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Reducing Environmental Impacts of Aluminium Cable Recycling Process with Life Cycle Assessment Methodology

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Abstract

Life cycle impact of European generic primary and secondary aluminium are well defined. However specific recycling processes are not available in literature. In this study, the environmental assessment of cable recycling processing is examined using the Life Cycle Assessment (LCA) methodology. The data come from a recycling plant (MTB Recycling) in France. MTB process relies only on mechanical separation and optical sorting processes on shredder cables. The LCA results demonstrate huge environmental benefits for aluminium recycled in comparison with primary aluminium.

This work was done firstly to document specific environmental impact of MTB recycling process in comparison with traditional aluminium recycling smelting. Secondly, to provide an environmental overview of the process steps in order to reduce the environmental impact of this recycling pathway. Using the identified hotspots from the LCA for the MTB specific recycling process for aluminium cables, we were able to provide help for designers to carry on reducing the environmental impact of the technologies used during the recycling pathway. This paper focuses on LCA results and implementations on the process for reducing the environmental impact.

Keywords: Life Cycle Assessment, Recycling, Aluminium, metal refining, Process optimisation

1. Introduction

Today, the life cycle environmental assessment of European generic primary and secondary aluminium are well defined through the work of the European Aluminium Association (EAA) [1]. However specific recycling processes are not available in literature. In this study, the environmental assessment of cable recycling processing is examined. The data come from a recycling plant (MTB Recycling) in France. The specific and innovative process was developed by MTB Recycling engineers and is sold as a process solution in different countries. The specificity of MTB process relies on the absence of fusion for metal refining. Nevertheless, it reaches standard aluminium purity up to 99.6%. This performance is obtained using only mechanical separation and optical sorting processes on shredder cables. Environmental impact assessment is done using ILCD Handbook recommendations [2]. Three systems are compared: European primary aluminium data from EAA aggregated in Ecoinvent 3.1, secondary aluminium from European remelter data from EAA aggregated in Ecoinvent 3.1 and MTB cable recycling process.

The European demand for aluminium has been growing over the past few decades at a rate of 2.4% per annum [3]. This increase is mainly supported by the rise of recycling which growth was in the same time about 5% per annum [3]. The abundance and the versatility of aluminium in various applications have made it one of the top solutions for lightweight metal strategy in various industries [4]. In the cable industry, substitute copper for aluminium can considerably reduce the linear weight without degrading too much the electrical properties [5]. To obtain optimal electrical conductivity, aluminium use for cables has purity above 99.7% [6]. Because secondary aluminium does not meet the quality requirements for aluminium cables manufacturers; only primary aluminium is used for the aluminium cables supply chain. Nevertheless, improvement in recycling could help reach quality targets, by using new sorting technologies.

Aluminium properties are not deteriorated by recycling. However, in most cases aluminium parts are mixed together at the end of life step without considering their provenance and use. According to this, the 7 series of aluminium are mixed together in waste treatment plant. All aluminium series do not have the same purity and alloying elements pollute aluminium. When aluminium series are mixed together, the cost-effective solution for refining use furnaces. As the metal is molten, the separation is done by using the difference of density and buoyancy (decantation methods, centrifugation, filtration, flotation, etc.). [7] Despite the technology optimisation, a fraction of metal is

un-recyclable [8]. Some alloying elements are lost in the process [9] and this results in a drop of quality which is akin to a down-cycling [10]. The solution lies in a better separation of aluminium series upstream from the recycling chain. This strategy should enable products to be guided through the best recycling path and maintain the quality of alloys.
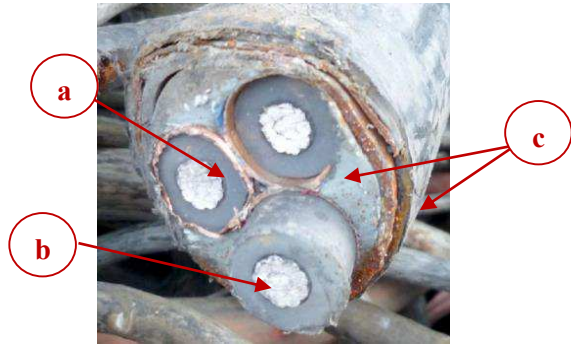

Fig. 1 Section of a cable having multiple beams of aluminium.

The cable is composed of an aluminium core cable (a), covered with a polymer thick layer (b) as illustrated in Fig. 1. Additional metallic materials (c) are coaxial integrated in order to finish the definition of this composite product. These cables are manufactured by extruding together all the materials that compose it.

Aluminium in cables represents between 35 and 55% of the total weight. Other metals are mainly steel, lead, copper, zinc. The variety of plastics contained in the sheath is even stronger than for metals: silicone rubber, Polyethylene (PE), cross-linking PE (xPE), Polychloroprene (PCP), vulcanised rubber, Ethylene Vinyl Acetate (EVA), EthylenePropylene Rubber (EPR), flexible PVC, etc. [11]

The Table 1 shows the mass proportion of materials contained in cables. Mass proportions are extracted from MTB monitoring data of cables recycled at the plant between 2011 and 2014. Aluminium in cables represents between 35 and 55% of the total weight. Other metals are mainly steel, lead, copper, zinc. The variety of plastics contained in the sheath is even stronger than for metals: silicone rubber, Polyethylene (PE), cross-linking PE (xPE), Polychloroprene (PCP), vulcanised rubber, Ethylene Vinyl Acetate (EVA), Ethylene Propylene Rubber (EPR), flexible PVC, etc. [11]

Table 1 Composition of recycled cables at the MTB plant (average for the period 2011-14)

Material	Proportion
Rigid aluminium	48.5%
Plastics and rubber	40.5%
Non-ferrous metals	4.5%
Ferrous metals (steel and stainless steel)	4.0%
Flexible aluminium	2.5%

Although aluminium cables represent about 8% of aluminium products in Western Europe [12]. The inherent purity of aluminium used for cables justifies differentiate recycling channels to optimise processing steps and improve cost efficiency. At the end of life, the challenge concerns the separation of materials from each other. The most economical way to separate different materials rely on a smelting purification.

An alternative process for cables recycling uses only mechanical steps instead of thermal and wet separation, as developed for several years by MTB Recycling. The aluminium obtained by recycling cables is specially appreciated by the smelter. Its high purity makes it easy to produce a wide variability of aluminium alloys. Recycled aluminium can then be used in a large number of aluminium products and not only in applications requiring high alloy aluminium.

Numerous studies were conducted concerning the sustainability of aluminium recycling in comparison with primary aluminium. Outcomes about global and local environmental impacts show decrease up to 90% by using recycled aluminium [3.13]. However, systems modelling always relate to the standard melting solution for recycling aluminium. In contrast this study focuses on the environmental assessment of cable recycling in MTB specific process.

On the one hand, the study demonstrates huge environmental benefits for aluminium recycled in comparison with primary aluminium. On the other hand, the results show the harmful environmental influence of the heat refining by comparison with cold recycling process. The study demonstrates the interest of recycling by sector rather than in blend. The data collection method does not allow the use of the results for other cables recycling processes. The results are representative only of recycling solutions developed by MTB.

Although the starting point of the study was to document the environmental impact of a specific recycling pathway; the results of this study have allowed to identify several hotspots of the recycling process. Thus it leads the development of effective fixes to reduce the overall impact of the recycling pathway. The purpose of this article is to explain how Life Cycle Assessment (LCA) methodology help MTB company to reduce environmental impacts of the aluminium cable recycling processes.

2. Analytical framework

2.1 Functional unit proposal

As part of this study, the functional unit used is as follows: producing one ton of aluminium intended for end-user applications, with a purity of> 97% using current industrial technologies (annual inbound processing> 10,000 t) located in Europe. The matching quality of the compared products can meet the same function as a high purity aluminium can be used for producing a large number of alloys without refining.

We selected three scenarios that meet all the conditions of the functional unit:

- *Scenario 1 or primary*: primary aluminium, resulting from mining.

- *Scenario 2 or secondary*: secondary aluminium from recycling by melting.
- *Scenario 3 or MTB*: MTB aluminium, from recycling using the MTB processes.

The primary aluminium production is used as a reference for guidance on the quality of production. Foremost, our analysis is intended to compare methods of recycling. Comparison with scenario 1 should help translate environmental benefits of recycling.

2.2 Presentation of the Study Scope

This study is based on a life cycle approach, in accordance with the standards of International Organisation for Standardisation (ISO 14,010/44) [14.15]. The Fig. 2 presents the study scope used for the life cycle analysis of MTB recycling process, the boundaries are based on the Ecoinvent modelling. The boundaries include cradle to exit gate stages [16.17]. Life in use of aluminium in the products are not included in our study scope. The study only focuses on transformation steps of aluminium. As shown on the Fig. 2 by-products are included in environmental impacts calculation, but no benefit of by-products recycling is integrated into the study.
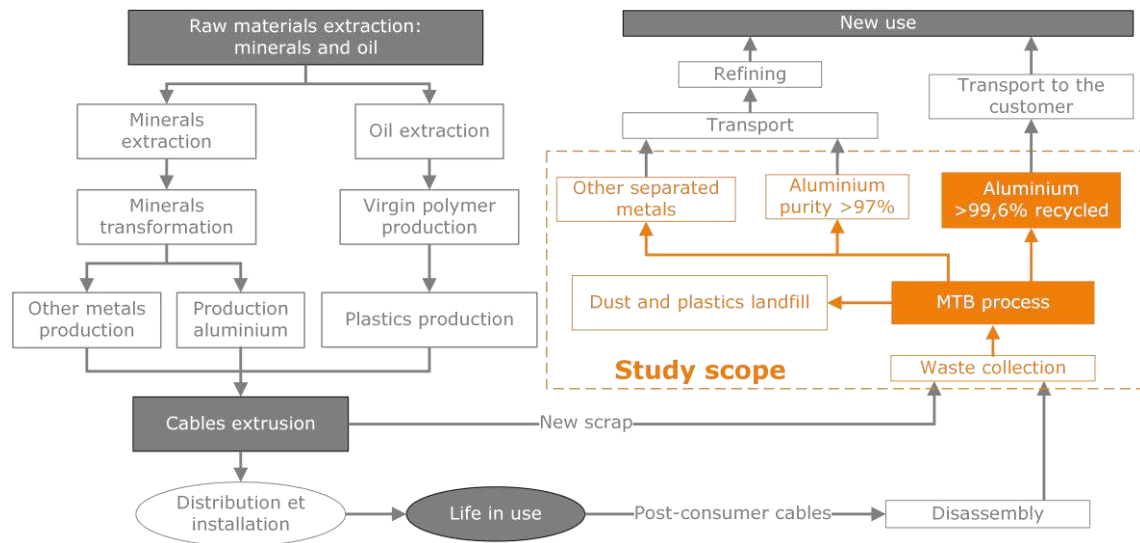

Fig. 2 Study scope for the cable recycling system boundaries

2.3 Sources of Data for the Life Cycle Inventory

The evaluation is designed by modelling input and output flows that describe different systems of aluminium recycling with the software SimaPro (8.04 [18.19]. All the flows are based on processes from Ecoinvent 3.1 library [20]. The systems are developed according to the local context of Western Europe. To allow comparison all the inventory elements are compiled based on the Ecoinvent database boundaries and data quality check [21.22]. Once modelling were done, the characterisation is conducted according to International Reference Life Cycle Data System (ILCD) Handbook [2] recommendations. The following sections detail key aspect of the methodology.

This study compares two different modelling systems. Both systems modelling using Ecoinvent data. Scenarios 1 and 2 using available data in Ecoinvent library without any modifications. And scenario 3 using Ecoinvent data to model MTB recycling process, the inventory data set was done using the inventory data sets recommendations from JRC [23]. The three modelling rely on the same system boundary.

3. Scenario Development

Aluminium recycling from remelter (scenario 2) is used as a baseline to evaluate the MTB alternative pathway (scenario 3). The baseline scenarios refer to the Western European aluminium average consumption. The scenario 2 and scenario 3 are based on Ecoinvent unit processes modelling. Ecoinvent database uses the EAA Life Cycle Inventory (LCI) [24]. For Ecoinvent v3.1 [25.26], the Aluminium processes are built with data collected by EAA in 2013 [27.28]. The Ecoinvent modelling using the average technology available on the market for Western Europe [22].

3.1 Scenario 2: Conventional Aluminium Recycling

Scenario 2 provides the modelling of the traditional aluminium recycling solution. This scenario is based on shredding steps and melting purification step made by refiners. As for scenario 1, the scenario 2 is based on average values of European smelters. The data was compiled by the EAA and provided in Ecoinvent database. The electricity mix used in the modelling is equivalent to the electricity mix provide by the European Network of Transmission System Operators for Electricity. It is mainly fossil fuel (48.3%), nuclear power (28.1%) and renewable energy (23.6%). The distance of transport takes into account for the scenario 2 is 322 km (20 km on water, 109 km by train and 193 km by road).

In Ecoinvent, there are 2 data collections. One data collection was done for production scraps (new scrap) and the other one for post-consumer scrap (old scrap). The processes

used for recycling new and old scraps are not the same. New scrap needs less operation than old scraps. The inbound logistics is also different because some of the waste is recycled directly on production plants. For the study the ratio between old and new scrap is based on European aluminium mix [27]. In 2013, old scrap represents 46.3% of aluminium recycled in Europe and new scrap 53.7%. After the recycling process, there are 2 outlets possible: wrought or cast aluminium. For the study, the choice falls on wrought aluminium because it has sufficient purity required by the functional unit (97%). The data chosen for the study is *Aluminium, wrought alloy {RER} | Secondary, production mix* [29].
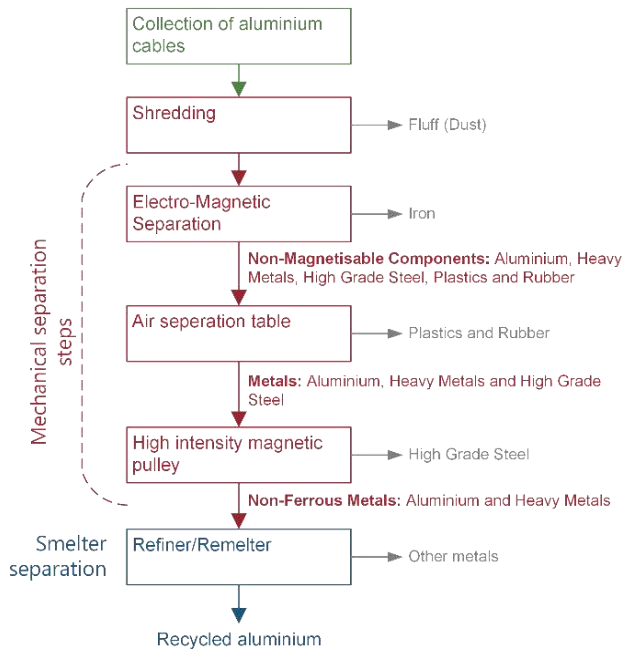

Fig. 3 Standard end-of-life recycling scenario for aluminium cables

The Fig. 3 presents aluminium recycling as modelled in the Ecoinvent dataset. The modelling is divided in 5 steps: 4 mechanical separation steps (in red on the figure) and 1 thermal steps (in blue on the Fig. 3).

3.2 Scenario 3: MTB Cables Recycling

The Fig. 4 shows all the steps take into account in the modelling of scenario 3. For this scenario, the distance of transport takes into account is 540 km for old scraps and 510 km for new scrap from various cable manufacturers. The intrinsic aluminium quality reaches at least 99.6% of aluminium purity (average quality check during the period 2012–2014). An intensive inventory analysis was developed during an internal survey conducted in collaboration with EVEA consultants firm at MTB Recycling plant during autumn 2014. Foreground data are based on measurement and on stakeholder interviews. Collection of background data comes from Ecoinvent 3.1 or relevant literature. For this scenario, the distance of transport takes into account is 540 km for old scraps and 510 km for new scrap from various cable manufacturers. The intrinsic

aluminium quality reaches at least 99.6% of aluminium purity (average quality check during the period 2012–2014).

MTB Recycling has an environmentally friendly strategy at a strategic level. As a consequence, they subcontracted with an energy provider that ensures an electricity mix from renewable energy source. Electricity comes almost exclusively from hydroelectric power (6.62% from alpine reservoirs and 2.4% from run of the river). The remaining electricity comes from waste to energy plants (0.51%) and from cogeneration plants (0.17%).
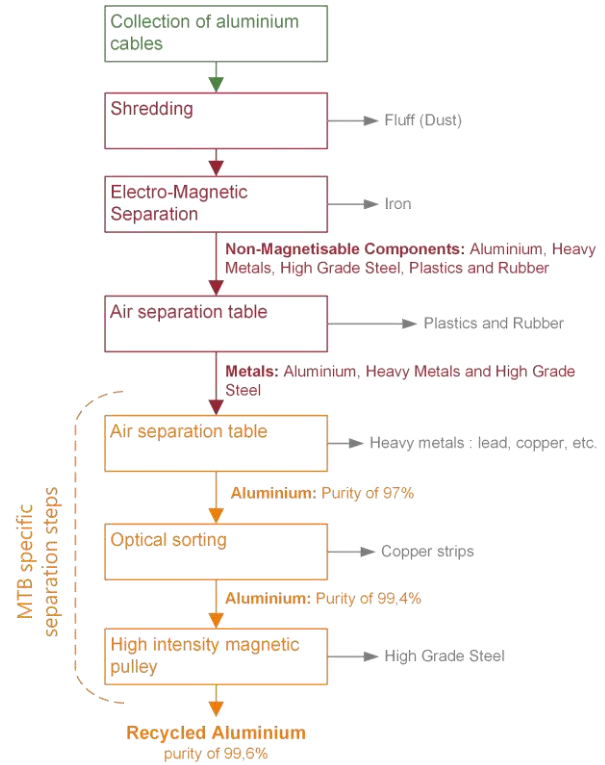

Fig. 4 MTB end-of life recycling process for aluminium cables

4. Life Cycle Assessment Results

4.1 Impact Assessment Method

The Table 2 presents the models of selected indicator of the Life Cycle Impact Assessment (LCIA) method. The two models in italics in the Table 2 are models replace compared to the recommended ILCD 2011 impact assessment methodology [30], which was used throughout the study. The ILCD method is used with 2 modifications on calculation factors:

- Human toxicity, non-cancer effects
- Water resource depletion

For human toxicity indicators, USEtox (recommended + interim) v1.04 (2010) [31] model was implemented to improve our characterisation method with latest calculation factors as recommended by UNEP and SETAC [32]. First results on water resource depletion with default calculation factor from Ecoscarcity [33], show anomalies. These anomalies are all related to the transportation modelling in Ecoinvent which involves electricity mix of Saudi Arabia. For the water resource

depletion indicator, the Pfister water scarcity v1.01 (2009) [34] calculation factor was implemented in our characterisation method. The Table 2 presents the models of selected indicator of the Life Cycle Impact Assessment (LCIA) method. The two models in italics are models replace compared to the recommended ILCD methodology.

Table 2 Indicators selected for the life cycle impact assessment [35]

Indicators	Model
Climate change	Baseline model of 100 years of the IPCC
Ozone depletion	Steady-state ODPs 1999 as in WMO assessment
Human toxicity, non-cancer effects	*USEtox model v1.04* [32]
Particulate matter	RiskPoll model
Ionising radiation HH	Human health effects model as developed by Dreicer
Photochemical ozone formation	LOTOS-EUROS
Acidification	Accumulated Exceedance
Freshwater eutrophication	EUTREND model
Freshwater ecotoxicity	USEtox model
Water resource depletion	*Pfister water scarcity v1.01* [33]
Mineral, fossil & ren resource depletion	CML 2002

A sensitivity analysis on the characterisation method was conducted using the ReCiPe Midpoint v1.1 method and CML IA Baseline v3.01 methods. This analysis has not yielded conflicting results.

4.2 Recycling Scenario Comparison

Our LCA show that secondary aluminium reaches approximately 10% of the impact of the primary aluminium scenario. And MTB aluminium shot is close to 5% of the primary aluminium impact on all the set of indicators. Those results correspondent to evaluation already done and meet the values given by the Bureau of International Recycling (BIR) for aluminium recycling benefits [36] and results from other studies publish in the International Journal of life Cycle Assessment [37].

The Fig. 5 gives the opportunity to compare more specifically the two recycling scenarios. On the Fig. 5, the impacts are presented using the specific electricity mix for the 2 recycling scenarios. On the set of indicators, the impact of scenario 3 does not exceed the impact of scenario 2. In addition, the impact of MTB recycling scenario represents between 2% and 46% of the impact of recycling by melting. The average impact of the solution is halved.
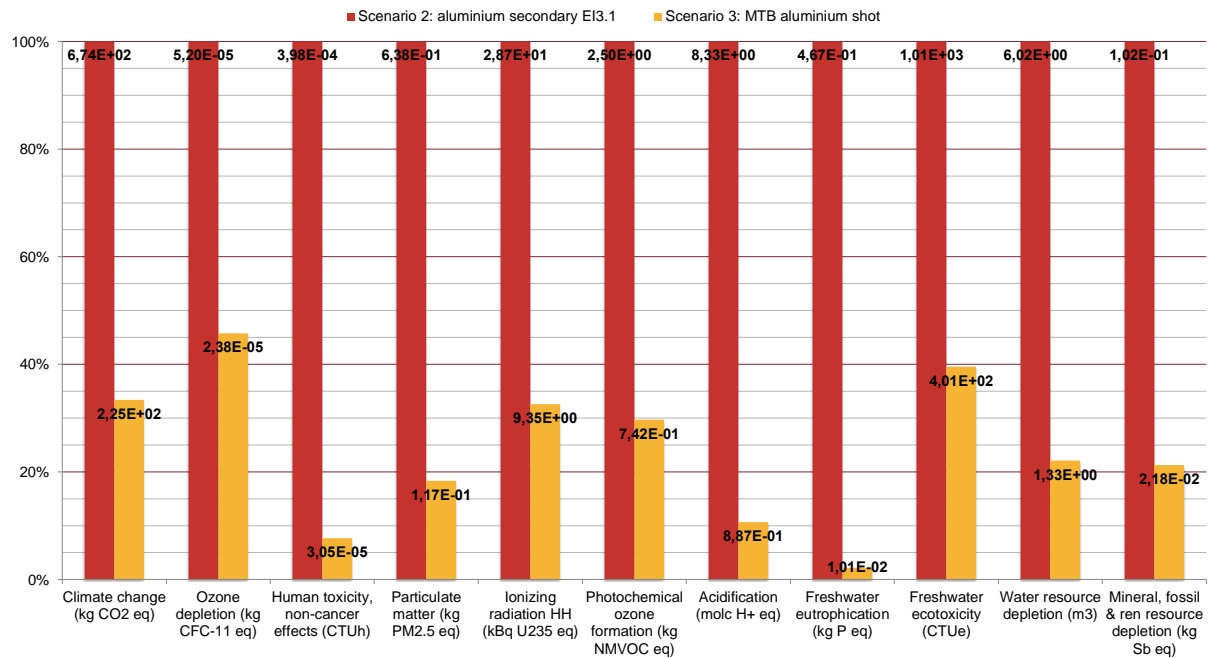

Fig. 5 Comparison of the characterisation of the 2 recycled scenarios using specific electricity mix

4.3 MTB Aluminium Environmental Impacts Assessment

LCA results allow us to establish a hierarchy between environmental recycling solutions for aluminium cables. Whatever the electricity mix used by the recycling plant, the MTB mechanical recycling process is the most environmentally friendly. In this last part of the article, we focus only on the MTB recycling pathway.

The Fig. 6 shows the results for the characterisation of the MTB aluminium shot, with the specific renewable electric mix used by MTB. The values used for representation in Fig. 6 are

given on the figure. The results show a very strong contribution from the upstream transport for the collection of waste in the total impact of the scenario. On the set of indicators, the MTB recycling steps represents between 11.4% and 79.7% of the total impact. The average of the 11 indicators brings up an average impact of 36.1% and a median of 33.0%.

Besides the influence of transport, the study identified a major contributor to the impact of the shredding step: the steel consumables used for the blades and screens.

When the European electricity mix is used for the characterisation, all the recycling stages of MTB scenario represent on average 50% of the total impact on the set of indicators.

All plastics from the cable sheaths are not recycled. The plastic mixture and the presence of aluminium dust greatly complicates mixture recycling. Plastics waste management appears as a huge impact hotspot. Indeed, this step represents about 5 to 10% of the overall environmental impact of the MTB pathway while it is only transport (25 km) and landfill.
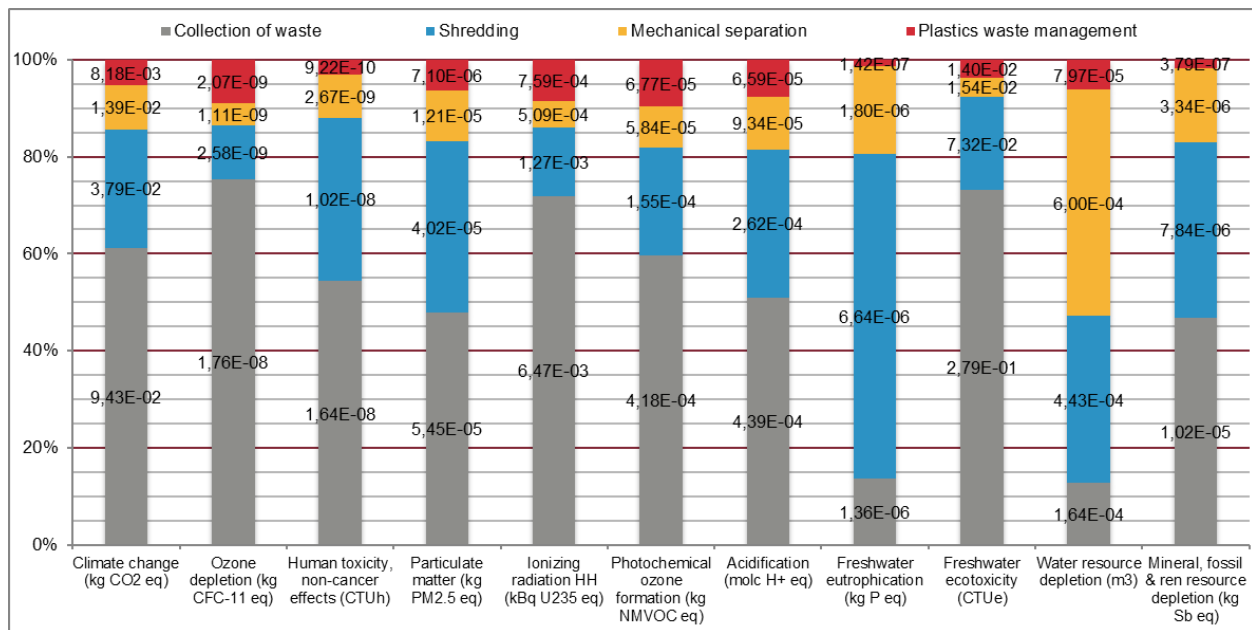

Fig. 6 Characterisation of MTB aluminium shot with purity of 99.6% specific electricity mix

5. Discussion and Conclusion

LCA results demonstrate that recycling when driven without loss of quality is a relevant alternative to mining. However, LCA also allowed showing the shredder consumables (steel blades and screens) as elements with a high impact in proportion to their mass. MTB has launched an ecodesign approach in collaboration with subcontractors to identify more durable steel alloys for shredding blades. The tests carried out with news blades demonstrate an increase of 30 to 60% of the lifetime.

This study highlights the need to develop green recycling processes for mixture of plastics. Following this study, MTB has initiated a development approach to sort and recycle the plastic mixture. A first prototype was developed in late 2015. The synoptic of plastic processing method is shown in Fig. 7. The separation is always based on simple mechanical steps that achieve a uniform separation. Be noted that the process is modified according to the stream of plastics produced by the aluminium separation step.

The shredding steps are on average 2 times more impacting than mechanical separation steps. Work on the efficiency of the shredder is necessary to reduce the electricity consumption of this step. For now, no solution emerges to reduce this impact.

Nevertheless, the energy recovery solutions and new electric motors are studied.

Our team is now working on automating this ecodesign in order to propose a roadmap for the designer and an assessment tool available for recycling pathways.
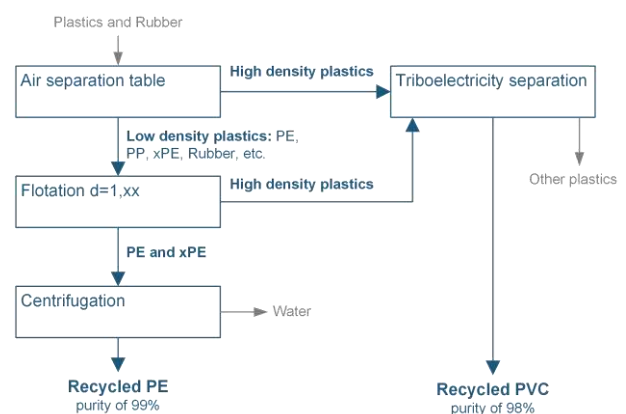

Fig. 7 Presentation of processes added to the MTB pathway to separate the plastics mixture

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