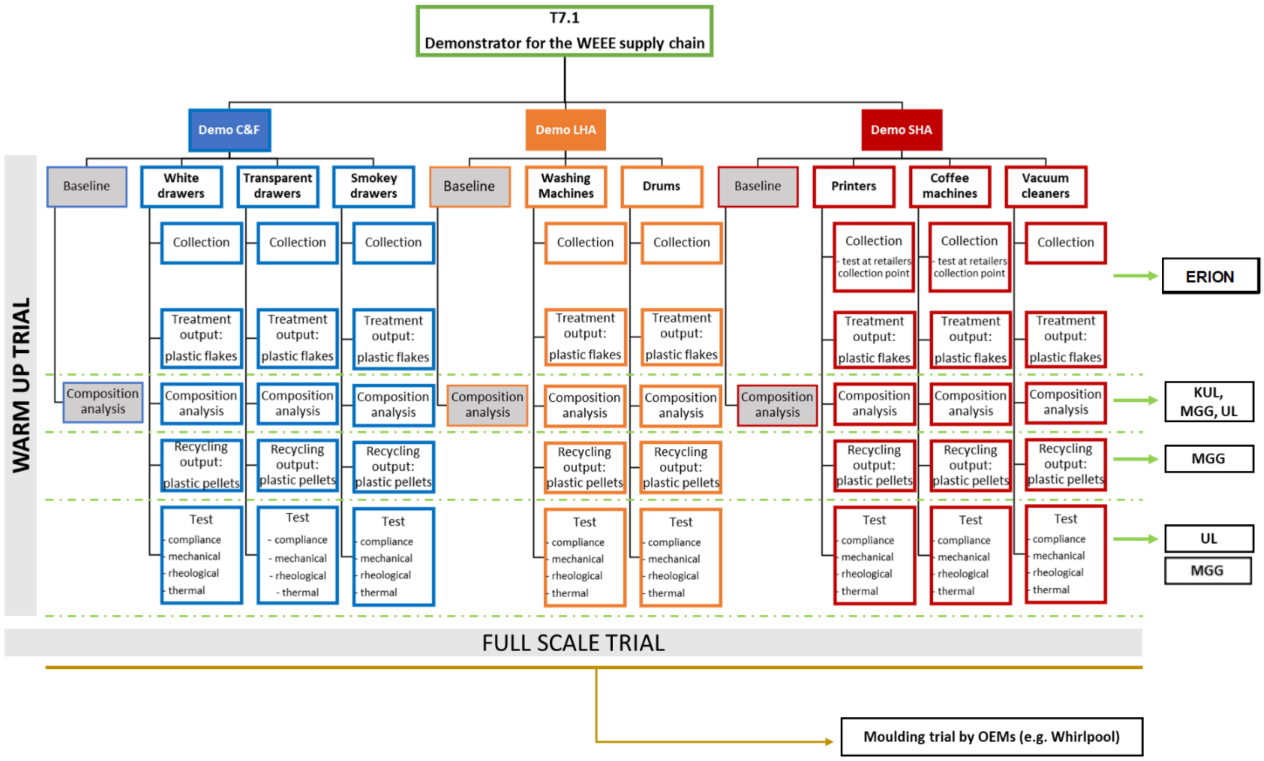

Figure 1. Demonstrator for the WEEE supply chain

The activities of the demonstrators have been planned and organized according to the results of each step of the trial. For this reason, some activities reported in the figure above have not been implemented (e.g., UL tests on white/transparent/smokey drawers).

All the activities performed during the demonstrator are described in detail in the following sections.

2.1 Demonstrators clusters

Different clusters have been tested through the demonstrator activities. As mentioned, the clusters have been selected considering the guidelines provided by the Task 3.2. However, also some additional aspects have been taken into account:

- **C&F clusters**

  During the demonstrators, **fridges' drawers** have been considered as a cluster; namely, fridges' drawers have been removed from the fridges waste flow (currently, after the depollution steps and the removal of the glass parts, fridges are entirely shredded) and treated separately. The strategy defined foresees the manual sorting of fridge drawers. Considering that in the current C&F waste flow it is possible to find drawers of different colours (and that the colour is a relevant aspect for the manufactures when it comes to select a material for a specific application), 3 drawers' sub-clusters have been defined: **white** drawer cluster, **transparent** drawers cluster, **smokey** drawers cluster.

Drawers have been considered suitable components for a cluster taking into account the following aspects:

- they are easy to **manually dismantle,** and WEEE pre-treatment operators need to handle fridges one by one during the depollution activities;
- they are present in significant amount in current C&F WEEE flow: from a sampling campaign performed in a WEEE pre-treatment plant by ERION it results that each old fridge contains on average ***1.5 kg of plastic drawers/balconies*****;**
- they give the opportunity to investigate the feasibility to produce/obtain food grade post-consumer recycled plastics from the treatment of refrigerators (drawers are already produced using virgin food grade plastic). The drawers cluster represents a case study to work towards a technical dossier for the application at EFSA (European Food Safety Authority) to achieve recycled polystyrene with food contact quality.

TARGET POLYMER	Possible final application
High quality PS	New fridge liners/door liners s/door liners (as described in deliverable 7.6 - Whirlpool Large domestic Appliances demonstrator)

- **LHA clusters**

The WEEE category LHA includes waste flow such as: dishwasher, kitchens, washing machines, dryers, heating and ventilation devices and microwaves. These products are currently all treated together in a WEEE pre-treatment facility

The LHA demonstrator has been designed and implemented covering the treatment of a cluster consisting of **washing machine** (pre-sorting and separate treatment of a specific product) and **drums** (separate treatment of a specific component which need to be manually disassembled).

Washing machines have been considered suitable components for a cluster taking into account the following aspects:

- they represent almost 72% (by weight) of LHA current waste flow;
- they contain on average 13% of plastic: 60.5% is PP;17.0% is ABS; 2.7% is PS (detailed information is available in *Deliverable 3.1 Quantification of material flows along the entire chain*).

TARGET POLYMER	Possible final application
High quality PP	New washing machine drum (as described in deliverable 7.6 - Whirlpool Large domestic Appliances demonstrator)

- **<u>SHA clusters</u>**

During the demo on SHA, specific products currently treated together with other small household appliances, have been treated separately, specifically: **printers**, **coffee machines** (professional coffee machines and domestic coffee machines) and **vacuum cleaners**.

The selected SHA clusters have been defined also taking the results of three sampling campaigns performed by ERION aiming to better understand the composition of current SHA flow in terms of presence of products. As shown in the table below (table 1), currently printers, coffee machines and vacuum cleaners are the most relevant products in terms of weight.

Table 1. Presence in current SHA flow (% by weight) of different products families

Products*	Sampling 1	Sampling 2	Sampling 3
	Presence in current SHA flow (% by weight)		
Printers – multifunction	12.1%	9.2%	5.2%
Printers – only	1.6%	15.5%	3.0%
CD/DVD/VHS readers	3.7%	1.3%	4.9%
Vacuum cleaners – with wheels	3.5%	3.7%	3.2%
Coffee machines	3.6%	4.4%	3.1%
Vacuum cleaners – electric broom	0.8%	3.2%	3.0%
TOT SHA weight	*733 kg*	*685 kg*	*709 kg*
**the main products identified during the sampling activity have been reported. The other SHA products that were below 3% are not reported in the table.*			

This aspect can be considerably beneficial for the clustering strategy implementation, considering that:

- it is easier to find the selected products in the SHA waste flow;
- it is easier to reach the number of products that allow to treat the cluster as a batch.

TARGET POLYMER	Possible final application
PS, ABS, PP, PC-ABS	New small EEE parts/components; final application needs to be assessed with manufacturers/designers taking into account the specific technical/esthetical requirements of the each specific EEE products

2.1.1 Clusters at retailer’s collection points

The effectiveness and feasibility of the cluster strategy have been also tested involving an Italian EEE retailer. Thus, the cluster collection trial targeting printers and coffee machines has been launched in a collection point managed by the retailer. All the e-waste collected in the retailer collection point have then been transferred through authorized logistic operators to EoL treatment operators, involved in the trial.

This approach is in line with the feedback received through the stakeholder’s consultation performed in Task 3.5 (*Re-design value and supply chain for maximum effect)*. In fact, stakeholders consider particularly relevant the recommendations elaborated by PolyCE and that are 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 consultation showed that cluster activities are often difficult to implement at municipal collection points level (for several reasons: additional space and authorization needed, training of the personnel and communication toward citizens required) as well as at WEEE pre-treatment facilities (for several reasons: additional trained personnel and storage space required, products arriving in bad condition and highly mixed from the municipal collection points, difficulty to identify a standardized process, slowdown of the production); while retailers in general have better sorted WEEE streams and have less contamination than Municipal sites. However, space can be limited also at the retailers shops; therefore the trial has been performed at the retailer collection point.

The figure below shows an overview of the cluster trial implemented at the retailer collection point (fig.2).

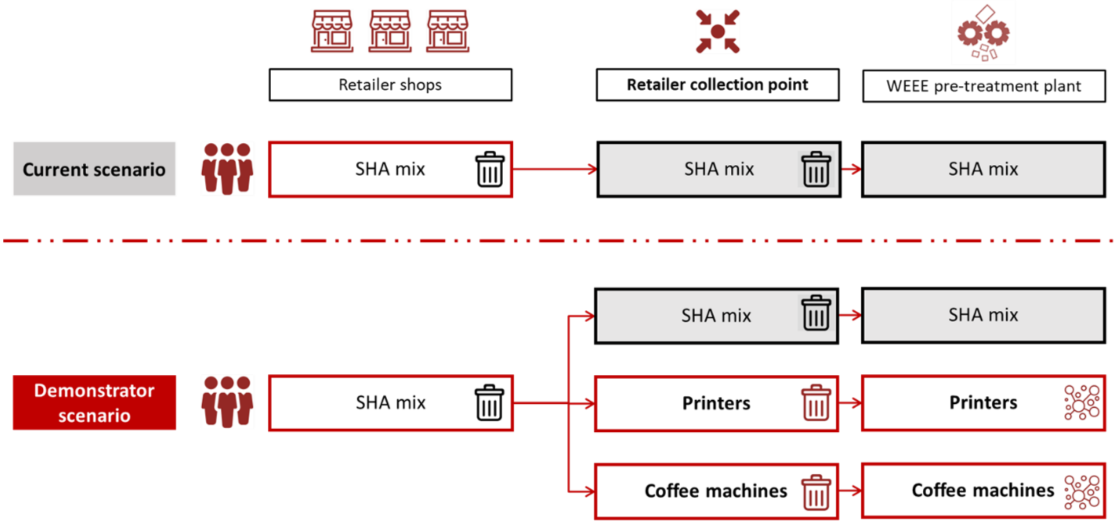

Figure 2. Clusters at the retailers collection point

During the demonstrator, from 31/07/2019 to 23/12/2019, two additional bins, one from for printers and one for coffee machines collection, have been placed at the MediaWorld collection point resulting in a collection of 2.7 tonnes of waste (2.2 tonnes of printers and more than 400 kg of coffee machines). There, an operator was in charge of clustering the products arriving from the retailer shops. In each retailer shop, as the current scenario, only one bin has been placed and citizens had the possibility to dispose of their SHA (mixed SHA).

2.2 Demonstrator steps

For each cluster, different activities have been implemented by different project partners as well as by external partners.

1. **<u>Collection and treatment</u>**

ERION, Task 7.1 leader and coordinator of all the demonstrator steps, was directly responsible for the collection (collection of the proper number of products for each cluster to perform the trial) and pre-treatment activities (until the production of plastic flakes).

To ensure the achievement of the project's goals, ERION put its effort to **engage all the suitable industrial partners to perform the trial**, taking advantage of its large Italian business network. The companies selected as project subcontractors have well-established relationships with ERION, they share with ERION the focus on environmental preservation, and they have a wealth of experience in their respective fields of expertise.

To identify the most suitable supplier able to properly perform the logistic and treatment services, ERION implemented a selection procedure involving several candidates. The adopted selection procedure is in line with ERION's internal procedure referring to external suppliers' selection for subcontractors' activities and other direct costs within funded project activities.

Additionally, it is specified that all the **legislative requirements** have been fulfilled during the demonstrator's implementation. Specifically, according to the Italian legislation (D.Lgs. n. 152/2006), for each of WEEE transports performed within the trial correspondent document called FIR (Formulario Identificativo dei Rifiuti) was required.

The FIR contained the following information:

- site where the WEEE was collected;
- data of WEEE collection;
- site where the WEEE was transported to;
- data of WEEE delivery;
- transport operator details;
- weight of the collected/transported WEEE;
- characterization of the waste.

As regards the material (plastic flakes) transportation outside Italy (e.g. to MGG treatment plant in Austria), the Annex VII of Regulation EC 1013/2006 (for green listed waste) has been compiled. The Annex VII document is intended to accompany a shipment of waste at all time from the moment the shipment starts in the country of dispatch to its arrival at a recovery facility or laboratory in another country. The Annex VII contains details regarding the following aspects: person who arranges the shipment, consignee, actual quantity, carrier, waste generator, recovery operation, description of the waste, waste identification code, countries concerned (export, transit, import), date of the shipment delivery.

Moreover, at the end of the pre-treatment steps, ERION was in charge of collecting **representative samples** of output plastic flakes to be sent to laboratory analysis (at KUL MGG and UL facilities). Therefore, within all the demonstrator activities plastic samples have been taken at the end of the treatment line from the output plastic flow at regular intervals (e.g. every 5/10 minutes), plastic samples have been then selected applying the coning and quartering methods. The selected samples have been shipped together with the metadata report, as explained in *Deliverable 4.3: Development of standard and systematic testing procedures for the different types of PCR to determine the PCR grade and to control quality consistency across the material value chain*.

Finally, during the demonstrator, ERION started to implement the ***checklist*** reported in *Deliverable 3.5: Re-design value and supply chain for maximum effect.* The checklist 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). The first results of the checklist implementation are reported in *Deliverable 3.2: Product clustering for improved collection, sorting and reprocessing and optimized recycling economics, high purity PCR plastics streams and uptake*.

2. Analysis

As mentioned above, plastic flakes samples from clusters pre-treatment activities have been shipped to KUL, MGG and UL for analysis. Each project partner performed a different set of analysis on the plastic flakes (tab.2).

Table 2. Analysis on plastic flakes

	Size & Shape	Colour	Composition	Compliance
KUL	X	X	X	
MGG			X	
UL				X*

*UL performed the legal compliance tests also on the plastic pellets.

The composition analysis performed by KUL and MGG are performed using Fourier Transform Infra-Red (**FTIR**) spectroscopy measures. This kind of analysis is particularly important to verify the effectiveness of the cluster strategy in terms of achieved output plastic quality. For this reason, the composition analysis is performed by KUL and MGG (moreover it is also in line with the internal MGG procedure of analysing each batch of material that needs to be processed in its facility).

The objective and methodology to perform the **Size&Shape and the Colour** analysis are detailed explained in *Deliverable 4.3: Development of standard and systematic testing procedures for the different types of PCR to determine the PCR grade and to control quality consistency across the material value chain*.

The **compliance test** performed by UL are listed below:

- Regulation (EC) n. 1907/2006 (REACH), Annex XVII, Point 50.5 (Aromatic Polycyclic Hydrocarbons);
- Regulation (EC) n. 1907/2006 (REACH), Annex XVII, Point 62 (Mercury compounds);
- Regulation (EC) n. 1907/2006 (REACH), Annex XVII, Point 63 (Lead);
- Regulation (EC) n. 1907/2006 (REACH), Annex XVII, Point 23.1 (Cadmium and its compounds);

- Regulation (EC) n. 1907/2006 (REACH), Annex XVII, Point 20 (Organostannic compounds);
- Regulation EC n. 1907/2006, article 33: determination of SVHC within the components of the sample received;
- Directive 2011/65/EU on the restriction of the use of certain hazardous substances in electrical and electronic equipment - Determination of level of ten regulated substances by the directive (RoHS).

The analysis performed by UL for the determination of Levels of ten substances regulated by European Directive 2011/65/EU on the restriction of the use of certain hazardous substances in electrical and electronic equipment are listed below:

- Lead Content;
- Cadmium Content;
- Mercury Content;
- Hexavalent Chromium Content;
- Polybrominated biphenyls (PBB) and Polybrominated diphenyl ethers (PBDE);
- Phthalates content (DBP,DiBP, BBP and DEHP).

The procedures adopted to perform the analysis mentioned above are listed below:

- REACH: IEC 623621: GCMS, XRF;
- RoHS: IEC 623621: GCMS, XRF;
- Bromine: CENELEC EN50625.

3. Recycling

The recycling activities have been performed at the MGG Polymers facility. After the analysis, the input plastic flakes have been processed and plastic granulates have been obtained. Plastic granulates samples, for each cluster, have been sent for further analysis to UL (laboratories in Krefeld, Germany).

It needs to be highlighted that for the demonstrator activities, MGG produced the plastic pellets using its small-scale laboratory compounding equipment; this is due to the fact that traditional compounding line require a very large amount of input material to properly work.

4. Test

Following the requests elaborated by the manufacturers (as for example Whirlpool) and according to the findings reported in the Deliverable 4.3. *Report on minimum material requirements for the trails,* UL performed the following injection moulding and performance testing (the adopted analysis procedure is also specified) on the plastic granulates compounded by MGG from the plastic flakes output of the different tested clusters:

- Infra-Red (IR) spectroscopy - Inhouse method;
- Ash Content - ISO 3451-1;
- Density - ISO 1183;
- Tensile Strength - ISO 527-2;
- Flexural Strength - ISO 178;

- IZOD Impact - ASTM D256 A;
- Dynamic Mechanical Analysis - ISO 6721-7;
- Mold Shrinkage - ISO 294-4;
- HDT - ISO 75;
- Differential Scanning Calorimetry (DSC) - ISO 11357;
- Linear Expansion Coefficient (CLTE) - ISO 11359-2;
- Melt Volume Rate (MVR) - ISO 1133;
- Capillary Rheometry - ISO 11443;
- Dielectric Strength (DS) - IEC 60243;
- Volume Resistivity (VR) - IEC 62631-3-1;
- Flammability – Horizontal Burning (HB) - UL 94;
- Flammability – Vertical Burning (VB) - UL 94;
- Glow Wire Flammability Index (GWFI) - IEC 60695-2-12;
- Glow Wire Ignition Temperature (GWIT) - IEC 60695-2-13;
- Molecular Weight by Gel Permeation Chromatography (GPC) - Inhouse method.

Additionally, MGG internally performed performance testing before shipping the pellets to UL. Below the list of tests (and corresponding methods) implemented by MGG:

- Density - MGG method;
- Melt Flow Rate (220°C / 10kg) - ISO 1133;
- Tensile modulus (23°C) - ISO 527-2/1;
- Tensile strength (23°C) - ISO 527-2/50;
- Izod impact strength, unnotched (23°C) - ISO 180/U;
- Izod impact strength, notched (23°C) - ISO 180/A.

The implementation of a Migration test to explore the food grade issues regarding the fridges' drawers cluster have been also considered; however, after the evaluation of the results obtained during the first phase of the dedicated trial and the investigation of the requirements needed to obtain the food grade approval, it has been decided to not perform this test.

2.3 Demonstrator phases

To mitigate the risks associated to the design and execution of a specific trial that could be unsuccessful, the demonstrator activities have been organized in two phases:

- **warm-up trial**: a reduced amount of material has been collected and processed for each cluster;
- **full scale trial**: a large amount of material has been collected and processed for the clusters that, from the analysis of the results of the previous phase, resulted most appropriated (good performance in terms of quality output plastic). The amount of material to be collected in this phase was determined one hand by the requests of the manufacturers that need a certain quantity of recycled pellets to run the moulding trials, on the other hand by the requests of the recyclers that need a certain amount of input material to run the sorting and compounding activities using the machineries they have available.

The implementation of the two phases just described is completed. In the following sections a detailed description of the warm-up and full scale trial is presented.

Moreover, all the demonstrator activities have been preceded by the evaluation of the baseline scenario. Namely, samples from mixed plastic from the traditional WEEE pre-treatment activities (not implementing the clustering strategy) have been collected and sent to KUL and MGG for analysis. The definition of a baseline scenario is necessary to evaluate the benefits in terms of plastic quality that can be achieved implementing the cluster strategy.

Additionally, it is important to underline that along the entire duration of the demonstrator activities, all the relevant stakeholders (project partners as well as external actors) have been informed about the demonstrators progresses and intermediated results. The consultation with stakeholders allowed to establish continuous and iterative cooperation and to make timely adjustment to the planned activities if required.

2.4 Timing

Below an overview of the timing developed to perform the demonstrator activities (fig. 3).

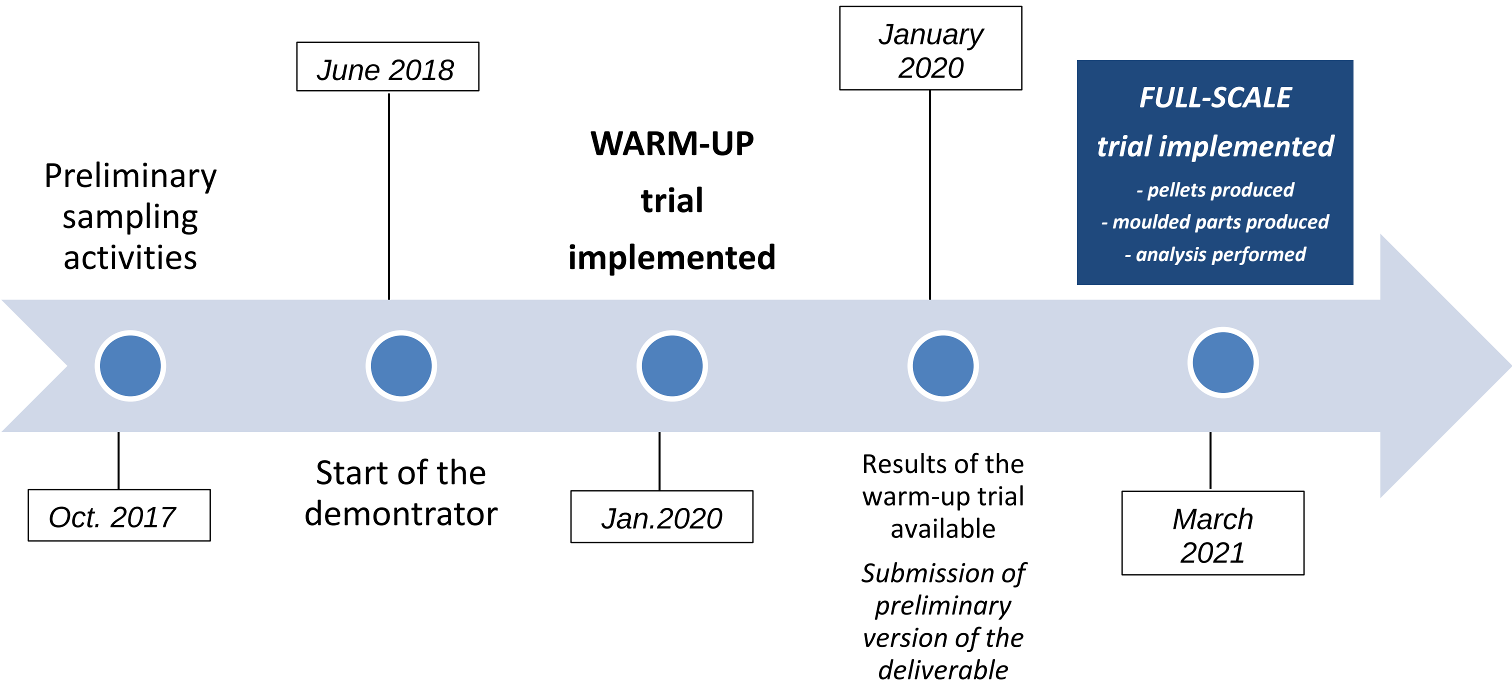

Figure 3. Demonstrator activities: timing

The present report contains information regarding the warm-up trial implementation and preliminary results; the report contains as well the operative details of the full-scale demonstrators' activities and the corresponding outcomes.

3 Cooling and Freezing Appliances

In the following sections a detailed description of the C&F cluster implementation is provided.

3.1.1 Partner

A brief description of the external partners involved in the C&F cluster trial is reported below.

STENA TECHNOWORLD: is a WEEE treatment operator which is running 3 plants in Italy for WEEE recycling. Today, STENA is one of Europe's leading recycling companies, which owns facilities in 6 European markets and businesses in 17 European countries. STENA is a member of EERA and has strong connections with downstream smelters ensuring optimal recovery of key metals. STENA plants are authorized for Cooling and Freezing Appliances treatment.

3.1.2 Implementation

WARM-UP trial

The fridges treated within the C&F demonstrators trial came from the traditional domestic WEEE collection.

The clustering activities targeting drawers (white, transparent and smoky ones, fig. 4) have been performed at WEEE pre-treatment facility. Namely, an operator of the WEEE treatment facility removed (and stored) fridges' drawers from the C&F flow arriving from municipal collection points.

Figure 4. Fridges' drawers clusters: white, transparent, smokey.

Main activities

- Additional treatment steps: the 3 drawers clusters have been shredded separately, the shredder has been cleaned before the treatment and between the treatment of one cluster and the other one.

Output plastic
The obtained plastic quantities have been:

- 450 kg of plastic from transparent drawers;
- 295 kg of plastic from smokey drawers;

- 488 kg of plastic from white drawers.

The plastic has been sent to MGG Polymers on 30/04/2019.

Analysis performed by KUL, MGG and UL.

MGG polymers produced plastic pellets.

Detailed Test not required in the warm-up phase.

FULL SCALE trial

The activities performed during the warm-up trial have been replicated during the full-scale phase implementing the following changes:

- during the full-scale trial, the clustering activities targeted **only two flows** of fridges drawers: white draws and transparent drawers.
  This approach has been elaborated considering the preliminary results reached after the warm-up phase:
  - ✓ as reported in section 6.2.1., it resulted that the presence of smokey flakes has a negative impact of the final colour of the compounded pellets;
  - ✓ often, it was difficult for the WEEE pre-treatment operators to distinguish transparent and smokey drawers; consequently, several smokey drawers ended up in the transparent drawers flow;
  - ✓ partners verified that it was not possible to obtain the food-grade approval for the PCR WEEE plastic; consequently, the colour of the output recycled pellets (that originally were intended to be used for the compounding of the *white* inner liner of a new fridge) was not a crucial aspect to be considered. In fact, it was decided to test, through the demonstrator activities, only the **technical feasibility** of the introduction of recycled materials in the plastic parts of a new fridges (without aiming at real application for which also aesthetical requirements should be met).
- during the full-scale trial, the 2 drawers clusters have been shredded jointly, assuming that the transparent colour would not affect the whiteness of the output material.

<u>Output plastic</u>: about 1,000 kg of plastics

<u>Analysis performed</u>: KUL, MGG and UL did not repeat the analysis on plastic flakes

Pellets production: MGG produced plastic pellets and shipped pellets samples to the UL laboratories

Tests: detailed tests have been performed on pellets by MGG and UL

4 Large Household Appliances Demonstrator

In the following sections a detailed description of the LHA clusters implementation is provided.

4.1 Washing machines cluster

4.1.1 Partner

A brief description of the external partners involved in the LHA cluster trial is reported below.

Seval is one of the biggest WEEE recyclers in Italy, who processed more than 32,000 tonnes in 2015.

Seveso Recuperi is an Italian WEEE pre-treatment operator that manages LHA stream.

Relight is a private company, part of TREEE Group, a leading industrial player operating in the Italian e-waste sector with a supply chain covering every segment from the home delivery of household appliances to the collection, treatment and recycling of electrical waste. TREEE is the Italian market leader with more than 90,000 tons of WEEE treated in 2017. Since its establishment, the main aim of Relight is to 'close the loop' and find solutions for the recycling of different fractions that constitute WEEE, especially for critical materials such as rare earths elements.

4.1.2 Implementation

WARM-UP trial

The washing machines treated within the washing machines demonstrators trial came from the traditional domestic WEEE collection.

The clustering activities targeting washing machines have been performed at WEEE pre-treatment facility. Namely, an operator of the WEEE treatment facility removed (and stored) washing machines from the LHA flow arriving from municipal collection points.

Figure 5. Washing machines cluster

Due to the need of validating the preliminary results of the washing machine trial, the washing machines pre-treatment activities have been performed twice, through the cooperation of different treatment plants.

Preliminary trial on 09/01/2019 performed in Seval pre-treatment plant

Input material

37 washing machines have been treated (corresponding to 2,132 kg).

Main activities

- According to traditional treatment procedures: some washing machines parts have been manually removed during the treatment, thought 3 removal steps along the whole treatment line:
    - at the beginning of the line: removal of door, drain hose and cables (fig. 6);
    - after the first smasher: removal of iron panel, drive motor, concrete block, cables and rubber seals (fig. 7);
    - at the end of the treatment line: removal of cables and pieces of glass (fig. 8).

Figure 6. Washing machines cluster treatment: first removal step

Figure 7. Washing machines cluster treatment: second removal step

 

Figure 8. Washing machines cluster treatment: third removal step

After the removal steps, washing machines are shredded (fig.9).

Figure 9. Output plastic flakes from the washing machines pre-treatment

Employees involved: 9 operators

Duration of the treatment: 2 hours

Output plastic
After the treatment, one material flow has been obtained: 183 kg of plastic.

FULL SCALE trial

Pre-treatment on 05/10/2019 performed in Seveso Recuperi and Relight pre-treatment plants

During this second pre-treatment trial, two different WEEE pre-treatment plants have been involved: Seveso Recuperi was in charge of performing the traditional treatment procedure as described above, while Relight was in charge of performing the fine shredding of the plastic obtained from the previous step (this is due to the fact that Seveso Recuperi does not have an appropriate shredder to perform this additional step, therefore Seveso Recuperi produces large plastic parts that are not suitable for further activities, fig. 10). The details referring to this additional fine shredding step are reported below.

Figure 10. Plastic fractions obtained from tjhe pre-treatment activities performed in Seveso Recuperi.

Input material
70 tons of washing machines have been treated by Seveso Recuperi, while 7 tons of plastic have been shredded by Relight.

Main activities

- Additional treatment steps: metals part have been manually removed**.**

Employees involved: 2 operators

Duration of the treatment: 4 hours (including 15 minutes of stoppage)

Output plastic
After the treatment, one material flow has been obtained: 5,263 kg of plastic flakes.

Analysis performed by KUL, MGG and UL.

MGG polymers produced approximately:

- 350 kg of PP-Talc rich pellets;
- 300 kg of PP-CaCO3 rich pellets.

UL performed the test on representative samples (about 15 kg each) of the available pellets.

4.2 Drums cluster

4.2.1 Partner

A brief description of the external partners involved in the LHA cluster trial is reported below.

Seval (description available above);

LaboRAEE: LaboRAEE is a company controlled by Amsa A2A Group (AMSA manages the integrated waste cycle, the cleaning of roads and other essential services for the environment and hygiene of Milan). The LaboRAEE initiative responds to the need to promote the socio-occupational inclusion of people in need. LaboRAEE runs a WEEE pre-treatment plant inside the Bollate prison where 5 inmates are employed. The plant occupies an area of approximately 3,000 m^2 and is authorized to treat 3,000 tons per year of WEEE. The waste treatment is carried out on two dismantling lines, the first dedicated to TVs, monitors and large appliances such as washing machines and dishwashers, the other for SHA.

4.2.2 Implementation

The washing machines treated within the drum's demonstrator trial came from the traditional domestic WEEE collection.

The clustering activities targeting drums have been manually performed by the inmates of the prison of Bollate (thanks to the collaboration with the company LaboRAEE). Inmates handled washing machines and manually removed drums. Two shipments of material have been organized from the LaboRAEE facility to Seval treatment plant:

- 1,560 kg of plastic have been shipped on 08/01/2019
- 2,380 kg of plastic have been shipped on 28/03/2019.

Pre-treatment activities have been performed on 09/01/2019 and on 04/04/2019 at Seval treatment plant. The details provided below applies to both the treatment events.

<u>Input material</u>
Totally, 3,940 kg of plastic from drums have been clustered by inmates and used like input material by Seval (fig.11).

Figure 11. Drums cluster: drums manually dismantled.

Main activities

- According to traditional treatment procedures: materials were loaded on a conveyor belt that led directly to the shredded (no other machinery for ferrous and non-ferrous metals was present). Before the shredder, an operator proceeded in the manual removal of some plastics and metal components (as rubber seals cables and plastics containing metals such as screws) (fig.12). Some smaller metallic components were not easily accessible and were not removed by the operator (fig.13).
- **Additional treatment steps**: all the material was shredded and then collected without any further treatment after the first manual treatment. However, the shredder and the conveyor belt were cleaned before the start of the process.

Employees involved: 1 operator

Duration of the treatment: 2 hours

Output plastic
After the treatment, 2 material flows have been obtained: plastic and plastic containing metals.

Figure 12. Drums cluster: parts manually removed from the plastic flow

Figure 13. Drums cluster: parts not manually removed from the plastic flow

During the treatment performed on 09/01/2019, 1 ton of plastic have been obtained, while during the treatment 04/04/2019, 2.172 kg of plastic have been obtained. Totally, about 3 tonnes of plastics have been obtained from washing machine drums cluster.

Analysis performed by KUL, MGG and UL.

MGG polymers produced approximately:

- 340 kg of PP pellets.

UL performed the test on representative samples (about 15 kg) of the available pellets.

FULL SCALE trial

As explained in detail in deliverable 7.6. *Whirlpool Large domestic Appliances demonstrator* and according to the results reported in section 6.2.2.1., the composition analysis of the plastic flakes coming from the treatment of the drums cluster did not show a significant difference in the quality/contamination. For this reason, it was decided to proceed with the full scale trial activities only for the washing machine cluster. In the case of the drums cluster, it was shown that the extra time, labour and space needed to sort parts instead of machines is not justified with an increase of material quality.

5 Small Household Appliances

In the following sections a detailed description of the SHA clusters implementation is provided.

5.1.1 Partner

A brief description of the external partners involved in the SHA cluster trial is reported below.

Relight (description available above);

Seval (description available above);

ECOLIGHT is an Italian WEEE collection scheme, that through the company ECOLIGHT Servizi provides logistic services.

5.1.2 **Printers cluster** implementation

The printers treated within the SHA demonstrator came from:

- the traditional domestic WEEE collection (municipal collection points);
- the WEEE collection performed in the retailer shop.

The clustering activities targeting printers have been performed:

- at WEEE pre-treatment plant, in the case of WEEE coming from the municipal collection points,
- at retailer's collection point, in the case of WEEE coming from the retailer shop.

Pre-treatment activities have been performed on 07/08/2019.

<u>Input material</u>
Totally, 4,575 kg of printers (fig.14). 2,208 kg of printers from the retailer collection point.

Figure 14. SHA cluster: printers, input material

Main activities

- According to traditional treatment procedures: manual removal of parts: toners (at the beginning of the treatment line), iron panels, wirings and parts that could damage the downstream machinery (after the first smasher), wiring, mother boards (after the second smasher).
- **Additional treatment steps**: the shredder and the conveyor belt were cleaned before the start of the process.

Employees involved: 4 operators

Duration of the treatment: 3.5 hours

Output plastic: the obtained plastic quantity has been: 2,616.5 kg (fig.15).

Figure 15. SHA cluster: printers, output material

Analysis performed by KUL, MGG and UL.

MGG polymers will produce plastic pellets after the evaluation and the comparison of the composition analysis results of three SHA clusters.

FULL SCALE trial

Pre-treatment on 29/06/2020 performed in Seval pre-treatment plant

During this second pre-treatment trial, Seval was in charge of performing the traditional treatment procedure as described above. In total, 14,414 kg of printers have been treated.

Output plastic: about than 6.7 tonnes of mixed plastics (fig. 16)

Analysis performed: KUL, MGG and UL did not repeat the analysis on plastic flakes

Pellets production: MGG produced plastic pellets (ABS pellets and PS pellets) and shipped pellets samples to the UL laboratories

Tests: detailed test have been performed on pellets by MGG and UL

Figure 16. SHA cluster: printers, output material

5.1.3 **Coffee Machines** cluster implementation

The coffee machines treated within the SHA demonstrator came from:

- the traditional domestic WEEE collection (municipal collection points);
- the WEEE collection performed in the retailer shop.

The clustering activities targeting printers have been performed:

- at WEEE pre-treatment plant, in the case of WEEE coming from the municipal collection points,
- at retailer's collection point, in the case of WEEE coming from the retailer shop.

Pre-treatment activities have been performed on 01/10/2019.

Input material

Totally, 6,231.5 kg of coffee machines (fig.17); 459 kg of coffee machines from the retailer collection point.

Figure 17. SHA cluster: coffee machines, input material

Main activities

- According to traditional treatment procedures: manual removal of parts: wiring and iron parts that could damage the downstream machinery.
- Additional treatment steps: the shredder and the conveyor belt were cleaned before the start of the process.

Employees involved: 4 operators

Duration of the treatment: 3 hours and 15 minutes

Output plastic: the obtained plastic quantity has been: 2,876 kg (fig.18).

Figure 18. SHA cluster: coffee machines, output material

Analysis performed by KUL and UL. Additional analysis will be performed by MGG.

MGG polymers will produce plastic pellets (PC/ABC pellets and PP pellets) after the evaluation and the comparison of the composition analysis results of three SHA clusters.

FULL SCALE trial

Pre-treatment on 29/06/2020 performed in Seval pre-treatment plant

Evaluating the results of the composition analysis performed on the plastic flakes produced during the warm-up trial (reported in section 6.1.2.3.), project partners decided to consider this first coffee machine cluster as a cluster consisting mainly of ***professional*** *coffee machines*. This is due to the fact that a considerable amount of PC/ABS was found in the plastic mix. The large presence of PC/ABS (which is an expensive polymer) in coffee machines was unexpected. Therefore, it can be assumed that professional coffee machines (more expensive products that can contain more expensive material) were largely present in the treated coffee machine batch.

During this full-scale trial, Seval was in charge of performing the traditional treatment procedure as described above. In this case, specific attention was devoted to treating a batch consisting only of ***domestic*** coffee machines. Totally, 12,890 kg of domestic coffee machines have been treated (fig. 19).

Figure 19. SHA cluster: coffee machines, input material

Output plastic: about 4 tonnes of plastics

Analysis performed: KUL and MGG repeated the composition analysis on plastic flakes

Pellets production: MGG produced plastic pellets (ABS pellets and PP pellets) and shipped pellets samples to the UL laboratories

Tests: detailed tests have been performed on pellets by MGG and UL

5.1.4 **Vacuum cleaners** cluster implementation

The vacuum cleaners treated within the SHA demonstrator came from the traditional domestic WEEE collection (municipal collection points).

The clustering activities targeting printers have been performed at the WEEE pre-treatment plant.

Pre-treatment activities have been performed on 06/12/2019.

Input material
Totally, 5,280 kg of vacuum cleaners (fig.20).

Figure 20. SHA cluster: vacuum cleaners, input materials

Main activities

- According to traditional treatment procedures: manual removal of parts: electrical motors and coils, cables and vacuum cleaners' bags.
- Additional treatment steps: the shredder and the conveyor belt were cleaned before the start of the process.

Employees involved: 4 operators

Duration of the treatment: 3 hours

Output plastic: the obtained plastic quantity has been: 1,878 kg (fig.19).

Figure 21. SHA cluster: vacuum cleaners, output material.

Analysis needs to be performed by KUL, MGG and UL.

MGG polymers will produce plastic pellets (PS pellets and ABS pellets) after the evaluation and the comparison of the composition analysis results of three SHA clusters.

FULL SCALE trial

The quantity of material obtained through the implementation of the warm-up trial was enough to perform the recycling activities at MGG polymers. For this reason, the full-scale trial was not implemented for the vacuum cleaners cluster.

6 Results

This section is dedicated to the presentation of the results achieved through the implementation of the warm-up phase of the trial (and the results of the composition analysis for the full-scale trial concerning the domestic coffee machines). These results have been carefully considered together with the project partners and stakeholders to design the full-scale demonstrators' activities.

6.1 Analysis on plastic flakes

In the following sections the results of the compliance analysis performed by UL and the results of the analysis regarding plastic flakes composition performed by KUL and MGG are summarized.

The detailed results of Size&Shape and the Colour analysis carried out by UL are reported in Annex 1 (results regarding printers and vacuum cleaners flakes are not included in the Annex 1 report).

6.1.1 Compliance

The results of the compliance analysis listed in section 2.2 (*2. Analysis*) are summarized in the table below (tab.3).

Table 3. Results of the compliance analysis performed by UL

		Regulation (EC) n. 1907/2006 (REACH)[1]	Directive 2011/65/EU							SVHC
			Lead	Cadmium	Mercury	Hexavalent Chromium	PBB	PBDE	DBP, DiBP, BBP and DEHP	
Drawers	White	✓	✓	✓	✓	✓	✓	✓	✓	✓
Drawers	Transparent	✓	✓	✓	✓	✓	✓	✓	✓	✓
Drawers	Smoky	✓	✓	✓	✓	✓	✓	✓	✓	✓
LHA	Washing machines	× (23.1)	✓	✓	✓	✓	✓	✓	×	×
LHA	Drums	✓	✓	✓	✓	✓	✓	✓	✓	*
SH	Printers	✓	✓	✓	✓	✓	✓	✓	✓	*

[1] Annex XVII, Points 50.5, 62, 63, 23.1 and 20

	Coffee machines - *professional*	✓	✓	✓	✓	✓	✓	✓	✓	*
	Vacuum cleaners	× (50.5, 23.1, 33)	✓	✓	✓	✓	✓	✓	✓	×

**Based on the results obtained, we found boron in concentrations equal to 0,1%. From the analysis performed it is not possible to determine if the presence of boron derives, or not, from one or more SVHC compounds of the substance.*

Based on the results of the sample, the tested plastic flakes from the washing machine cluster do not comply with the requirements indicated by European Directive 2011/65/EU on the restriction of the use of certain hazardous substances in electrical and electronic equipment and following amendments. Based on the analysis performed there is evidence of the presence of SVHC (substances of very high concern, as published on July 16th, 2019) in concentration above the 0.1% by weight (substance found: Bis (2-ethyl(hexyl)phthalate) – DEHP). Specifically, samples cases of non-compliance refer to phthalates content (DBP, DiBP, BBP and DEHP) of 1,160 ppm (allowed threshold 1,000 ppm); Bis (2-ethyl(hexyl)phthalate) content (DEHP) of 1,100 ppm (allowed threshold 1000 ppm); Cadmium of 500 ppm (allowed threshold 100 ppm).

However, no boron was detected (as it was the case for washing machine drums sample) and no restricted flame retardants were measured.

In this regard, it should be highlighted that the sample size (20 flakes from 5 kg sample have been tested, and one flake out of 20 resulted not compliant) analysed is not fully representative to the several tones of batch that will be processed at the end of the full trial implementation. Therefore, it is necessary to consider that single flake not compliant and does not necessarily reflect the compliance of a final recycled plastic (due to dilution)

The results have been considered as a first screening for indications of non-compliance that should help us get a better insight on the samples and allow MGG and WEEE pre-processing to take appropriate processing actions.

6.1.2 Composition

Below the results of the composition analysis performed by MGG and KUL are reported. The results differ to each other due to the fact that MGG and KUL adopted different analysis methodologies.

6.1.2.1 C&F clusters

Table 4. Composition of the plastic flakes from C&F clusters

	C&F clusters						Baseline*	
	White drawers		Transparent drawers		Smoky drawers		KUL	MGG
	KUL	MGG	KUL	MGG	KUL	MGG		
PP filled		0	0	0	0	0		
PP talc filled	8.1							
PP CaCO3 filled	8.1						2.6	
40% filled PP								
20% filled PP								2.01
10 % filled PP								
SAN			5.1	8.14		2.56		
POM								0.34
PS	17.3	78.97	89.3	83.82	97.7	94.62	17.0	
HIPS	64.6		1.1		1.1		48.4	67.39
ABS		2.12		1.78		1.26	23.5	4.80
PP		15.48				1.11	2.6	3.05
PC/ABS							3.9	
PE							1.3	
PVC		0.23					0.1	9.78
PC			4.5	4.84				3.32
PBT								2.02
Fines		0.56		0.14		0.18		
Other plastics	1.2	2.22		1.27	1.1	0.25		7.29
Other material	0.8	0.42		0.01	0.2	0.03		7.29
Metals		0.33					0.4	
Rubber							0.1	
Cables/PVC								
Glass. concrete. ceramic							0.1	
Wood							0.1	
Foam	0.1	0.09		0.01		0.03		
Others	0.7				0.2			
Plastic	99.3	99.58	100	99.99	99.9	99.98	99.4	
TOT	100.1	100	100	100	100.1	100.01	100.01	100

**from composition analysis*

Figures in table 4 show that the polymeric distributions of drawers are more homogenous than the plastics of refrigerators when treated as a whole. Specifically, looking at the target polymer for this cluster, it results that:

- PS from normal C&F treatment accounts (combining the PS and HIPS values) for less than 70% of materials found in the analysed samples;

- PS from drawers clusters accounts (combining the PS and HIPS values), on average, almost for 90% of the materials found in the analysed samples.

The PS and HIPS values are considered together because further investigation needs to be performed to understand the sensitivity of the analysis approach adopted by KUL and MGG.

From the analysis performed by KUL, it resulted also a significant difference between the compositions of white cabinets (predominantly HIPS) and transparent cabinets (predominantly PS).

Additional discussions need to be dedicated to the impurities issue. All samples of fridge drawers did contain minor contents of impurities of other plastics; further impurities of dirt and films might come from the contamination of the drawers in the end-of-life fridges or possible contamination due to transportation and storage in not cleaned containers.

Considering the target of food contact material from drawers cluster, a strategy on how to reduce these impurities has been discussed and the possible implementation of a washing step to remove impurities from the previous life of the drawers and that avoid contamination should have been considered. However, these activities have not been implemented during the further steps of the demonstrator due to the fact that after the investigation of the requirements needed to obtain the food grade certification, project partners realized that it was not possible to obtain EFSA approval from PCR WEEE plastic (additional details are available in deliverable 7.6. *Whirlpool Large domestic Appliances demonstrator*).

6.1.2.2 LHA clusters

Table 5. Composition of the plastic flakes from LHA clusters

	LHA cluster				Baseline
	Washing machines		Drums		*LHA*
	KUL	*MGG*	*KUL*	*MGG*	*composition**
PP filled	*75.8*	94.77	98.6	94.07	56.22
PP CaCO3 filled	75.8		70.1		
PP talc filled			12.1		
40% filled PP		48.76		48.4	
20% filled PP		28.3		28.09	
10 % filled PP		17.71		17.58	
PP glassfibre			16.4		
PP unfilled				0.01	
PE unfilled				3.26	
POM		0.27		0.27	
ABS	12.4		1.1		14.89
PP	5.5				
PE		3.28			0.91
PVC	0.6	0.07		0.08	3.52
PS					2.80
PA					0.21
PC					0.94
Other plastics	2.9	1.6		1.58	20.16
Other material	3.7	0	0.3	0.74	
Metals	1.8			0.44	

Rubber	0.7			0.1	
Cables/PVC					
Glass. concrete. ceramic	0.6		0.1	0.11	
Wood	0.1		0.1		
Foam			0.1	0.09	
Fines					
Others	0.5				
Plastic	97.2	99.99	99.7	99.27	
TOT	100.9	99.99	100	100.01	100

**from the results of Deliverable 3.1 Quantification of material flows along the entire chain*

Similarly to the previous one, also the LHA clusters demonstrator shows that the PolyCE strategy leads to a significantly increased purity of plastics. Specifically, looking at the target polymer for this cluster, it results that:

- PP from traditional LHA treatment accounts for about 60% of materials found in the analysed samples;
- PP from LHA clusters accounts (combining the PP filled and PP unfilled values), on average, almost for 95% of the materials found in the analysed samples.

Moreover, the analysis of the material composition showed that washing machines and drums clusters leads to a similar purity of plastics. Therefore, these preliminary results of the warm-up trial suggest that the manual dismantling of the washing machine drums, that is extremely costly and time consuming in terms of required manual labour, is not worth. Consequently, the full-scale trial has been implemented only for the washing machine cluster.

6.1.2.3 SHA clusters

Table 6. Composition of the plastic flakes from SHA clusters

	SHA clusters								
	Printers		Coffee machines *- professional -*		Coffee machines *- domestic -*		Vacuum cleaners		Baseline*
	KUL	MGG	KUL	MGG	KUL	MGG	KUL	MGG	
PP filled		0.4				10.9		2.8	14.55
PP talc filled					3.4				
PP CaCO3 filled									
40% filled PP									
20% filled PP									
10 % filled PP									
PP unfilled		0.2	17.4	5.1	7.9	3.9	25.86	10.4	
PET	7.2								
PA	2.4		3.8		2.2		1.65		0.48
POM									
PS		44.9		2.8	19.2	1.1	42.43	2.1	15.91
PC	3.6		7.4				1.5		4.17
HIPS	4.8		1.3		1.1		0.46		
ABS	18.1	15.4	16.1	4.1	38.5	39.2	5.79	40.7	35.62
PC/ABS	41.1	3.6	28.6	46.9	4.0	4.2		2.4	

ABS/PMMA			2.5		2.2				
PE							1.65		1.00
PC/ABS BR FR									
ABS BR FR									
Other plastics	6.0	27.5	1.3	30.2	14.1	30.7	6.32	18.4	27.91
Other material	16.5	8.0	21.7	10.9	7.4	10.0	14.07	23	0.36
Metals	6.9	0.1	13.5	1.8	1.8	1.5	1.3	1.7	
Rubber	0.3	1.5	1.3	1.2	1.9	6.2	6.16	7.6	
Cables/PVC	1.8		2.8		1.9		2.55		0.36
Glass, concrete. ceramic	2.2		1.3	1.3	0.2			0.4	
Wood	0.1		0.3				0.04		
Foam	0.2								
Fines	4.6	0.2	0.2		0.3	0.5	0.22	2.7	
Others	0.7	6.2	2.3	6.6	1.2	1.8	3.8	10.6	
Plastic	83.2	92.0	78.4	89.1	94.5	90	85.66	77	
TOT	99.7	100.0	100.1	100.0	101.9	100.0	99.73	100.0	100

**from the results of Deliverable 3.1 Quantification of material flows along the entire chain*

The composition of each of the tested SHA products is highly complex. Particularly, the large percentages of unknown substances in vacuum cleaners and printers are still problematic. However, some predominant polymers can be identified in the plastic mix:

- from *Printers* cluster: PC/ABS ≈ 40%, ABS ≈ 18% (according to KUL results); PS ≈ 45% (according to MGG results)
- from *Coffee machines professional* cluster: PC/ABS ≈ 28% - 47%; ABS ≈ 16% (according to KUL results); PP unfilled ≈ 17% (according to KUL results);
- from *Coffee machines domestic* cluster: ABS ≈ 39%;
- from *Vacuum cleaner* cluster: PS ≈ 42% (according to KUL results); ABS ≈ 40%; (according to MGG results).

Consulting the PolyCE partners regarding the figures reported in table 6, some specific issues have emerged. Namely:

- by the analysis, an high value of PC/ABS have been detected in the plastic mix coming from the pre-treatment activities performed within the warm-up phase of the demonstrator. According to manufacturer's inputs PC/ABS is an expensive material, thus the amount of this material in *domestic* products was expected to be lower. It can be assumed that during the warm-up phase of the demonstrator, a significant amount of professional coffee machines have been treated in the coffee machines batch.
  Therefore, the decision of introducing a new cluster, namely of introducing the distinction between domestic and professional coffee machines, has been taken. Operatively, during the full-scale phase of the demonstrator, it was carefully monitored that no professional coffee machines were treated in the coffee machines batch;

- too low value of PP unfilled have been detected by the analysis. Likely PP with glass fiber has been detected as PP unfilled.

6.2 Analysis on the plastic pellets

Overall, from the different plastic flakes described above, plastic pellets for the following plastic pellets have been produced:

- **PS** from fridges;
- **CaCO3 rich PP** and **Talc rich PP** from washing machines cluster;
- **PS** and **ABS** from printers within the small household appliance cluster;
- **PP** and **ABS** from vacuum cleaner within the small household appliance cluster;
- **PP** and **ABS** from domestic coffee machines within the small household appliance cluster;
- **PP** and **PC/ABS** from professional coffee machines within the small household appliance cluster.

In the case of the small household appliance clusters, the composition analysis presented in the previous section have been taken into account to decide on which polymers to focus on during the further plastic recycling activities.

Unfortunately, were not successful with the recovery of filled PP from domestic coffee machines, an additional target polymer of the PolyCE activities, due to technical problems with density separation at MGG facilities.

UL performed the legal compliance tests also on the plastic pellets. **All the tested pellets comply with the current regulation in terms of chemical conten**t. The only exception is represented by the vacuum cleaners clusters pellets: in facts, based on the analysis performed there is evidence of the presence of SVHC (substances of very high concern, as published on January 19th, 2021) in concentration above the 0.1% by weight of the article1 under evaluation (for 15 pellets over 20 pellets testes) – substance found: 4,4'-isopropylidenediphenol (bisphenol A; BPA)).

In the following sections the most relevant results of the **injection moulding and performance testing** analysis performed by UL and MGG are summarized (although all the tests listed in section 2.2. have been performed, only the main parameters are reported in the following sections).

6.2.1 C&F clusters

Initially, a small amount of plastic flakes from the treatment of fridges drawers (smokey, white and transparent) have been compounded. From this preliminary activity, that was necessary to define the following research steps, it was possible to make a few additional comments regarding the quality achieved for PS pellets from transparent drawers cluster. The transparent PS produced opaque, smokey parts (as shown in figure 22).

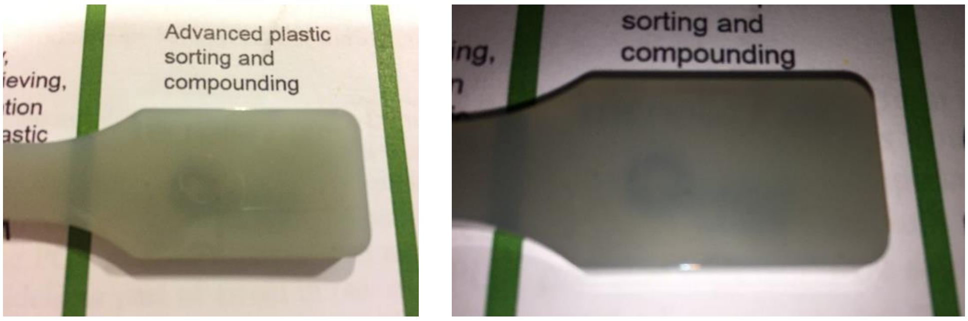

Figure 22. Advanced plastic sorting and compounding: PS from drawers cluster

Excluding crystallization effects, as crystals usually break colour and do not absorb it, the cause of smokey colour can be carbon black impurities that were present still in the sample or in the extruder. From the Colour analysis performed by KUL, it resulted that roughly 15% of the pieces within the transparent cluster were of a smoky colour. More details on the plastic flakes samples can be found in Annex II.

As explained in section 3 of this deliverable, after that partners verified that it was not possible to obtain the food-grade approval for the PCR WEEE plastic, the colour of the output recycled pellets (that originally were intended to be used for the compounding of the white inner liner of a new fridge) it stopped being a crucial aspect to be considered. In fact, it was decided to test, through the demonstrator activities, only the technical feasibility of the introduction of recycled materials in the plastic parts of a new fridges (without aiming at real application for which also aesthetical requirements should be met).

However, to avoid as much as possible impurities, during the implementation of the full-scale phase of the demonstrator, particular attention was devoted in cleaning the WEEE pre-treatment machineries before the treatment of the drawers batch (consisting of white and transparent drawers).

Figure 23. PS produced from the plastic flakes coming from the treatment of fridges drawers cluster

Table 7. Plastic pellets from C&F cluster – performance analysis results

	C&F cluster – MGG results	
	Material properties PS	**Analysis Method**
Density	1.04 g/cm^3	MGG method
Melt Flow Rate (200°C / 5kg)	7.2 g/10 min	ISO 1133
Tensile modulus (23°C)	2,000 MPa	ISO 527-2/1
Tensile strength (23°C)	35 MPa	ISO 527-2/50
Izod impact strength, unnotched (23°C)	31 kJ/m²	ISO-180/U
Izod impact strength, notched (23°C)	6 kJ/m²	ISO-180/A

	C&F clusters – UL results	
	Material properties PS	**Analysis Method**
Density	1.051 g/cm^3	ISO 1183
Melt Volume Rate (210°C)	3.22 cm^3/10 min	ISO 1133
Tensile modulus (23°C)	2,668 MPa	ISO 527-2
Tensile strength (23°C)	13.56 MPa	ISO 527-2
Izod impact strength, notched (23°C)	5.13 kJ/m²	ATSM D256A
Izod impact strength, notched (23°C)	32.75 kJ/m²	ATSM D256E

6.2.2 LHA clusters

MGG did not performed the performance analysis on LHA cluster pellets.
Additional details on the quality of the pellets obtained from the treatment of this cluster are available in deliverable 7.6.

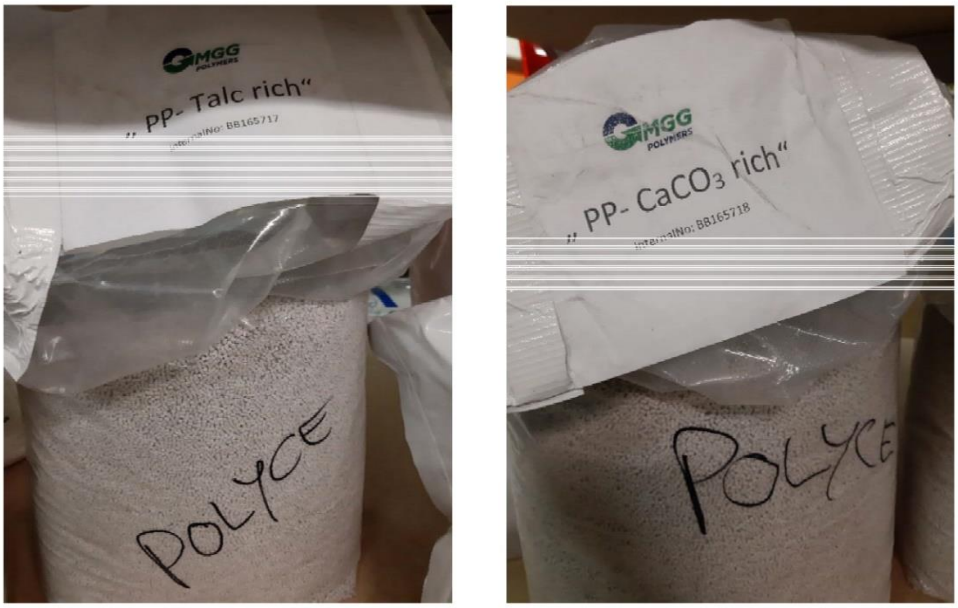

Figure 24. PP Talc-rich and PP CaCO3 rich produced from the plastic flakes coming from the treatment of washing machine cluster

Table 8. Plastic pellets from Washing Machines cluster – performance analysis results

	LHA clusters – UL results		
	Material properties		Analysis Method
	PP talc rich	PP CaCO3 rich	
Density	1.139 g/cm³	1.214 g/cm³	ISO 1183
Tensile modulus (23°C)	2,968 cm³/10 min	2.975 cm³/10 min	ISO 527-2
Tensile strength (23°C)	25.56 MPa	24.14 MPa	ISO 527-2
Izod impact strength, notched (23°C)	3.76 MPa	2.94 MPa	ATSM D256A

6.2.3 SHA clusters

Figure 26. PC/ABS produced from the plastic flakes coming from the treatment of professiona coffee machines cluster

Figure 25. ABS produced from the plastic flakes coming from the treatment of vaccum cleaners cluster

Table 9. Plastic pellets from printers cluster – performance analysis results

	SHA clusters – printers – MGG results		
	Material properties		Analysis Method
	PS	ABS	
Density	1.04 g/cm³	1.07 g/cm³	MGG method
Melt Flow Rate	7.5 g/10 min[1]	29 g/10 min[2]	ISO 1133
Tensile modulus (23°C)	2,000 MPa	2,200 MPa	ISO 527-2/1
Tensile strength (23°C)	30 MPa	43 MPa	ISO 527-2/50
Izod impact strength, unnotched (23°C)	29 kJ/m²	26 kJ/m²	ISO-180/U
Izod impact strength, notched (23°C)	11 kJ/m²	10 kJ/m²	ISO-180/A

[1]Melt Flow Rate (200°C / 5kg)
[2]Melt Flow Rate (220°C / 10kg)

	SHA clusters – printers – UL results		
	Material properties		Analysis Method
	PS	ABS	
Density	1.045 g/cm³	1.084 g/cm³	ISO 1183
Melt Volume Rate	3.08 cm³/10 min[1]	3.67 cm³/10 min[2]	ISO 1133
Tensile modulus (23°C)	2,192 MPa	2,519 MPa	ISO 527-2
Tensile strength (23°C)	28.43 MPa	43.06 MPa	ISO 527-2
Izod impact strength, notched (23°C)	9.71 kJ/m²	6.04 kJ/m²	ATSM D256A
Izod impact strength, notched (23°C)	23.47 kJ/m²	21.51 kJ/m²	ATSM D256E

Table 10. Plastic pellets from vacuum cleaners cluster – performance analysis results

	SHA clusters – vacuum cleaners – MGG results		
	Material properties		Analysis Method
	PP	ABS	
Density	0.94 g/cm³	1.05 g/cm³	MGG method
Melt Flow Rate	12 g/10 min[3]	25 g/10 min[4]	ISO 1133
Tensile modulus (23°C)	1,200 MPa	2,200 MPa	ISO 527-2/1
Tensile strength (23°C)	23 MPa	39 MPa	ISO 527-2/50
Izod impact strength, unnotched (23°C)	35 kJ/m²	26 kJ/m²	ISO-180/U
Izod impact strength, notched (23°C)	5 kJ/m²	9 kJ/m²	ISO-180/A

	SHA clusters – vacuum cleaners – UL results		
	Material properties		Analysis Method
	PP	ABS	
Density	0.945 g/cm³	1.067 g/cm³	ISO 1183
Melt Volume Rate	18.83 cm³/10 min[5]	2.40 cm³/10 min[6]	ISO 1133
Tensile modulus (23°C)	1,458 MPa	2,405 MPa	ISO 527-2
Tensile strength (23°C)	25.52 MPa	40.81 MPa	ISO 527-2
Izod impact strength, notched (23°C)	5,77 kJ/m²	6.91 kJ/m²	ATSM D256A
Izod impact strength, notched (23°C)	30.69 kJ/m²	16.01 kJ/m²	ATSM D256E

[1]Melt Flow Rate (210°C)
[2]Melt Flow Rate (220°C)
[3]Melt Flow Rate (230°C / 2.16kg)
[4]Melt Flow Rate (220°C / 10kg)
[5]Melt Volume Rate (230°C)
[6]Melt Volume Rate (220°C)

Table 11. Plastic pellets from domestic coffee machines cluster – performance analysis results

	SHA clusters – domestic coffee machines – MGG results		
	Material properties		Analysis Method
	PP	ABS	
Density	0.96 g/cm³	1.05 g/cm³	MGG method
Melt Flow Rate	11 g/10 min[1]	34 g/10 min[2]	ISO 1133
Tensile modulus (23°C)	1,700 MPa	2,400 MPa	ISO 527-2/1
Tensile strength (23°C)	28 MPa	46 MPa	ISO 527-2/50
Izod impact strength, unnotched (23°C)	33 kJ/m²	25 kJ/m²	ISO-180/U
Izod impact strength, notched (23°C)	4 kJ/m²	9 kJ/m²	ISO-180/A

	SHA clusters – domestic coffee machines – UL results		
	Material properties		Analysis Method
	PP	ABS	
Density	0.93 g/cm³	1.066 g/cm³	ISO 1183
Melt Volume Rate	17.57 cm³/10 min[3]	3.64 cm³/10 min[4]	ISO 1133
Tensile modulus (23°C)	1,575 MPa	2,561 MPa	ISO 527-2
Tensile strength (23°C)	30.91 MPa	45.78 MPa	ISO 527-2
Izod impact strength, notched (23°C)	3.79 kJ/m²	5.90 kJ/m²	ATSM D256A
Izod impact strength, notched (23°C)	28.28 kJ/m²	18.37 kJ/m²	ATSM D256E

Table 12. Plastic pellets from professional coffee machines cluster – performance analysis results

	SHA clusters – professional coffee machines – MGG results		
	Material properties		Analysis Method
	PP	PC/ABS	
Density	0.93 g/cm³	1.14 g/cm³	MGG method
Melt Flow Rate	14 g/10 min[5]	28 g/10 min[6]	ISO 1133
Tensile modulus (23°C)	1,400 MPa	2,500 MPa	ISO 527-2/1
Tensile strength (23°C)	30 MPa	48 MPa	ISO 527-2/50
Izod impact strength, unnotched (23°C)	29 kJ/m²	N.A.	ISO-180/U
Izod impact strength, notched (23°C)	3 kJ/m²	N.A.	ISO-180/A
	SHA clusters – professional coffee machines – MGG results		
	Material properties		Analysis Method
	PP	PC/ABS	
Density	0.92 g/cm³	1.201 g/cm³	ISO 1183
Melt Volume Rate (230°C)	20.84 cm³/10 min	48.5 cm³/10 min	ISO 1133
Tensile modulus (23°C)	1,624 MPa	2,773 MPa	ISO 527-2
Tensile strength (23°C)	33.78 MPa	12,40 MPa	ISO 527-2

[1]Melt Flow Rate (230°C / 2.16kg)
[2]Melt Flow Rate (220°C / 10kg)
[3]Melt Volume Rate (230°C)
[4]Melt Volume Rate (220°C)
[5]Melt Flow Rate (230°C / 2.16kg)
[6]Melt Flow Rate (240°C / 5kg)

Izod impact strength, notched (23°C)	3.30 kJ/m²	1.72 kJ/m²	ATSM D256A
Izod impact strength, notched (23°C)	25.84 kJ/m²	3.98 kJ/m²	ATSM D256E

7 Discussion

The overall conclusions of the several clusters proposed are very positive. All properties analysed are found to be aligned with the properties of virgin materials and to be suitable for industrial applications.
Consulting relevant stakeholders, such as recyclers and OEMs, regarding the performance of the demonstrator implemented in task 7.1, two main aspects can be highlighted:

- clustering strategies allow to obtain **<u>good quality</u> PCR WEEE plastics**;
  this is evident considering that:
  - the PP plastic pellets produced by MGG processing the material of the washing machines cluster have been used by Whirlpool to mould a component (the drum) of a new washing machine. This means that the PCR WEEE plastic have not been downcycled, as currently occur; while it was possible to **close the loop** of the material (more details are available in deliverable 7.6);
  - the results of the injection moulding and performance testing are in line with the performance of the material currently produced by MGG.

  Assessing the quality of the obtained materials, it is important to bear in mind that each application has different requirements in terms of aesthetical and technical performance of the used material; therefore, it is extremely important to look at the material properties not in absolute term but putting them in relationship with the manufacturers and designers' specific needs.

- clustering strategies allow increase the **<u>marketability</u> of PCR WEEE plastics**
  this is evident considering that:

  - clusters allow recyclers to provide a **quick response to market request** of specific polymers; for example, if a recycler has in its warehouse mixed plastic materials coming from the pre-treatment of the vacuum cleaners batch, he/she can easily produce ABS from that cluster when there is an high request of ABS in the market. This responsiveness of the production is not typical of the recycling sector, considering that the input material of the entire recycling process consists of WEEE flows, that are highly mixed and heterogeneous (in an unpredictable manner) along the time;
  - clusters allow recyclers to **expand their portfolio**: treating the mixed plastic coming from the different clusters, it was possible to produce the same polymer but characterized by some specific properties. For example, the ABS produced from the vacuum cleaners cluster results to have a different MFR from the ABS produced from the coffee machines cluster. Having both ABS in their portfolio, allows recyclers to respond to different market requests and to different manufacturers' needs;
  - similarly to the previous point, clusters allow recyclers to expand their portfolio due to the fact that they will deal with less mixed plastic fraction; consequently, they will have the possibility to experiment additional separation, for example sorting out *homopolymer* and *copolymer* PP.

However, considering the benefits related to the implementation of the clustering approach in terms of quality of the output materials and in terms of their marketability, it is not possible to neglect the **additional effort** (and consequently the **additional costs**) associated with the activities of the demonstrators. The cost of clustered WEEE treatment is currently higher than the cost of traditional one. In details, as extensively reported in deliverable 3.5. *Re-design value and supply chain for maximum effect*, performing the clustering steps in the WEEE pre-treatment plants requires supplementary manual labour and supplementary processing time. Therefore, to guarantee the profitability of the clustering approach (and to actually introduce the materials produced within the demonstrator on the market), further assessments should be conducted regarding the economic valorisation of the obtained PCR WEEE plastic.

Unfortunately, considerations cannot be made regarding the yield (quantity of input mixed plastic flakes Vs quantity of output pellets) of the recycling processes implemented during the demonstrator. This is due to the fact that recyclers need a certain amount of input material to run the sorting and compounding activities using the machineries they have available (input plastic flakes: about 200 tons/day); consequently, the sorting and compounding activities of the demonstrator have been performed by MGG using laboratory scale equipment, characterized by very low efficiency.

It is clear that recycling and collection are closely interlinked steps of the WEEE plastic value chain. Figures reported in PolyCE deliverable 3.1. *Quantification of material flows along the entire chain* show as the reintroduction of recycled WEEE plastics into the EEE value chain is obstructed by losses and difficulties in different steps of the studied WEEE value chain. The gap between disposed WEEE and WEEE actually collected by take-back schemes tremendously reduces the amount of available WEEE plastics that can be potentially recycled.

To evaluate the potential upscaling of the solutions proposed in the PolyCE project and specifically to scale up the benefits obtained through the demonstrator an estimation of waste plastics potentially available has been performed (source of data and approach differ to the one adopted in deliverable 3.1. mentioned above), as explained in the following paragraph. Methods are discussed in more detail in [1], deliverable 3.2 (*Product clustering for improved collection, sorting and reprocessing and optimized recycling economics, high purity PCR plastics streams and uptake*) and a forthcoming PhD Thesis by KU Leuven.

7.1 Potential upscaling of the clustering solutions

Clustering

Clustering was carried out using a k-means algorithm. The number of clusters is determined through an elbow-method with two curves indicating the recycling rates and recycling facility profits. Optima of these two objectives are determined through an optimization routine. Novel feature engineering techniques measure separation efficiencies of clusters' polymeric compositions. Thus, a cluster does not only contain products similar in composition, but also products for which the polymers are easy to separate from those of other products in the cluster. To approximate the ease of separability of materials, the densities of 584 samples were recorded. Figure 27 shows resulting density spectra for ABS and HIPS. The overlap in these spectra entails that these polymers cannot easily be separated through density-based sorting solely. Spectroscopy was also taken into consideration based on separation efficiencies reported in literature [2, 3]. Color distributions of samples were gathered through manual composition analysis and NIR's reduced ability to process dark plastics [4] is taken into consideration.

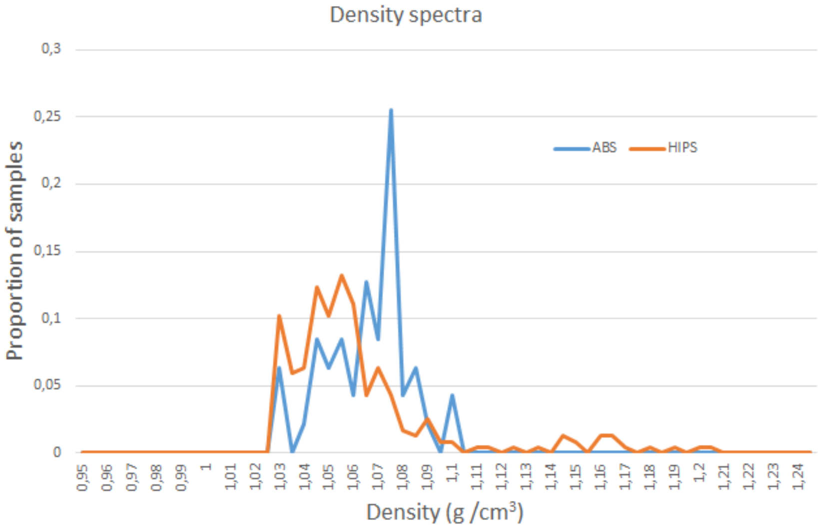

Figure 27. Density spectra of ABS and HIPS

Recycling facility modeling

To evaluate the recycling rates and recycling facility economics, a model of a material recycling facility was used. The model is based on [5-7], with novel adaptations to more realistically model density-based sorting and spectroscopy, the two most prevalent separation technologies for WEEE plastics in practice [8,9,10]. Separation efficiencies were based on literature [4, 11, 12, 13, 14, 15] and data gathered at KU Leuven, both as part of the PolyCE project and from prior projects.

Clustering the demonstrator cases

Product clustering strategies can improve recycling efficiency. One such strategy, based on the proprietary data outlined in this work package, is depicted in Figure 28. For each cluster, a target polymer is indicated. Weight percentages of the products as proportion of the collected WEEE in their category are indicated. Weight percentages of these categories in the total collected WEEE stream in the EU are also provided. Note that there is a discrepancy between WEEE collection categories according to the WEEE directive and industrial best practices. This is a result of the rarity of some categories in the directive, as well as the need to remove toxic components from certain categories, fostering separate collection. Likewise, the television and screens waste stream (±15% of the WEEE stream) is not taken into consideration in the demonstrator cases. This stream is relatively complex in composition, containing polymers rarely encountered in the other streams [16], as well as significant toxic content (mainly Cd, Pb and Br) [17-22]. Due to the need to remove toxic content, the stream is also already collected and treated in isolation.

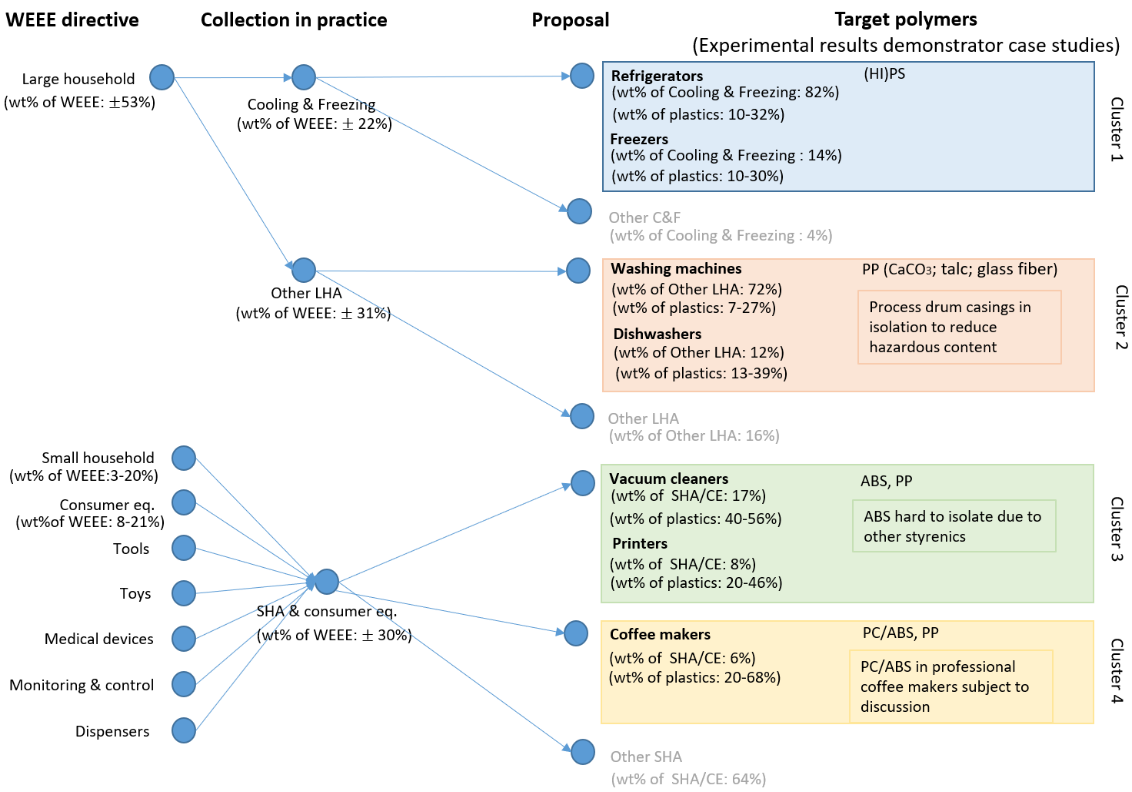

Figure 28. Clustering approach based on the collected data. Weight percentages as indicated are based on [22-34].

Discussion of demonstrators

Figure 28 indicates that the cooling and freezing and other LHA streams are fairly homogeneous in plastic composition. One or two product types make up most of these streams. The SHA stream has a more complex composition. However, the case studies indicated that the three main constituents of the SHA stream (vacuum cleaners, printers, coffee machines) have a relatively large plastic fraction. Furthermore, the analyzed samples of these products were RoHS-compliant. Literature corroborates the former finding and indicates that this property carries over to other SHA products [16, 17, 35, 36]. More research is required to assess the latter property in other SHA products, as only indications for the entire SHA stream are currently available [19, 20]. In the present study, the polymeric compositions of coffee machines and printers were not very homogeneous. For coffee machines, this is not corroborated by literature, as two independent references found that coffee machines consist almost exclusively out of PP [17, 35].

Furthermore, literature indicates that a collection of only nine products (printer, desktop PC, radio, iron, vacuum cleaner, DVD player, coffee maker, toaster, speaker) accounts for 48-75% of the total weight of the SHA stream [21-34]. This may make the stream more homogeneous than assumed. In conclusion, the SHA stream is rich in plastics. Presence of hazardous substances was negligible for all three analyzed product types. The plastic content of SHA products appears compositionally manageable. Finally, additional investments are needed to process and manage each cluster. Due to their size and weight, handling the SHA stream is much more cost-efficient than the other WEEE streams. As such, the investments needed for more SHA clusters is manageable. For these reasons, incorporating the SHA stream in clustering strategies in practice may be viable.

Potential of Informed Product Clustering in the European Union - Clustering with extended data

To upscale the experiments to a practically relevant clustering strategy, experimentally obtained data was augmented by data from literature. In particular, six distributions were estimated:

1. The total collected mass of WEEE in the EU [18];
2. The mass proportions of each of the collection categories in accordance with the WEEE directive [22];
3. The mass proportions of each of the collection categories adhered to in practice [1, 19, 21, 23, 24, 28, 37];
4. The mass proportions of specific products in each of these categories [2, 20, 35, 37, 38, 39];
5. The mass proportion of plastics in each of these products [2, 3, 19, 20, 26, 30, 35, 36, 40, 41, 42];
6. The polymeric distribution of the products (i.e.: what particular polymers are present in the plastics fraction) [2, 3, 4, 19, 20, 35, 37, 38, 39, 43].

Each study reporting findings on one of these quantities was evaluated based on *conventionality* (status as peer-reviewed; number of citations, impact factor); *age* (with more emphasis on more recent publications) and *methodology* (experiments or data aggregation? In the former case: number of samples and number of sites sampled). This resulted in an indicator of a study's reliability. Proprietary data was evaluated using this same indicator. For each quantity, a weighted average was then computed, with weights proportional to the indicator values. The clustering experiment was repeated on the obtained data set. The results indicate that a strategy with six clusters is optimal in terms of recycling facility profits as well as plastics recycling rates. This is shown in the plot in Figure 29. The optimal clustering proposal resulting is depicted in Figure 30 (see Annex I). Figure 31 (see Annex I) shows the composition of the WEEE stream at collection, culminating in the proposed clusters.

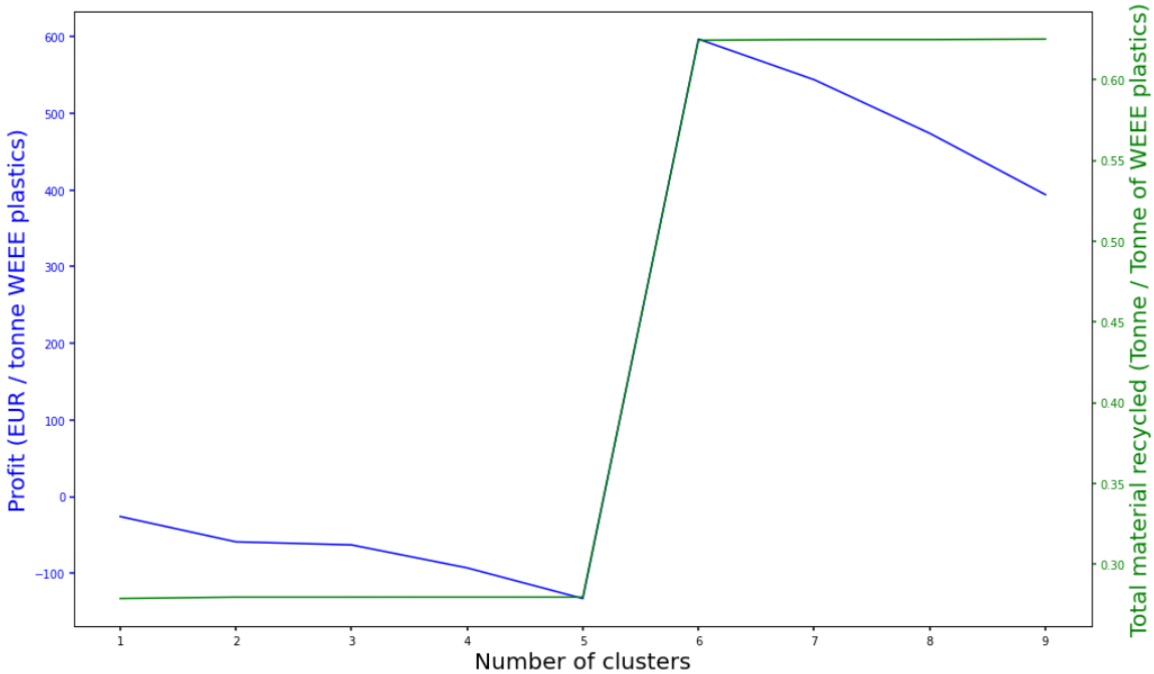

Figure 29. Profits and recycling rates per unit tonnage of recycled WEEE plastics (distributed as in the collected WEEE plastics stream in the EU) when applying optimal clustering strategies for various numbers of clusters.

Discussion of obtained clusters

Recall that the engineered features represent ease of separation through density-based methods as well as spectroscopy. The latter metric is dependent on the treated material's color. This needs to be taken into consideration when considering clustering results. As Figures 30 and 31 (both in Annex I) indicate, six clusters with the following characteristics are obtained:

- Cluster 1: This cluster is rich in light-colored (HI)PS. The (HI)PS and PP in this stream are easily extracted.
- Cluster 2: This stream is rich in both PP and ABS. A large fraction (49%) of the PP is $CaCO_3$-filled. This may be targeted separately through isolation of washing machine drum housings, analogous to cluster 2 of the demonstrator cases.
- Cluster 3: This cluster is rich in ABS and PP. In the proprietary experiments, most of the PP of the SHA stream was unfilled. The PP in this cluster is therefore expected to be mostly unfilled. Both fractions are likely easily isolated.
- Cluster 4: This cluster contains product types that are often constructed using ABS or (HI)PS. In consequence, the cluster is rich in both. The involved plastic components also often have a black color. In consequence, isolating the polymers takes significant effort in this stream.
- Cluster 5: This cluster is rich in (HI)PS, mostly dark colored. The cluster likely contains traces of bromine.
- Cluster 6: This cluster contains CRT monitors containing large quantities of bromine, as well as the collective “other SHA” stream, which is diverse in composition. Thus, it is suitable only for energy recovery.

For six obtained clusters, Figure 31 provides an overview of the annual potential tonnage that can be harvested, as well as a graphical representation of the involved polymers per cluster. The figure indicates that 849,228 tonnes of WEEE plastics befitting the clusters are collected annually. Upscaling the results from Figure 29, this equates to a potential of 526,521 tonnes (=849,228×0.62) potentially recyclable plastics. This, in turn, is roughly 16wt% of the entire collected WEEE stream.

Conclusions

1. The SHA WEEE category is complex in terms of product composition. However, a limited number of products accounts for most of the stream's total mass. Furthermore, SHA products have large plastic weight percentages and relatively homogenous polymeric compositions. This makes the stream particularly suitable for plastics recycling;
2. Various aspects of WEEE (plastics) at collection in the EU were quantified based on available literature as well as experimentally obtained data. A novel data aggregation method was introduced for doing so. This method computes weighted averages based on an indicator of source's reliability;
3. Informed product clustering can help identify promising product groupings. These can help increase WEEE plastics recycling rates;
4. The demonstrator cases gave rise to an initial promising clustering strategy;
5. A more encompassing strategy with five useful clusters was proposed based on the aggregate data;
6. By applying the clustering strategy, an estimated 526,521 tonnes of WEEE plastics can be recuperated on an annual basis in the European Union. This equates to roughly 16% of the total WEEE stream at collection. In consequence, clustering makes plastics recycling viable and can potentially contribute to increased WEEE recycling rates.

Limitations

1. Experimentally obtained results deviated from those reported in literature in key respects. In particular, the polymeric composition of the plastic fraction of coffee machines (both professional and domestic) varied widely in proprietary data. Moreover, professional coffee machines in the trials contained relatively expensive polymers such as PC/ABS blends. In the literature, the polymeric composition of coffee machines documented is a very homogenous PP stream;
2. Polymeric compositions of product components are expected to have a strong geographic dependence. Disparities in culture and application of EEE products likely have an impact on their design. Used materials can therefore vary greatly between locations. This factor was beyond the scope of the clustering experiment, as data is too scarce for multiple locations to be accurately represented.
3. Data scarcity pervades the field of WEEE(p) management. At the level of the European Union, data regarding WEEE streams at collection is currently self-reported by Member States [11]. A standardized method to systematically evaluate key quantities is required. The insight thus obtained will result in more accurate clustering strategies, possibly increasing plastics recycling rates. The known dependence of WEEE plastics compositions on time and location further stress the need for systematic monitoring. At present, scientific literature on the matter oftentimes regurgitates data from temporally and geographically unrepresentative sources.

7.2 Stakeholders feedback

As mentioned in *section 2.3*, along the entire duration of the demonstrator activities, all the relevant stakeholders (project partners as well as external actors) have been informed about the demonstrators progresses and intermediated results. In addition to this, specific consultation initiatives have been organized to gather industrial stakeholders' feedback.

In this regard, the PolyCE workshop titled "*How to Optimize Plastics Recycling to Obtain High Quality Polymers for Circular Electronics?"* held during the 19th International Electronics Recycling Congress IERC 2020 (January 21 – 24, 2020 Salzburg, Austria), has been a very valuable opportunity to present the cluster strategy, its implementation through the demonstrators activities and to collect comment and suggestion from experts within the EEE/WEEE value chain.

Workshop participants (EEE manufacturers, WEEE take back schemes, WEEE pre-treatment operators, plastic and metals recyclers from Europe as well as Canada, Japan, Rwanda and South Africa) on one hand confirmed the inputs received during the consultations implemented within T3.5 activities (shortly, claiming that ensure the feasibility of the proposed solutions, particular attention should be devoted to key aspects as avoid additional manual work, take into account space constraints and procession time variation as well as consider the quality of the input material in the WEEE pre-treatment plant); on the other hand, pointed out that, to ensure the economic sustainability of the PolyCE approach it is fundamental:

- to engage more consumers to facilitate cluster activity already in the collection phase;

- to explore technological solutions for the automatic sorting of products;
- to create synergies with the management of other types of waste, such as batteries and electronic components;
- to implement practices that ensure large volumes of WEEE to be treated;
- to create incentive mechanisms for the use of recycled plastic by producers.

8 Conclusion

Overall, the *Demonstrator for the WEEE supply chain* was able to:

- validate the viability of the clusterization methods identified and assess their potential benefits together with relevant industrial partners (producers, designer, WEEE pre-treatment operators, recyclers and take back schemes);
- provide a detailed description of the performed activities to ensure that evidence from PolyCE development and research is replicated in the European product and waste-related framework.

Specifically, the demonstrators' proved the improvements expected by redesigning the supply and value chain of WEEE post-consumer plastics, including redesign of the collection, clustering, pre-treatment and recycling of WEEE. In a real industrial environment, WEEE were collected and classified to optimize the subsequent treatment operations, implemented in specialized WEEE treatment plants. The treatment steps were performed using available technologies and new procedures.
The plastic leaving the WEEE pre-treatment plants continued its journey until it was recycled in several different polymers and successfully reintroduced into original equipment manufacturer moulds for the manufacture of new equipment components, thus closing the production-use-reuse cycle, such as in the case of the washing machine cluster.

Moreover, the findings of this deliverable highlight that WEEE collection should be promoted and the gap between WEEE generated and WEEE collected should be reduced (especially concerning Small Household Appliances). Overall, the demonstrator showed that organizing the collection in clusters (e.g., products families defined taking into account the plastic content of the products) can increase the efficiency of the subsequent treatment steps.

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Annex I

		(HI)PS			ABS			PP			PC				Other		
Category	Product	HIPS	HIPS Br	PS	ABS	ABS Br	ABSPMMA	PP	PP Talc	PP CaCO3	PC	PCABS	PCABS PFR	PCASA	Other	Cluster	Target(s)
C&F	Refrigerator	0,58833	0	0,2437	0,07464	0	0	0,03506	0,00547	0,003904	0,00037	0	0	0	0,038	1	(HI)PS
C&F	Freezer	0,4912	0	0,2469	0,04272	0	0	0,05246	0	0	0	0	0	0	0,16654	1	
LHA	Washing machine	0,02771	0	0	0,20079	0	0	0,29862	0,02471	0,398429	0,00509	0,00803	0	0	0,04701	2	PP; ABS
LHA	Dishwasher	0	0	0,0065	0,5911	0	0	0,30363	0	0	0,00683	0	0	0	0,09196	2	
LHA	Dryer	0	0	0,0446	0	0	0	0,9258	0	0	0,00854	0	0	0	0,021	2	
SHA	Vacuum cleaner	0,00273	0	0,0567	0,65783	0	0	0,18034	0,00987	0,005508	0,00306	0,00333	0	0,00208	0,0779	3	ABS; PP
SHA	Desktop PC	0,0043	0	0	0,94324	0	0	0	0	0	0	0	0	0	0,04816	3	
SHA	Radio	0,15	0	0	0,54	0	0	0,02	0	0	0	0	0	0	0,29	3	
SHA	Coffee maker	0,03006	0	0,0086	0,08929	0	0	0,68663	0,00246	0,000643	0,00461	0,11003	0	0,00244	0,06341	3	
SHA	Toaster	0	0	0,03	0,17	0	0	0,42	0	0	0,06	0	0	0	0,32	3	
SHA	Iron	0	0	0	0,09685	0	0	0,55343	0	0	0,00657	0,25769	0	0	0,08546	3	
TV/S	FPD monitor	0,21	0	0	0,58	0,018	0,031	0	0	0	0	0	0,15	0	0,011	4	ABS
SHA	DVD player	0,1	0	0	0,51	0	0	0,03	0	0	0,07	0	0	0	0,29	4	
SHA	Speaker	0,25	0	0	0,49	0	0	0,03	0	0	0,03	0	0	0	0,2	4	
SHA	Printer	0,20967	0	0,3066	0,16126	0	0	0,00187	0	0	0,01934	0,15503	0	0	0,14262	4	
TV/S	CRT TV	0,74	0,052	0	0,049	0,018	0	0,029	0	0	0	0,013	0,016	0	0,083	5	HIPS; misc.
TV/S	FPD TV	0,37	0,13	0	0,053	0,034	0,071	0	0	0	0	0,007	0,24	0	0,095	5	
TV/S	CRT monitor	0,033	0,0082	0	0,063	0,55	0	0	0	0	0	0,15	0,16	0	0,0358	6	NA
SHA	Other SHA	0,05	0	0	0,22	0	0	0,31	0	0	0,06	0	0	0	0,35	6	

Figure 30. Heatmap of polymeric compositions, stratified by cluster. Numbers indicate weight percentage of total plastic content.

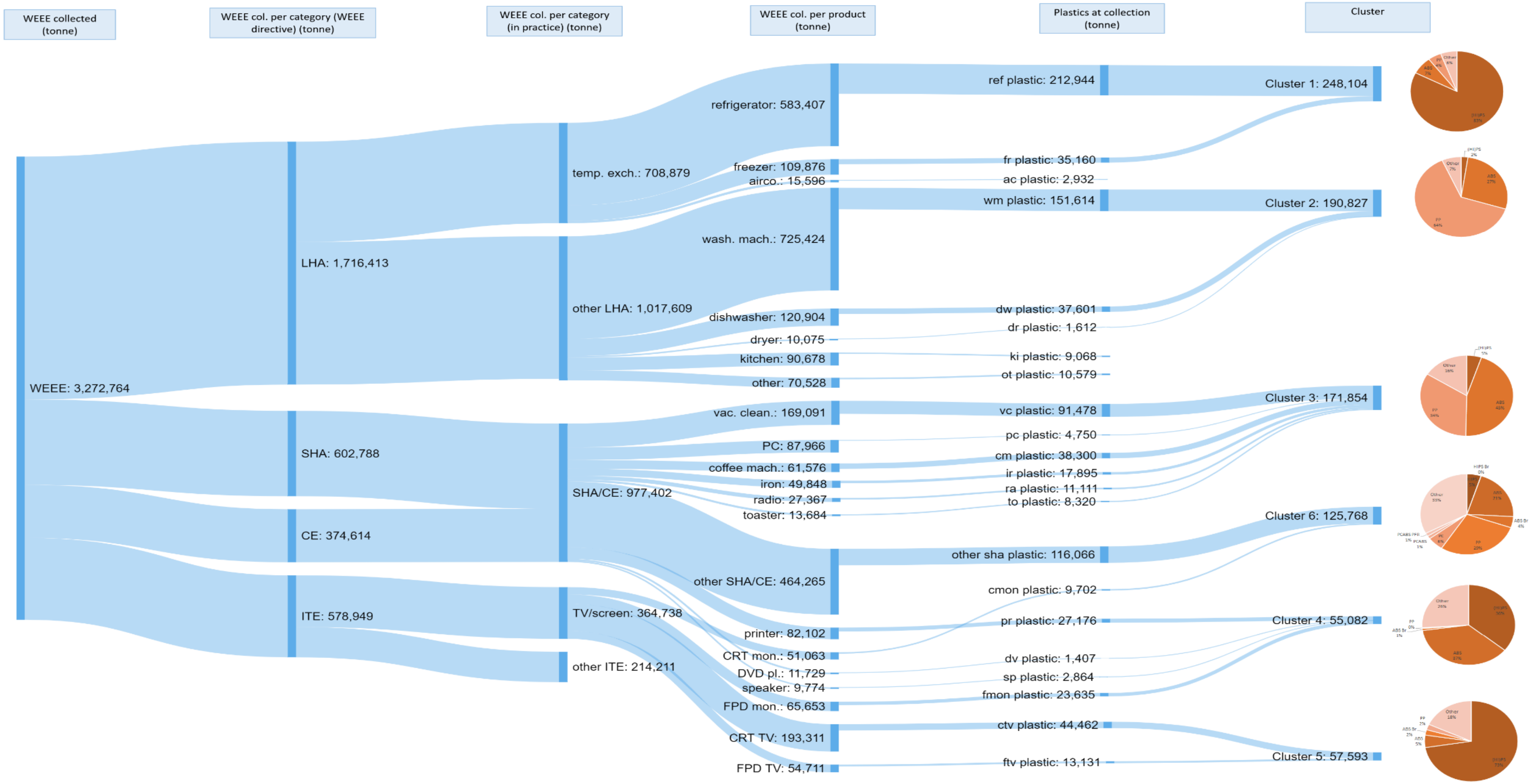


Figure 31. Overview of WEEE (and WEEE plastics) at collection and final clustering results. Numbers indicate tonnages collected in the EU, including associated Nordic countries. (LHA: large household appliances; SHA: small household appliances; CE: consumer equipment; ITE: IT and telecommunications)

Annex II

PolyCE

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

Subject: Analysis of plastic flakes from fridges, fridge drawers, washing machines and washing machine drums

Report for project internal communication

Author: KUL

Date: 29.07.2019

Report content

The report includes the following samples:

Samples		Pre-Processing (Metadata)	Fines content	Size & Shape Analysis	Colour Analysis	Composition with FTIR
Case study PS from fridges						
1	Entire fridges	Yes	Yes	Yes	Yes	Yes
2	Fridge drawers transparent	Yes	Yes	Yes	Yes	Yes
3	Fridge drawers smokey	Yes	Yes	Yes	Yes	Yes
4	Fridge drawers white	Yes	Yes	Yes	Yes	Yes
Case study PP from washing machines						
5	Washing Machines	Yes	Yes	No	No	Yes
6	Washing Machine Drums	Yes	Yes	Yes	Yes	Yes

1. Case study PS from fridges

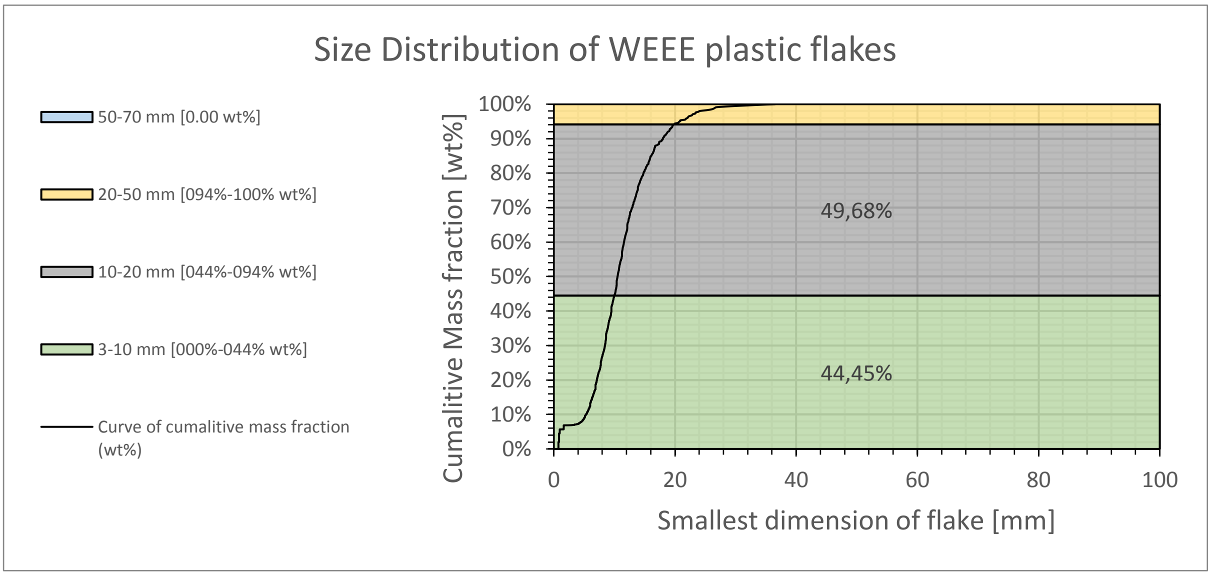
The first case study includes the results of task 7.1 for the separate processing of drawers from fridges to achieve an improved quality compared to the processing of plastics from entire fridges. The main goal of the case study is to work towards a technical dossier for the application at EFSA to achieve recycled polystyrene with food contact quality. This report shows the results of the full trial warm-ups that have been conducted by the processing of 500 kg of plastic drawers that have been sorted by colour (transparent, smokey and white). The drawers have been separated by colour visually at the pre-processing plants of STENA in Italy, organized by ECODOM. The material was send to MGG Polymers who sent a representative sample of each batch to KUL for the flake analysis. Further RoHS and REACH tests are being conducted by UL.

1.1. Entire fridges

1.1.1. Metadata

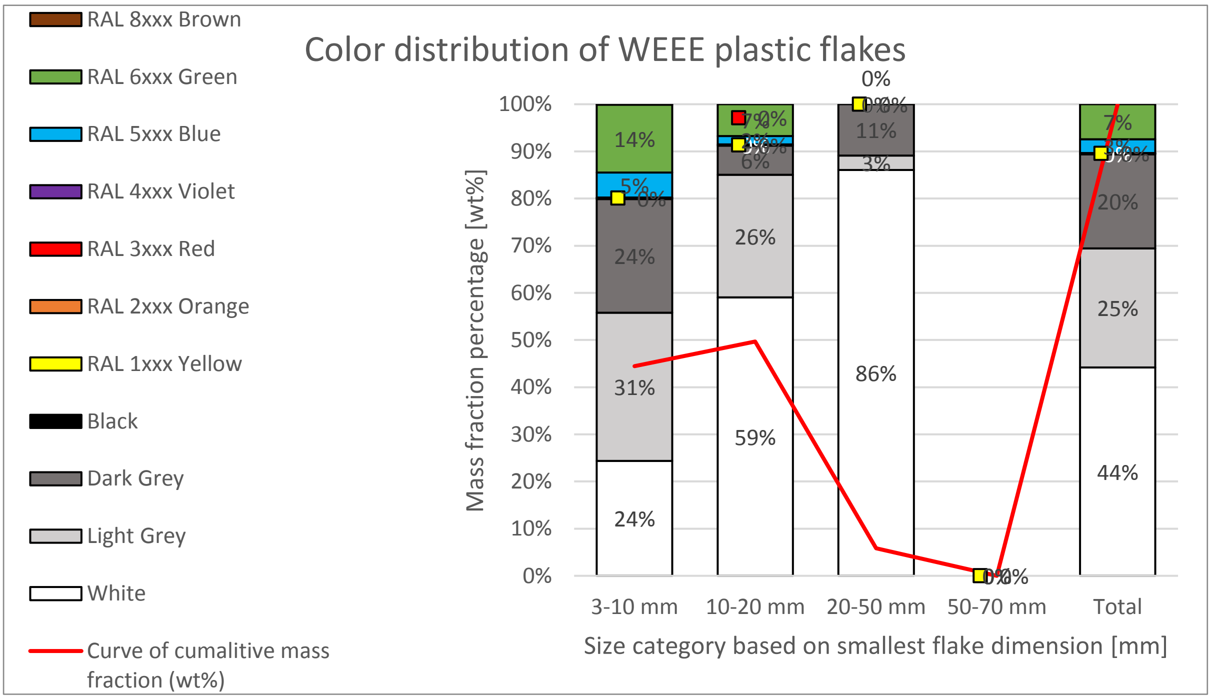
(To be anonymized)		
Company	SEVAL	(name)
Date sample sent	30/04/2019 (to MGG)	(dd-mm-yyyy)
Date sample received	*May 2019*	(dd-mm-yyyy)
Sample identification code	*20_Seval fridges*	(unique sample code)
Full address of the plant	Via la Croce, 14, 23823 Colico LC	(address)
E-mail address contact person	campadello@ecodom.it	(e-mail)
Phone number contact person	0039 333 6070931	(phone number)
General Description		
(Used confidentially)		
Product categories:		
Cooling and freezing equipment	yes	(yes/no)
Manual sorting		
Components manually removed pre-shredder	compressor, oil gas, glass, cable	(component(s) description)
Size reduction processes:		
Other, please specify	blade shredder	(description)
Sieving:		
Sieving size(s)	less than 2 cm	(max mech size in mm)
Metal sorting technology:		
Magnetic roller	yes	(yes/no)
Other, please specify:	vibrating tables	(description)
Plastic sorting technology:	no	

1.1.2. Fines, size and shape analysis



The size distribution of the plastic flakes from frides is characterized by relatively small flake sizes due to the processing of the plastics in a blade shredder. The fines content smaller than 3mm was tested by sieving and resutled in 1,9 wt%.

1.1.3. Colour analysis



The colour composition of the sample consists of various shades of white, grey and dark grey. Blue and green flakes could also be observed in the sample and confirmed visually. However, the relative amount of 14 % of green colour shades in the 3-10 mm category is expected to be lower, due to the measurement of the green conveyor belt in the case of poor recognition of very small flakes.

1.1.4. Sample composition

Material [%]	**Trial 2019**	**Trial 2018 with flotation**	**Trial 2018 without flotation**
Plastics	**99,4**	**99,0**	**88,0**
ABS	*23,5*	*14,6*	*12,8*
HIPS	*48,4*	*64,1*	*56,0*
PS	*17,0*	*16,0*	*11,2*
PP	*2,6*		
PP CaCO3	*2,6*		*1,6*
PP talc		*2,9*	
PC/ABS	*3,9*		
PE	*1,3*		
PVC	*0,1*		*3,2*
PA			*1,6*
Other		*1,5*	*1,6*
Metals	**0,4**	**<1**	**11**
Rubber	**0,1**		
Glass, Concrete, Ceramic	**0,1**	**<1**	**1**
Wood	**0,1**	**<1**	
Foam	**0,0**	**<1**	
Others	**0,0**	**<1**	

The sample contained 99,4 wt% plastics and was mainly composed of High Impact PolyStyrene (HIPS 48,4 wt%), Acrylonitrile Butadiene Styrene (ABS 23,5 wt%) and PolyStyrene (PS 17,0 wt%). Smaller amounts of PolyCarbonate/ABS (PC/ABS 3,9 wt%), unfilled (or glass fibre filled) PolyPropylene (PP 2,6 wt%), calcium carbonate filled PP (PP $CaCo_3$ 2,6 wt%) and PolyEthylene (PE 1,3 wt%) were measured. The PolyVinylChloride (PVC 0,1 wt%) was a result of cables present in the sample.

Previous trials at STENA in 2018 showed that on plastics from fridges were characterized with a comparable purity of 99 wt % if a sink-float separation step was used. Only 88 wt% of purity were achieved without the separation step in the first trial. The plastics compositions of the trials in 2018 were dominated by ABS (14,7 wt%), HIPS (64,7 wt%) and PS (16,2 wt%), taking into account only the plastics composition without the purity as shown in the table above. The trial without the flotation in 2018 resulted in comparable percentages. The main difference of the trail in 2019 is the higher ABS and lower HIPS content compared to the trials in 2018.

1.2. Fridge drawers transparent

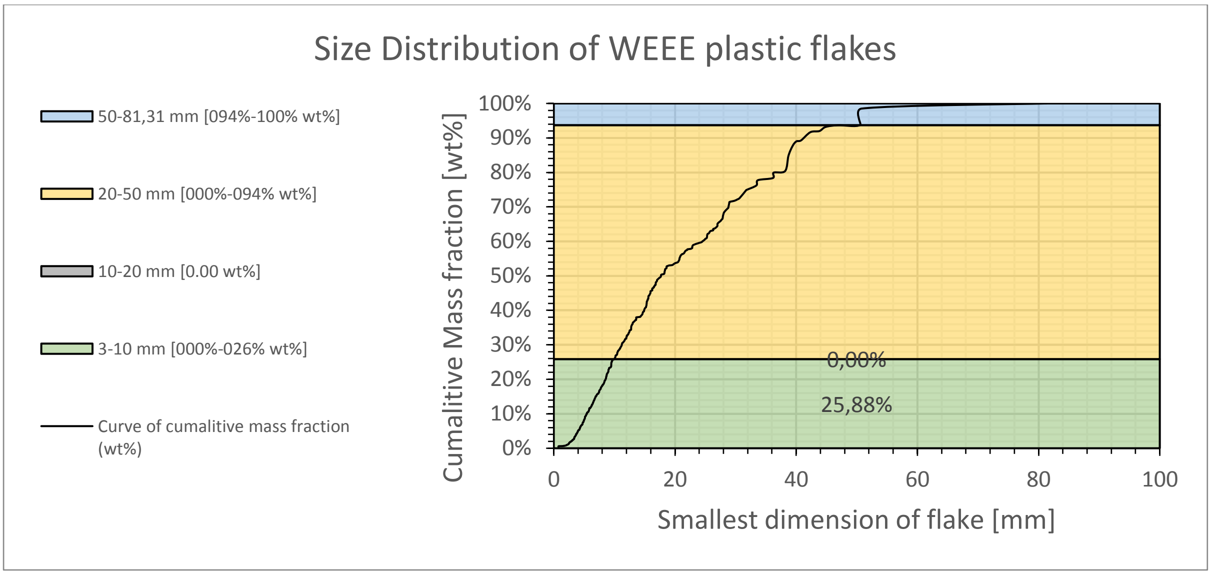
For this trial the drawers were removed from the fridges at the pre-processing phase and subsequently sorted based on colour into the categories transparent, smokey and white.

1.2.1. Metadata

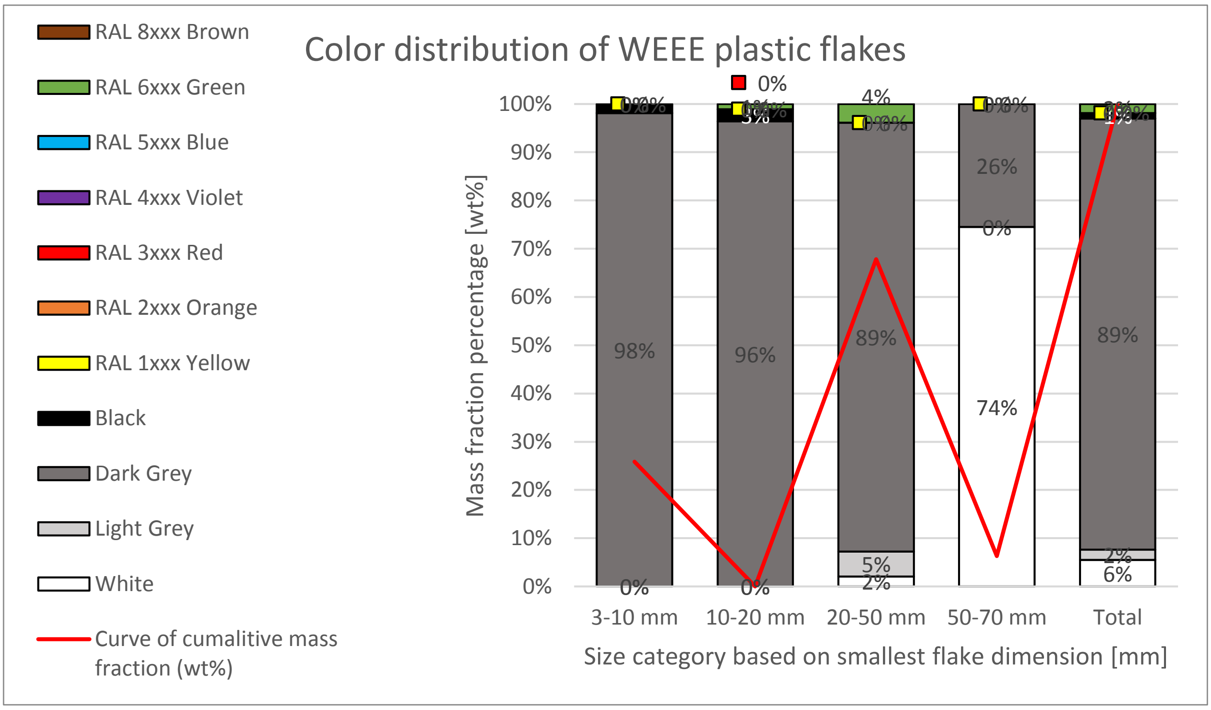
(To be anonymized)		
Company	STENA TECHNOWORLD	(name)
Date sample sent	30/04/2019 (from STENA to MGG)	(dd-mm-yyyy)
Date sample received	*May 2019*	(dd-mm-yyyy)
Sample identification code	*22_fridge drawers-transparent_full trial_warm up*	(unique sample code)
Full address of the plant	Via dell'industria, 483, Angiari (VR)	(address)
E-mail address contact person	campadello@ecodom.it	(e-mail)
Phone number contact person	+39 3336070931	(phone number)
General Description		
(Used confidentially)		
Product categories:		
Cooling and freezing equipment	yes	(yes/no)
Sample size		
Weight of sample sent to KU Leuven	5	(mass in kg)
Total weight in sampling campaign	450	(mass in kg)
Manual sorting		
Components manually removed pre-shredder	transparent fridges drawers manually removed to be shredded separately	(component(s) description)
Size reduction processes:		
Hammer mill	yes	(yes/no)
Metal sorting technology:	no	
Plastic sorting technology:	no	

1.2.2. Fines, size and shape analysis

The plastic drawers were processed in a hammer mill and resulted in plastic flakes with sizes up to 60 mm. This is significanlty larger compared to the flake size of the trial of entire fridges where approximately 90 % of the flakes showed sizes smaller than 20 mm, after processing in a blade shredder. The fines content smaller than 3mm was tested by sieving and resutled in 0,2 wt%.



1.2.3. Colour analysis



The colour composition of the transparent flakes resulted in black and grey shades in the computer vision system. The transparency itself is not reflected in the analysis results and all grey and black shades are expected to come from the transparent plastic flakes. The minor green content comes from the green conveyor belt, the flakes were measured on. The white colour tones in the size range of 20-50 mm are expected to come from reflections, while in the size range of 50-70 mm a large plastic piece could be measured. The presence of white impurities was visually confirmed and FTIR analysis characterized it as HIPS impurities. The weight concentration of the HIPS particles in the sample were manually analysed to be approximately 1 wt %.

1.2.4. Sample composition

Material	%
Plastics	**100,0**
SAN	5,1
HIPS	1,1
PS	89,3
PC	4,5
Metals	**0,0**
Rubber	**0,0**
Glass, Concrete, Ceramic	**0,0**
Wood	**0,0**
Foam	**0,0**
Others	**0,0**

The sample consists purely out of plastic flakes with no contaminations of other materials that could be observed. The transparent drawers are composed of 89,3 wt % of PS, 5,1 wt% of SAN, 1,1 wt % of HIPS and 4,5 wt% of PC according to the FTIR results. The amount of HIPS in the sample reflects the manually measured amount of approximately 1 wt %. Previous discussions with Ecodom indicated that SAN impurities could be present in the sample, which could be confirmed by the FTIR measurements. This plastic composition differs from the 100 % of PS that was measured in the previous warm up trial.

1.3. Fridge drawers smokey

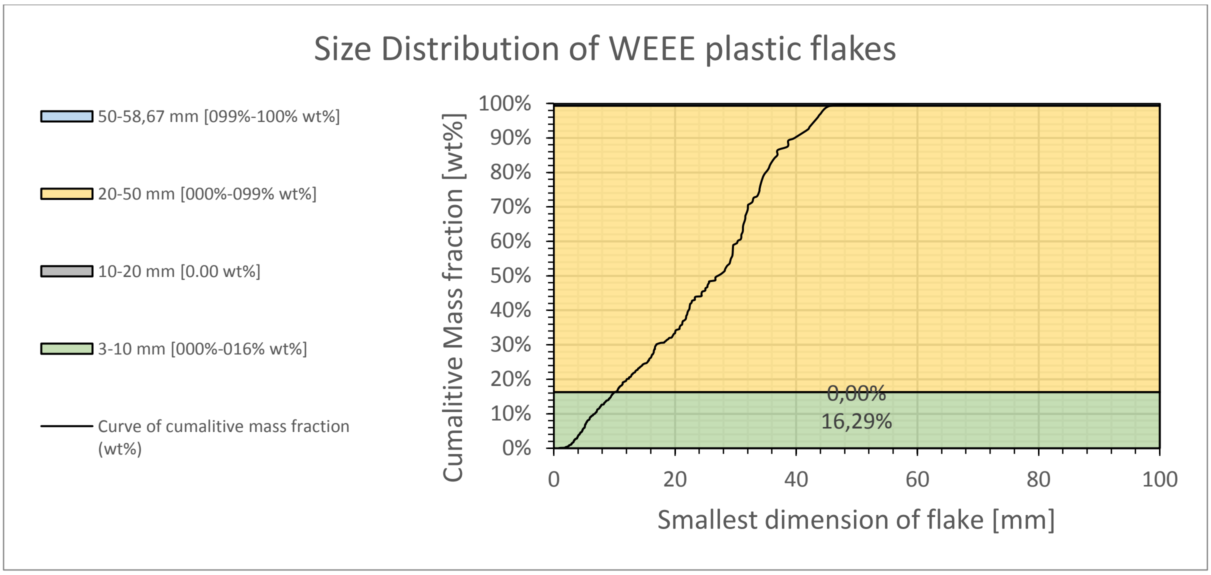
For this trial the drawers were removed from the fridges at the pre-processing phase and subsequently sorted based on colour into the categories transparent, smokey and white.

1.3.1. Metadata

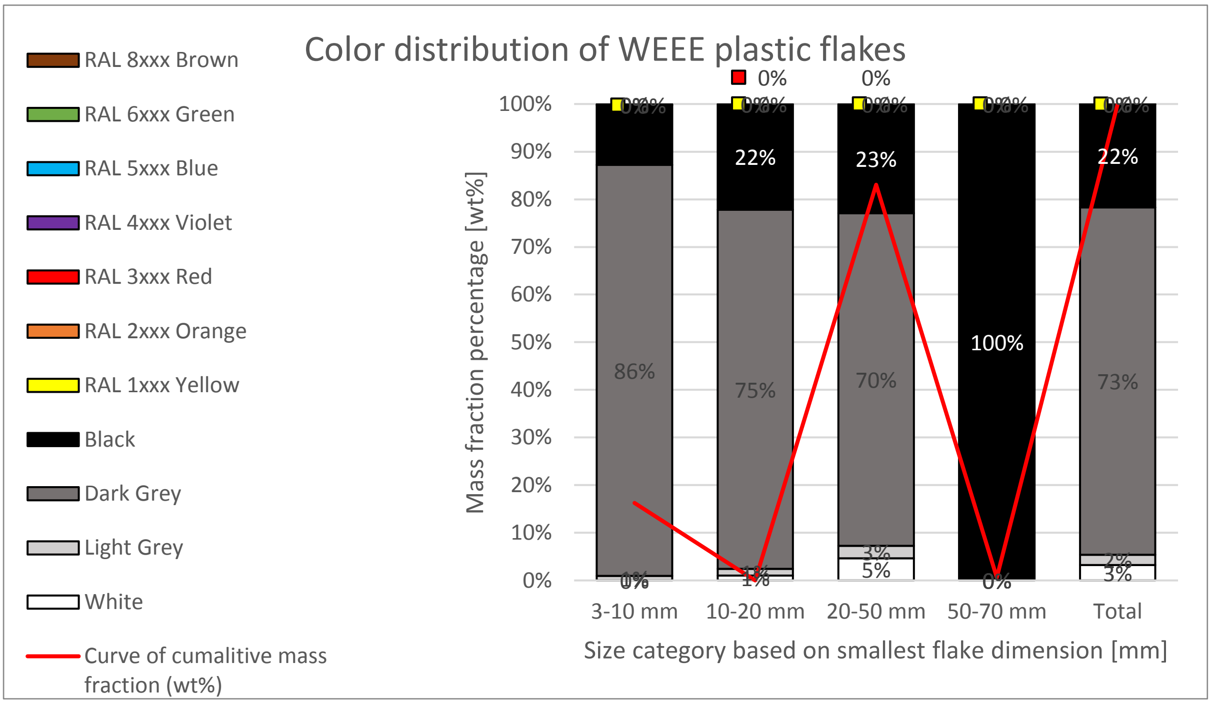
(To be anonymized)		
Company	STENA TECHNOWORLD	(name)
Date sample sent	30/04/2019 (from STENA to MGG)	(dd-mm-yyyy)
Date sample received	*May 2019*	(dd-mm-yyyy)
Sample identification code	*23_fridge drawers-smokey_full trial_warm up*	(unique sample code)
Full address of the plant	Via dell'industria, 483, Angiari (VR)	(address)
E-mail address contact person	campadello@ecodom.it	(e-mail)
Phone number contact person	+39 3336070931	(phone number)
General Description		
(Used confidentially)		
Product categories:		
Cooling and freezing equipment	yes	(yes/no)
Sample size		
Weight of sample sent to KU Leuven	5	(mass in kg)
Total weight in sampling campaign	295	(mass in kg)
Manual sorting		
Components manually removed pre-shredder	smokey fridges drawers manually removed to be shredded separately	(component(s) description)
Size reduction processes:		
Hammer mill	yes	(yes/no)
Metal sorting technology:	No	
Plastic sorting technology:	No	

1.3.2. Fines, size and shape analysis

The size distribution with the computer vision system shows comparable results to the transparent flakes with flake sizes up to 50 mm and an almost linear distribution. The fines content smaller than 3mm was tested by sieving and resutled in 0,2 wt%.



1.3.3. Colour analysis



The colour composition of the smokey flakes was characterized by dark grey and black shades. Compared to the transparent samples, more black shades were measured, indicating a darker composition. Again no transparency could be reflected in the results and the minor amount of white flakes is expected to come from reflections as no white pieces could be visually observed. A minor grey content could be measured and visually confirmed as grey, non-transparent impurities. A visual analysis did indicate that a large part of the plastic pieces might still be indicated as transparent, as only 40 – 50 % of the pieces were clearly determined as smokey.

1.3.4. Sample composition

The plastic flakes with a purity of 99,81 wt% were composed of 97,7 wt% of PS with minor impurities of 1,1 wt% of HIPS and 1,1 wt% of not identified plastics.

Material	**%**
Plastics	**99,81**
HIPS	1,1
PS	97,7
Other	1,1
Metals	**0,0**
Rubber	**0,0**
Glass, Concrete, Ceramic	**0,0**
Wood	**0,0**
Foam	**0,0**
Others	**<0,2**

1.4. Fridge drawers white

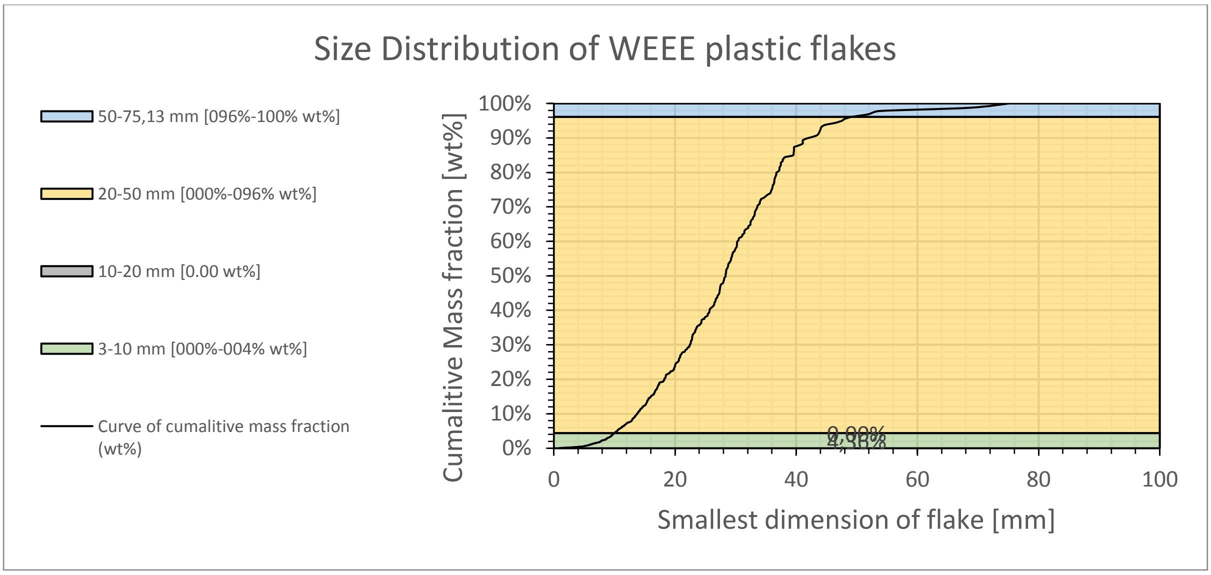
For this trial the drawers were removed from the fridges at the pre-processing phase and subsequently sorted based on colour into the categories transparent, smokey and white.

1.4.1. Metadata

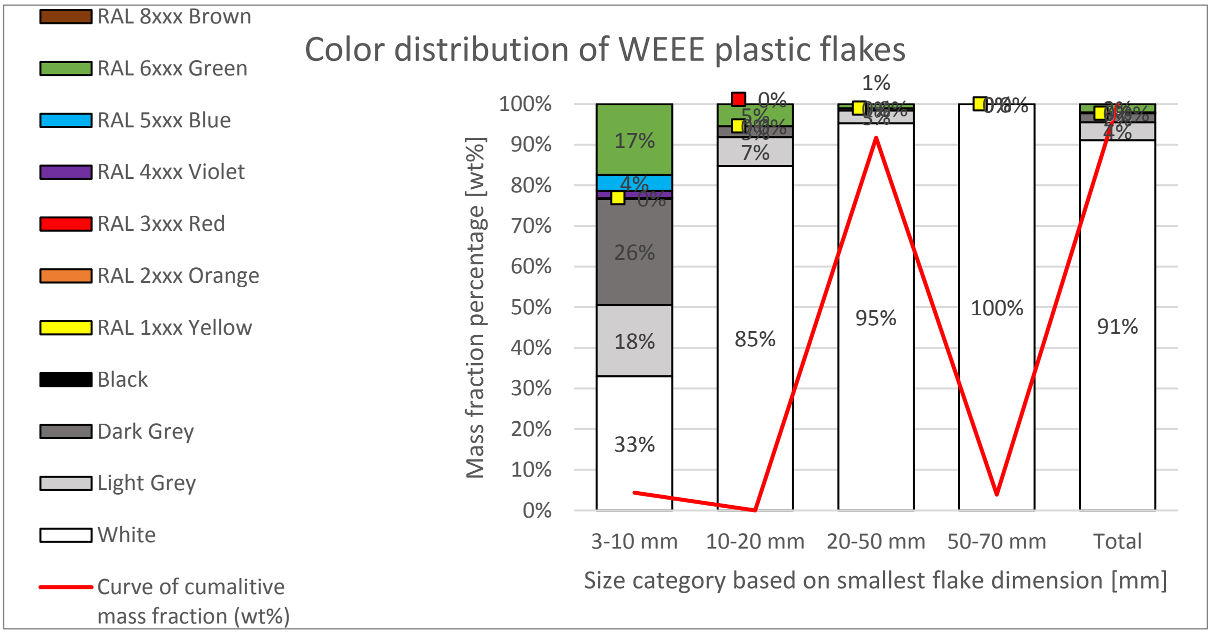
(To be anonymized)		
Company	STENA TECHNOWORLD	(name)
Date sample sent	30/04/2019 (from STENA to MGG)	(dd-mm-yyyy)
Date sample received	*May 2019*	(dd-mm-yyyy)
Sample identification code	*24_fridge drawers-white_full trial_warm up*	(unique sample code)
Full address of the plant	Via dell'industria, 483, Angiari (VR)	(address)
E-mail address contact person	campadello@ecodom.it	(e-mail)
Phone number contact person	+39 3336070931	(phone number)
General Description		
(Used confidentially)		
Product categories:		
Cooling and freezing equipment	yes	(yes/no)
Sample size		
Weight of sample sent to KU Leuven	5	(mass in kg)
Total weight in sampling campaign	488	(mass in kg)
Manual sorting		
Components manually removed pre-shredder	white fridges drawers manually removed to be shredded separately	(component(s) description)
Size reduction processes:		
Hammer mill	yes	(yes/no)
Metal sorting technology:	no	
Plastic sorting technology:	no	

1.4.2. Fines, size and shape analysis

The size distribution with the computer vision system shows comparable results to the transparent and smokey flakes. The maximum flake size was up to 75 mm, while around 90 % of the flakes were smaller than 40 mm. The fines content smaller than 3 mm was tested by sieving and resutled in 0,3 wt%.



1.4.3. Colour analysis



The colour composition of the flakes was dominated by white and light grey shades. A minor content of grey and transparent pieces in the sample was observed visually and is expected to cause the dark grey colour in the composition. The green is expected to come from the conveyor belt as no green pieces could be observed.

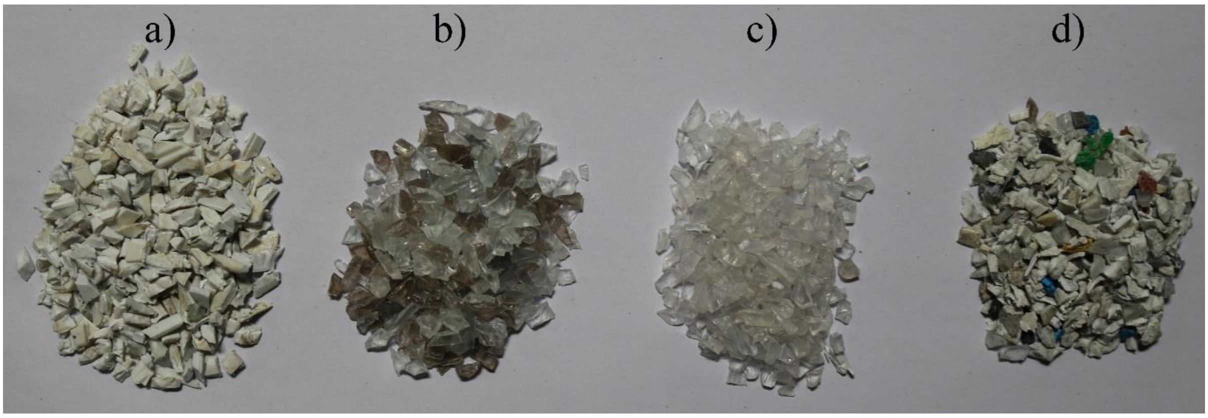
1.4.4. Sample composition

The sample was composed of 99,2 wt % plastics with minor impurities of films and dirt. The plastics were composed of HIPS (64,6 wt %), PS (17,3 wt%), PP filled with calcium carbonate (8,1 wt%), PP filled with talc (8,1 wt%) and 1,2 wt% of other plastics. The plastic composition corresponds to the measurement results of the warm up trial. The HIPS composition of the trial was lower, while more PS was measured. As the HIPS with a low butadiene content give similar FTIR responses to pure PS, the difference in results could be due to the difficult discrimination between the two materials.

Material	%
Plastics	**99,3**
HIPS	64,6
PS	17,3
PP CaCO3	8,1
PP talc	8,1
Other	1,2
Metals	**0,0**
Rubber	**0,0**
Glass, Concrete, Ceramic	**0,0**
Wood	**0,0**
Foam	**<0,1**
Others	**0,7**

1.5.Summary and conclusion

The figure below shows shredded flakes of the white drawers (a), smokey drawers (b), transparent drawers (c) of fridges and of entire fridges (d).



The results of the material composition indicate a clear reduction of impurities from the entire fridges sample to the fridge drawers. However, all samples of fridge drawers did contain minor contents of impurities of other plastics. The cause of cross contamination of plastics of different colours in the flakes should be discussed with the consortium partners and possible precautions for a cleaner sorting of the transparent drawers might be necessary of full transparency of the final recycled plastics wants to be achieved. Further impurities of dirt and films might come from the contamination of the drawers in the end-of-life fridges or possible contamination due to transportation and storage in not cleaned containers. Considering the target of food contact materials a strategy on how to reduce these impurities should be discussed and the possible implementation of a washing step to remove impurities from the previous life of the drawers might avoid contamination.

2. Case study PP from washing machines

The second case study includes the results of task 7.7 for the dismantling and separate processing of washing machine drums to achieve an improved quality compared to the processing of plastics from entire washing machines. The main goal of the case study is to recycle PP with fillers for the application in electronic products. This report shows the results of the full trial warm-ups that have been conducted by the processing of 20 tons of washing machines and 3 tons of dismantled washing machine drums. The sampling has been conducted at SEVAL pre-processing plants in Italy, organized by ECODOM. Representative sample were send to KUL for the flake analysis.

2.1. Entire washing machines

2.1.1. Metadata

(To be anonymized)		
Company	SEVAL	(name)
Date sample sent	04/06/2019 (to MGG and KUL)	(dd-mm-yyyy)
Date sample received	*June 2019*	(dd-mm-yyyy)
Sample identification code	*25_Seval_washing machines_full trial warm up*	(unique sample code)
Full address of the plant	Via la Croce, 14, 23823 Colico LC	(address)
E-mail address contact person	campadello@ecodom.it	(e-mail)
Phone number contact person	0039 333 6070931	(phone number)
General Description		
(Used confidentially) **Product categories:**		
Washing machines and dryers	yes (separate treatment of washing machines only)	(yes/no)
Manual sorting		
Components manually removed pre-shredder	cables, door, drain hose	(component(s) description)
Components manually removed post-shredder	Step1: iron panel, drive motor, concrete block, cables/rubber seals Step2: cables	(component(s) description)
Size reduction processes:		
Hammer mill	yes	(yes/no)
Crusher	yes	(yes/no)
Metal sorting technology:		
Magnetic roller	yes	(yes/no)
Eddy currents	yes	(yes/no)
Plastic sorting technology:		
Near-infrared spectroscopy (NIR)	yes	(yes/no)

2.1.2. Fines, size and shape analysis

Due to a reconstruction of the computer vision system the measurements can only be conducted until the beginning of October. The fines content smaller than 3mm was tested by sieving and resutled in 0,04 wt%.

2.1.3. Colour analysis

Due to a reconstruction of the computer vision system the measurements can only be conducted until the beginning of October.

2.1.4. Sample composition

Material %	Trial 2019	Trial 2018
Plastics	**96,4**	**98,4**
ABS	*12,4*	*0,0*
PP	*5,5*	*14,4*
PP CaCO3	*75,8*	*65,6*
PP talc	*0,0*	*14,4*
PVC	*0,6*	*0,1*
PA	*0,0*	*2,1*
Other	*2,9*	*2,1*
Metals	**1,8**	**0,3**
Rubber	**0,7**	**0,8**
Glass, Concrete, Ceramic	**0,6**	**0,1**
Wood	**0,1**	**0,0**
Foam	**0,0**	**0,0**
Others	**0,5**	**0,3**

The sample was composed of 96,4 wt% of plastics with mainly metals as impurities (1,8 wt%). Compared to the warm up trial in 2018 this is a lower purity, mainly due to the metal content. The metadata indicated that metal removal was conducted by Eddy-current and magnetic separation for both samples. The plastics found by the FTIR analysis were PP filled with calcium carbonate (75,8 wt%), ABS (12,4 wt%), PP unfilled (5,5 wt%), PVC (0,6 wt%) other plastics (2,9 wt%). This composition is also dominated by the PP filled with calcium carbonate, as the warm up trial conducted in 2018. However, in 2019 no PP filled with talc could be measured, while ABS was not previously found in the 2018 trial. The PP unfilled could also contain glass fibres as they are known to be present in some washing machine drums and cannot be determined purely by FTIR without the use of TGA or a density treatment. In addition, the content of PVC increased. The metadata indicated that in the trial in 2019 a NIR treatment was conducted, which was not indicated in the metadata in 2018.

2.2. Washing machine drums

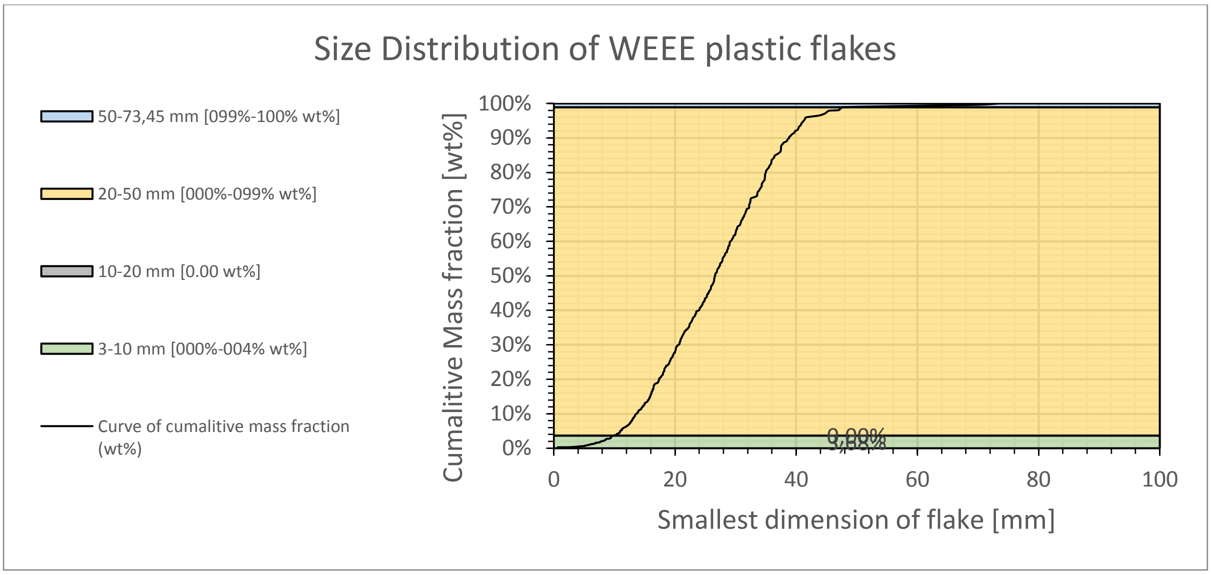
The dismantling of washing machine drums and the removal of main impurities manually before further, separate treatment is the main goal of this case study in order to produce recycled PP with fillers with a high quality for the reapplication in electronic products.

2.2.1. Metadata

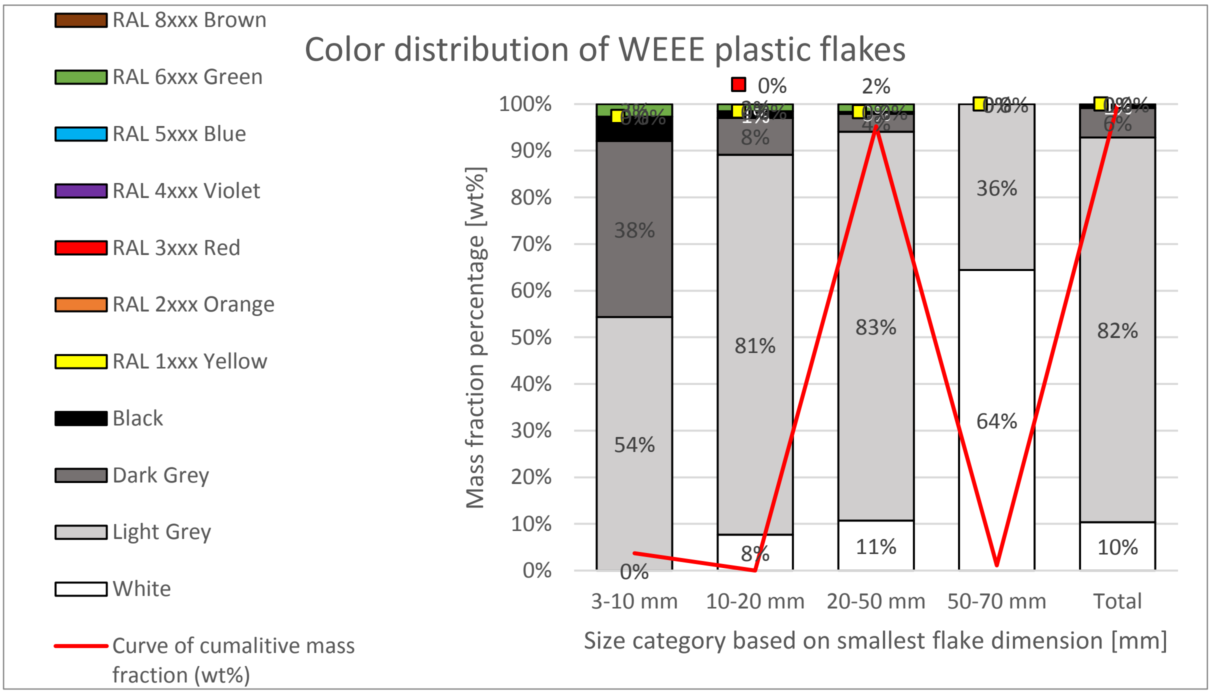
(To be anonymized)		
Company	SEVAL	(name)
Date sample sent	30/04/2019 (from SEVAL to MGG)	(dd-mm-yyyy)
Date sample received	*May 2019*	(dd-mm-yyyy)
Sample identification code	*21_Seval_washing machine drums_full trial_warum up*	(unique sample code)
Full address of the plant	Via la Croce, 14, 23823 Colico LC	(address)
E-mail address contact person	campadello@ecodom.it	(e-mail)
Phone number contact person	0039 333 6070931	(phone number)
General Description		
(Used confidentially)		
Product categories:		
Large household appliances	yes	(yes/no)
Sample size		
Weight of sample sent to KU Leuven	5	(mass in kg)
Total weight in sampling campaign	2900	(mass in kg)
Manual sorting		
Components manually removed pre-shredder	washing machine drums manually removed to be shredded separately	(component(s) description)
Components manually removed post-shredder	rubber seals cables and plastics containing metals	(component(s) description)
Size reduction processes:		
Hammer mill	yes	(yes/no)
Crusher	yes	(yes/no)
Metal sorting technology:		
Magnetic roller	yes	(yes/no)
Eddy currents	yes	(yes/no)
Plastic Sorting	no	

2.2.2. Fines, size and shape analysis

The size distribution of the flakes of washing machine drums show a relatively linear behavior with flake sizes up to approximately 50 mm. According to the metadata the size reduction was conducted by a hammer mill and a crusher. The fines content smaller than 3 mm was tested by sieving and resutled in 0,8 wt%.



2.2.3. Colour analysis



The colour of the sample was dominated by white and light grey pieces. Dark grey and minor amounts of black pieces were also observed and could influence the final colour shade of the recyclate.

2.2.4. Sample composition

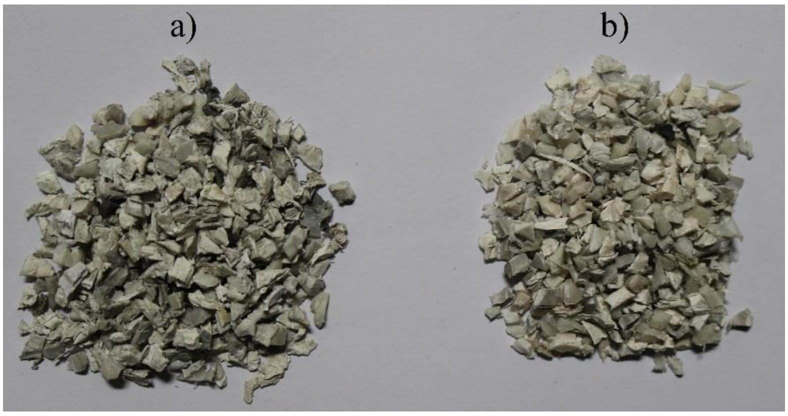
The sample composition showed an increased purity of 99,7 wt % plastics compared to the 96,4 wt% of the entire washing machines samples. This confirms the results of the warm up trials in 2018, where also an improved plastics purity was measured. The plastic composition is dominated by 70,1 wt% of PP filled with calcium carbonate, PP filled with talc (12,1 wt%)

and PP filled with glass fibres (16,4 wt%). Minor amount s of ABS (1,1 wt%) were also measured by FTIR. Compared to the warm up trial in 2018 the amount of PP filled with glass fibres is lower and the amount of PP filled with talc is higher.

Material [%]	**Trial 2019**	**Trial 2018**
Plastics	**99,7**	**99,9**
ABS	*1,1*	*0,0*
PP CaCO3	*70,1*	*61,6*
PP talc	*12,1*	*6,4*
PP glassfibre	*16,4*	*31,9*
Metals	**0,0**	**<1**
Rubber	**0,0**	**0,0**
Glass, Concrete, Ceramic	**0,1**	**<1**
Wood	**<0,1**	**0,0**
Foam	**0,1**	**0,0**
Others	**0,1**	**0,0**

2.2.5. Conclusion

The figure below shows the shredded pieces of plastic of entire washing machines (a) and dismantled washing machine drums (b) as used for FTIR analysis.



The analysis of the material composition showed that that dismantling of washing machine drums leads to a significantly increased purity of plastics. The identification of calcium carbonate and talc fillers in plastics is possible with FTIR, while for the identification of glass fibres an additional technique is necessary. TGA in combination with microscopy is able to detect glass fibres and was used to improve the discrimination between the filler types for selected 2018 warm up trial samples by Whirlpool. The results showed that the washing machine drums consisted of calcium carbonate, talc or glass fillers with different concentrations, not commonly used for this kind of application. The results showed that a density treatment at 1 g/cm³ is effective in separating PP with low amounts of fillers (approximately 0-10 wt%). The test at flake level indicate a promising quality of the filled PP, where further tests will be conducted by MGG, Whirlpool and UGent to evaluate the achievable final quality based on this cluster.