A comprehensive methodology to calculate WEEE recycling an recovery rates in Portugal

M. Luízio, S. Ferreira, P. Ferrão, E. Santos, P. Ribeiro, IN+ Center for Innovation, Technology and Policy Research, Instituto Superior Técnico, Universidade Técnica de Lisboa

Abstract

One main challenge for Amb3E the main WEEE collective take back system in Portugal is to measure the effective performance obtained in WEEE recycling and recovery by its recovery operators in order to calculate and compare the system's overall results against the legally binding recycling and recovery targets.

To that extend Amb3E developed a "Procedure for WEEE Treatment Tests" based on the material flow analysis methodology and the WEEE Forum Guidelines and Checklists. The procedure was carried out in 2007 and 2008 and tests were performed for the WEEE treatment categories and Amb3E operators.

Given the European dimension of the WEEE management a question that arises is the comparability between different systems and countries. Therefore in order to have a standardized classification of components fractions and technologies Amb3E tests data were inputted to the WEEE Forum tool – Reptool.

This paper presents the treatment tests methodology and results namely in the context of the environmental results obtained and in particular of hazardous substances removed. Additionally the technologies used by the recovery operators and the input and output fractions obtained are characterized quantitatively and qualitatively and the European method to ensure comparability of results (Reptool) is analyzed.

Furthermore the technical limitations of Amb3E's method are identified and discussed and possible solutions are suggested namely in the context of the Amb3E legal boundary and its relation with the entire WEEE value chain from the waste collection until the moment where WEEE materials are effectively reincorporated in new products.

Keywords: WEEE, treatment categories, material fractions, reuse/recycling and recovery rates.

1. Introduction

Based on the principle of Extended Producer Responsibility, EEE producers in each Member State of the European Union (EU), are responsible for managing and financing the operations at the end of life of their products and are obliged to take this responsibility individually or to transfer it to a Collective Take Back Scheme also known as WEEE Systems. According to this concept, the producers' responsibility is extended to after-use, thus including the whole lifecycle of the product, meaning the stages of the selection of raw materials, production, marketing, use and end of life product. (Ferrão & Luízio, 2005).

With the transposition of the European Directives 2002/96/EC and 2002/95/EC of the European Parliament and of the council into the Portuguese Law, Decreto-Lei 230/2004, EEE producers in Portugal could start the necessary mechanisms to take responsibility for the end of life management of their products, which culminated with licensing by the Portuguese Government of two Collective Take Back Schemes on the 27th of April 2006: Amb3E and ERP Portugal.

The main responsibilities of the Collective Take Back Schemes are:

1. Develop an infrastructure of collection points, transporters and treatment plants, among a set of Municipal facilities, private waste companies, logistics companies, major producers of WEEE and retailers to ensure the compliance with the collection target (4 kg per inhabitant per year) as well as the reuse/recycling and recovery targets set out in Article 7 of the Decreto-Lei 230/2004 (see Table 1)
2. Ensure the monitoring and control of the integrated system, especially with regard to the fractions that flow from the treatment of WEEE and report the results of the Systems' activities to National Authorities.

Table 1 - WEEE reuse/recycling and recovery legally binding targets (article 7 of Decreto-Lei n.º230/2004)

Legal Category	Reuse/Recycling Target (%)	Recovery Target (%)
1. Large household appliances **10. Automatic dispensers**	**≥75%**	**≥80%**
3. IT and telecommunications equipment **4. Consumer equipment**	**≥65%**	**≥75%**
2. Small household appliances **5. Lighting equipment** **6. Electrical and electronic tools** **7. Toys, leisure and sports equipment** **9. Monitoring and control instruments**	**≥50%**	**≥70%**
5.4. L Discharge lamps	**≥80%**	**-**

Note: Targets for legal category 8 - Medical Devices should by the Commission until 31/12/2008.

They also have to:

1. Promote research and development of new methods for dismantling, separation of materials and for recycling materials and components of WEEE;
2. Raise awareness and public information in terms of WEEE management.

The activities of monitoring and control of the material flows that input and output the treatment plants are critical to assess the compliance with treatment requirements and the fulfillment of reuse/recycling and recovery targets by the WEEE Systems and, ultimately, by the country. In this context, several questions remain unanswered within the current legal framework:

- How to ensure the accuracy of treatment and reuse/recycling and recovery results?
- How to ensure the comparability of results between different plants and Member States?

The origin of these questions lye on the legal requirements in the present framework on the management of WEEE, namely:

- Definition of WEEE treatment;
- Differences between legal requirements for monitoring treatment, reuse/recycling and recovery results, by legal category, and the effective operational practice, by treatment category;
- Scope of the treatment results considering the different levels of the treatment chain;
- Distinct classifications by Member States on recovery and disposal operations.

2. Objectives and Methodology

Considering the open questions stated in the previous section and the context of the activities under the responsibility of the WEEE Systems, this paper focuses on the monitoring and control of the performance of the treatment infrastructure of the responsibility of Amb3E.

In line with the strategic framework outlined by Amb3E, the objectives of the study were to develop and implement a methodology to determine the reuse/recycling and recovery rates obtained by the treatment plants within Amb3E's System.

The methodology is based on the measurement of material flows from the treatment of WEEE and required an implementation of industrial scale mass balances, representative of the processes and technologies installed on Amb3E's treatment plants. In this study, it was also analyzed the impact on the accuracy of reuse/recycling and recovery rates given the level within the WEEE treatment chain to which the results are calculated, so that they can be comparable and transparent.

The methodology set for this study involved the following tasks:

- Survey of legal requirements related to WEEE treatment and reporting of treatment results;
- Argumentation for considering the treatment category as a functional unit for setting targets for reuse/recycling and recovery;
- Implementation of 9 sampling campaigns of treatment category C – small appliances (other) , in order to obtain the necessary data to set reuse/recycling and recovery targets for all treatment categories;
- Development of a treatment test procedure based on an international benchmarking and a pilot test conducted in an Amb3E treatment plant. The treatment tests allow to determine qualitatively and quantitatively all the fractions that are obtained from treating a significant sample of each treatment category;
- Presentation of practical considerations about the difference between determining rates of reuse/recycle and recover rates at "the gate" of the treatment plant and at the end of the treatment chain;
- Implementation and validation of the treatment test procedure, by carrying out 16 treatment tests.

3. Requirements affecting the calculation of WEEE treatment results

Starting with the definition of treatment the WEEE Directive says that it "means any activity after the WEEE has been handed over to a facility for de-pollution, disassembly, shredding, recovery or preparation for disposal and any other operation carried out for the recovery and/or the disposal of the WEEE"

Regarding the specifications for the estimation of reuse/recycling and recovery targets, there is only one reference in Article 7, paragraph 1 of number 3 of the WEEE Directive: the Commission states that producers or third parties acting on their behalf have to keep records on the mass of WEEE, their components, materials or substances when entering (input) and leaving (output) the treatment facility and/or when entering (input) the recovery or recycling facility.

3.1. Interpretation and practical implementation

From an analysis of the definition of treatment it is concluded that this activity covers the recovery and disposal. However, the European Commission when it establishes the obligation to keep records on the mass of WEEE treated distinguishes treatment plant from recycling or recovery plant.

That said and to avoid inconsistencies the need to distinguish treatment plant from recycling or recovery and disposal plant arises, in order to implement a consistent registration procedure. For this purpose it is defined:

- Treatment plant: any plant of dismantling (manual or mechanical), crushing or separation;
- Recycling or recovery plant: any plant of final processing aimed at recovering materials or energy, such as steel mill, aluminum or copper smelter , incineration with energy recovery;
- Disposal plant: any plant of final processing where it doesn't occur material or energy recovering, such as landfills and incineration without energy recovery.

Since WEEE is a multi-material waste stream with a high level of complexity, treatment and recovery reflects the same level of complexity, as a typical treatment chain usually incorporates various technologies and a high number of resulting material fractions: Figure 1 represents a typical WEEE treatment chain.

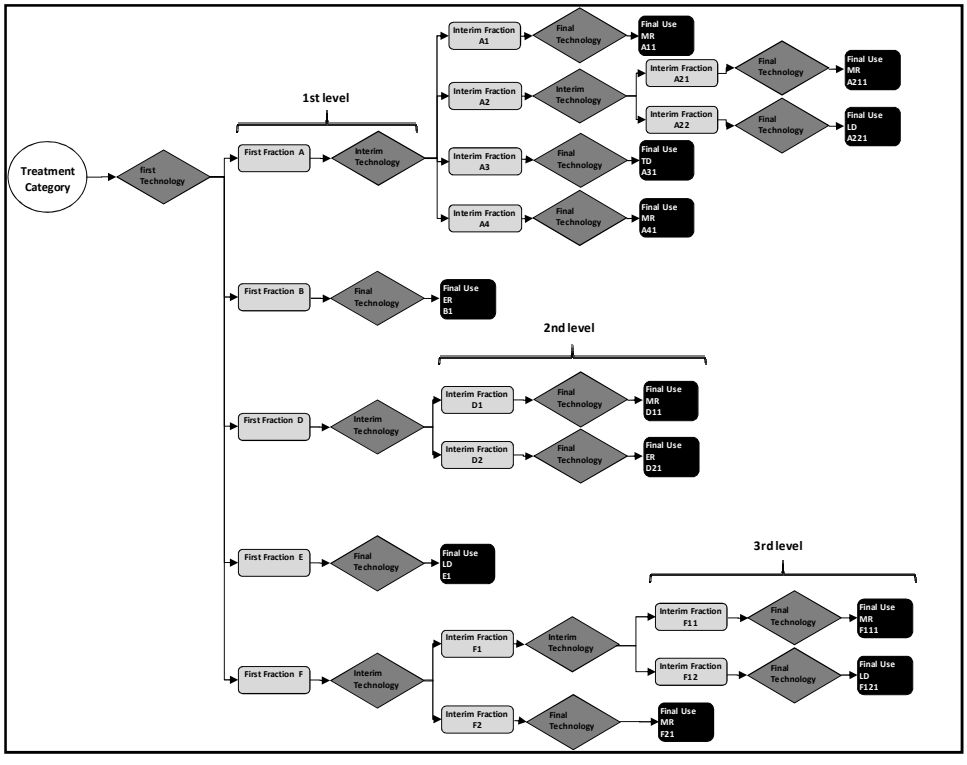

Figure 1 – Typical WEEE treatment chain

A WEEE treatment chain is usually made up of different treatment, recycling or recovery and disposal plants. However, WEEE Systems, usually only establish contracts with treatment plants.

Thus, when the Directive 2002/96/EC defines the obligation to keep records on the mass of WEEE treated, it is concluded that from an operational point of view this will only be achievable through mass balances at treatment plants that have a contract with the WEEE System, as the other plants involved in the treatment chain, are not subject to any obligation of reporting by contract or law. Therefore, to implement mass balance for the treatment of WEEE at an industrial scale, a borderline has to be drawn at the treatment plants that belong to the WEEE System.

3.2. Organization of different types of WEEE – Legal Category vs. Treatment Category

In accordance with Annex IA of the WEEE Directive, this specific waste flow is organized in 10 legal categories; this categorization is based primarily on the functionality of equipment during its lifetime, not including the characteristics that determine its management when they reach the end of life.

On the other hand, the sorting of WEEE into 5 treatment categories aims to optimize the management of WEEE from the operational point of view, since it groups the equipments according to the treatment technology installed, as well as to promote the optimization of space in transport. Figure 2 establishes the correspondence between legal categories and treatment categories.

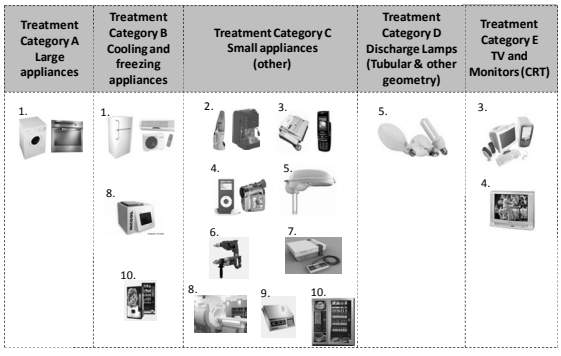

Figure 2 – Legal and treatment categories

As already mentioned the legislation in force, sets targets for reuse/recycling and recovery for each legal category, and determines that they should be calculated based on mass balances to the treatment plants belonging to the WEEE system.

However, for the results to be representative they should translate the processes and technology installed on the treatment plants. Since WEEE are treated in treatment categories and not in the form of legal categories, the assessment of reuse /recycling and recovery rates would be more practical and representative of day-to-day practices of the treatment plants if treatment categories are the functional unit for mass balances. In addition, the implementation of operational practices dedicated to each legal category would demand:

- High labor force to perform the sorting in 10 legal categories;
- An increase in need of available space to storage of each category, until the beginning of test;
- An increase in the number of treatment tests (from 5 to 10) with consequent immobilization of lines for cleaning and preparation for the test;

That is, a greater operational and financial effort.

It is still necessary to define a methodology that relates the targets of each legal category, established by the WEEE Directive, with the treatment categories, so that after a treatment test is performed it can be evaluated whether a treatment plant, meets the targets of the treatment category tested.

Analyzing the correlation between legal category and treatment category it shows that treatment categories A and D consist only of one legal category each, so the setting of targets is direct. Treatment categories B and E have in their composition more than one legal category. However, the definition of targets for these waste streams is also direct, since their categories have the same reuse/recycling and recovery targets.

Finally, treatment category C consists of a group of legal categories with different reuse/recycling and recovery rates. For this reason, it is necessary to set an operational methodology that will allow the definition of targets for treatment category C – Small appliances (other). Table 2 summarizes the correspondence between the targets of legal and treatment categories:

Table 2 - Targets correspondence between the targets of legal and treatment categories

Treatment Category	Legal Category	Legal Category		Treatment Category	
		Reuse/Recycling Target (%)	Recovery Target (%)	Reuse/Recycling Target (%)	Recovery Target (%)
A. Large appliances	1. Large household appliances	75%	80%	75%	80%
B. Cooling and freezing appliances	1. Large household appliances	75%	80%	75%	80%
	8. Medical devices	-	-		
	10. Automatic dispensers	75%	80%		
C. Small appliances (other)	2. Small household appliances	50%	70%	?	?
	3. IT and telecommunications equipment	65%	75%		
	4. Consumer equipment	65%	75%		
	5. Lighting equipment	50%	70%		
	6. Electrical and electronic tools	50%	70%		
	7. Toys, leisure and sports equipment	50%	70%		
	8. Medical devices	-	-		
	9. Monitoring and control instruments	50%	70%		
	10. Automatic dispensers	75%	80%		
D. Discharge lamps	5. Lighting equipment	80%	-	80%	-
E. TV and Monitors(CRT)	3. IT and telecommunications equipment	65%	75%	65%	75%
	4. Consumer equipment	65%	75%		

3.3. Setting targets for treatment categories – Sampling of treatment category C – Small appliances (other)

From a mathematical point of view the reuse/recycling and recovery targets for treatment category C results from a weighted average of the targets of each legal category, in which the weighting factor is the percentage in weight of each legal category in a certain period of time.

To obtain the composition of treatment category C for 2008 9 sampling campaigns were performed, where the sampling unit was equivalent to a load, which depending on the mix of products is normally between 3-4 tones. The results of the sorting of 34.477 kg after the 9 campaigns are identified in Figure 3.

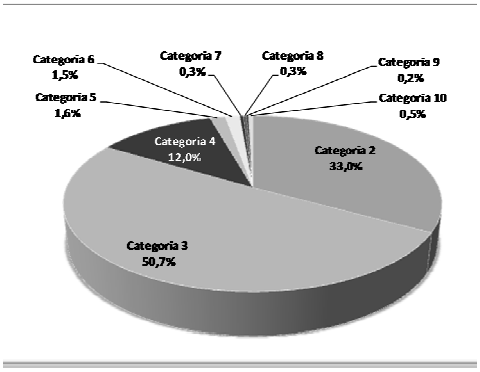

Figure 3 – Sorting results

The analysis of Figure 3 shows that the legal categories 2 - Small Appliances, 3-IT and Telecommunications and 4 - Consumer equipment account for more than 95% of the weight of treatment category C and therefore also have a higher weighting factor in determining the targets of this stream.

Known all variables to determine the targets of reuse/recycling and recovery of treatment category C is now possible to determine the targets for all treatment categories which are presented in Table 3.

Table 3 – Targets for treatment categories

Treatment Category	Reuse/Recycling Target (%)	Recovery Target (%)
A. Large appliances	75,0%	80,0%
B. Cooling and freezing appliances	75,0%	80,0%
C. Small appliances (other)	59,5%	73,2%
D. Discharge lamps	80,0%	-
E. TV and Monitors(CRT)	65,0%	75,0%

4. Procedure for the implementation of treatment tests

Treatment tests refer to the monitoring of WEEE treatment performed in each treatment plant, through one of the following methods:

- Treatment of a pre-selected amount of a treatment category, or
- Treatment of a treatment category during a pre-determined period of time.

In each method the sample should be representative of the material usually treated in the plant. Likewise, it is important to ensure that the test reproduces the normal conditions and treatment processes of the plant.

The purpose of the treatment test is to determine quantitatively and qualitatively all the fractions that are obtained from the treatment of each WEEE treatment category. So at the end of the test the following data should be obtained:

- Treatment line diagram;
- Destination and characterization of each fraction;
- Mass balance;
- Potential for reuse/recycling and recovery of the treatment category tested.

4.1. From potential to effective reuse/recycling and recovery rates

The main objective of the tests is to determine reuse/recycling and recovery rates achieved by each treatment plant for every treatment category. For this purpose, for every fraction resulting from the treatment test the treatment plant provides information on the recovery or disposal operation performed at the plant in the subsequent level of the treatment chain according to the Directive 2006/12/EC, of April 5th. As this information does not include the whole treatment chain at this point, only the potential reuse/recycling and recovery rates are determined.

To achieve effective reuse/recycling and recovery rates it is necessary to integrate the entire chain of treatment in the calculation method. The following data is required:

- Characterization of each end of treatment line fractions;
- Downstream monitoring of every fraction by gathering information given by the first treatment plant where the treatment test takes place;
- Bibliographic research on the technologies usually applied to specific fractions.

Once the tests are concluded and the data mentioned above is gathered it is possible to start editing data into Reptool[1] and determine effective reuse/recycling and recovery rates.

[1] WEEE Forum reporting tool to determine transparent and comparable reuse/recycling and recovery rates

5. Results from a treatment test – Case study on treatment category A – Large appliances

5.1. Characterization of input material

Treatment category A (Large appliances) is characterized by being composed of large household appliances with a high metal content and low hazard levels. Table 4 presents the sample for the test which was selected accordingly to the usual mix of products collected by the WEEE System under this treatment category.

Table 4 – Characterization of input material

A. Large appliances	% (in wheigh)	Average weight (kg/unit)
Washing machines	71,9%	61,0
Dishwashers	14,2%	55,0
Electric cookers	13,4%	40,0
Microwaves	0,5%	16,0
Total	100%	57,1

5.2. Characterization of the treatment line

Representative of the existing technologies, the treatment line dedicated to large appliances is composed of two levels of treatment, a manual dismantling and a large scale shredding process.

The purpose of the manual dismantling is to de-pollute the appliances (e.g., capacitors containing PCBs) and separate some materials that could not be recovered after the shredding process. Among these materials, we highlight the concrete counterweight in washing machines that depending on the composition of the sample may represent 25% of the weight.

The large scale shredding process constitutes the second level of treatment and it takes place in a car shredder. This process aims especially at the separation of ferrous metals. The technologies at car shredder plants include a fragmentation with separation of the light fraction, through cyclones, from the heavy fraction mainly composed of metal. The iron fraction is then recovered by a magnetic separation. The remaining fraction consists of non-ferrous metals, rubber, among other materials; the non-ferrous metals are recovered by heavy media separation.

In Portugal as there are only three car shredders, most treatment plants only carry out the manual dismantling.

5.3. Treatment line technologies and fractions

The treatment test selected for this study was carried out at a treatment plant with only one treatment level. Figure 4 represents the large appliances treatment line.

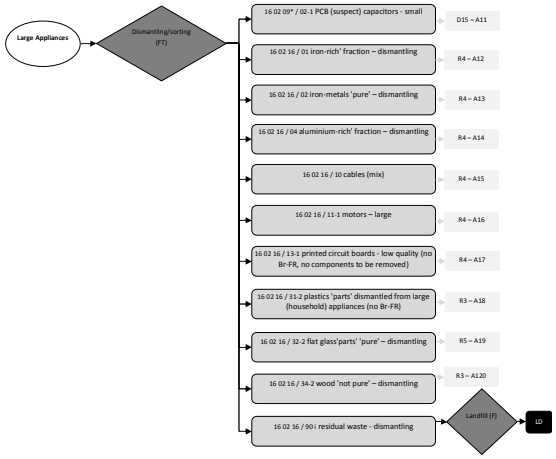

Figure 4 – Treatment chain

Table 5 presents the complete list of parts obtained in the test flow, the respective percentages by weight and destination, recovery or disposal, in accordance with Annexes IIA and IIB of Directive 2006/12/EC.

Table 5 – List of fractions (Reptool)

Reptool-Code	Reptool-Fraction	% (weight)	Operation
16 02 16 / 01	iron-rich' fraction – dismantling	86,46%	R4
16 02 16 / 11-1	motors – large	7,95%	R4
16 02 16 / 02	iron-metals 'pure' – dismantling	2,64%	R4
16 02 16 / 31-2	plastics 'parts' dismantled from large (household) appliances (no Br-FR)	1,43%	R3
16 02 16 / 10	cables (mix)	0,78%	R4
16 02 16 / 34-2	wood 'not pure' – dismantling	0,38%	R3
16 02 09* / 02-1	PCB (suspect) capacitors - small	0,12%	D15
16 02 16 / 32-2	flat glass'parts' 'pure' – dismantling	0,08%	R5
16 02 16 / 04	aluminium-rich' fraction – dismantling	0,07%	R4
16 02 16 / 90	residual waste - dismantling	0,06%	D1
16 02 16 / 13-1	printed circuit boards - low quality (no Br-FR, no components to be removed)	0,02%	R4

5.4. Reuse/recycling and recovery rates

Figure 5 shows the reuse/recycling and recovery rates calculated at the end of the treatment line and at the end of the treatment chain.

Regarding reuse/recycling rates, results from both methods are above the target. However, the difference between the rates at the end of the treatment line and treatment chain is 24,4%.

Regarding the recovery rates, we see that they are the same as the reuse/recycling rates as there is no energy recovery solution. The figure also shows that the target is only achieved at the end of the treatment line as the rate at the end of the treatment chain is 4,5% below the target.

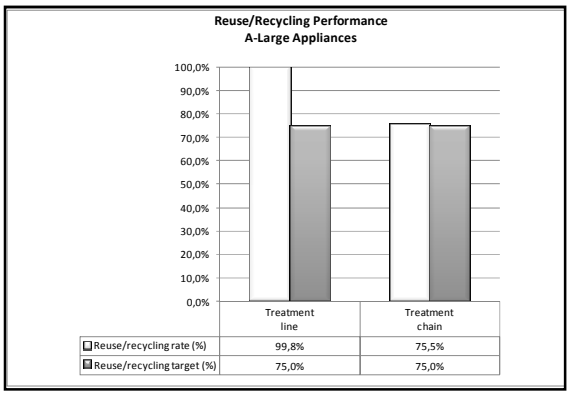

Figure 5 – Reuse/recycling rates

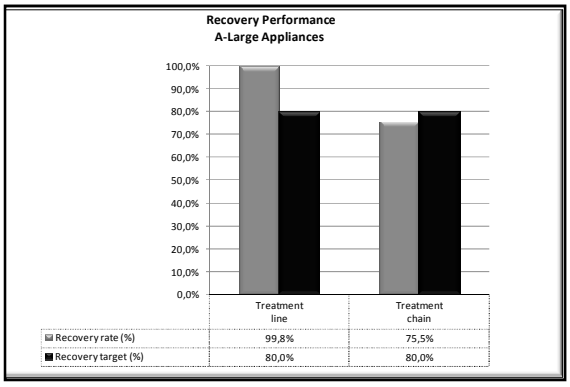

Figure 6 – Recovery rates

5.5. Characterization of fractions at the end of the treatment line

The iron rich fraction is the most significant fraction of Large appliances representing almost 85% of the weight and is also the largest contributor to the difference of the reuse/recycling and recovery rates, between the end of the

treatment line and the treatment chain. This is due to the fact that the treatment plant forwards the entire iron fraction to a car shredder giving it a recovery operation code R4 - Recycling/ reclamation of metals and metal compounds, therefore the entire mass of the fraction is contributing to the reuse/recycling and recovery rates.

On the other hand if the whole treatment chain is incorporated on the calculation, by analyzing Table 6 that shows the content of the iron rich fraction, we realize that after the car shredder process only the iron and the copper will be recovered and thus contribute effectively for the reuse and recycling. Since the cement represents a considerable proportion in the fraction and will end up in the light fraction of the car shredder, which currently in Portugal is being disposed by landfilling, its mass has to be subtracted from the reuse/recycling and recovery rates.

Table 6 – Content of iron rich fraction

Reptool Fraction	Reptool Code	Picture	Composition
iron rich fraction dismantling	16 02 16 / 01		70% Iron 25% Concrete 4% Copper 1% Other

6. Results from all treatment categories

Based on the methodology implemented in this study, it was possible to determine the 2008 rates of reuse/recycling and recovery obtained by Amb3E for all treatment categories, as represented in Figure 7.

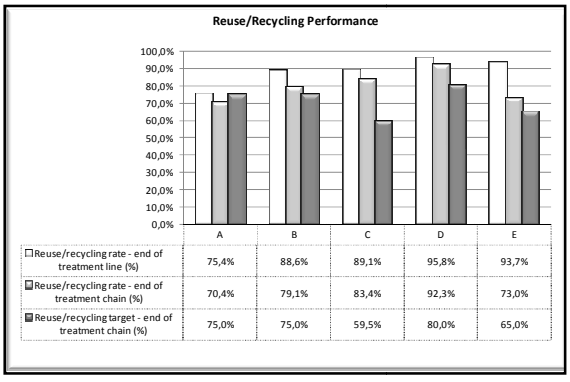

Figure 7 – Reuse/recycling overall rates

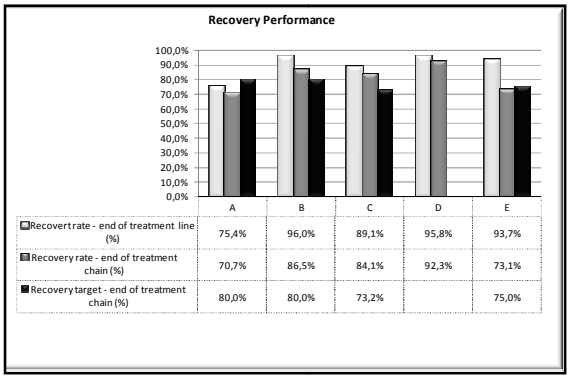

Figure 8 – Recovery overall rates

Analyzing the results of each of the five treatment categories, we can outline the following:

Treatment Category A – Large Appliances, the reuse/recycling rate obtained at the end of the treatment chain is 70,4%, meaning that the rate of this treatment category is below the 75,0% target. Similarly, for the recovery rate Large appliances fall short of the goal as the rate obtained is 70,7% and the target 80,0%. This lack of reuse/recycling and recovery performance is due mainly to insufficient levels of recovery of inert – concrete block - and also because currently in Portugal, there are still no viable solutions to the light fraction of shredders in terms of energy recovery.

Treatment Category B – Cooling and freezing appliances meet all targets as the reuse/recycling rate achieved is 79,1% and the target 75,0%. As for the recovery rate it surpassed the 80,0% target in 6,5%.

Treatment Category C – Small appliances (other) despite the significant losses within the treatment lines the reuse/recycling and recovery rates are clearly higher than targets. Regarding reuse/recycling the rate determined is 83,4% and target 59,5%, for recovery the rate achieved is 84,1% and the target 73,2%.

Treatment Category D – Discharge Lamp, for this treatment category the reuse/recycling target of 80% was exceeded in 12,3%.

Treatment Category E – TV and Monitors (CRT) for reuse/recycling the target set at 65,0% was surpassed, as the calculated rate was 73,0%. However, the 73,1% of recovery rate obtained is below the target set at 75,0%, this result is mainly due by the lack of solutions to recover the cone glass contaminated with lead.

7. Conclusions

The methodology presented in this article ensures the monitoring of treatment practices and the assessment of reuse/recycling and recovery rates based on operational data, in a more transparent and universal method. This enables the comparability of results among Systems using the same method, an essential requirement of the harmonized approach towards the EU Member States behind the WEEE Directive.

Results presented in this article show that the methodology enables the measurement of the effective reuse/recycling and recovery rates, considering downstream levels of the treatment chain, providing further detail and allowing for the calculation of effective results.

This methodology also aimed at minimizing the operational constraints for performing treatment tests and downstream monitoring. However, WEEE is a multi-material waste stream with a high level of complexity, therefore their treatment and recovery throughout the whole treatment chain, translates into an equally complex process. Consequently, an efficient monitoring and control of materials resulting from the treatment of WEEE, will always demand an operational and financial burden that without the existence of the WEEE Systems, could be highly compromised.

As a consequence of the development and implementation of the methodology presented in this study, Amb3E holds today a thorough knowledge of technologies and processes installed in the treatment plants that belong to its WEEE System and also the fractions resulting from the treatment of each treatment category.

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