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# Eco-Balance analysis of the disused lead-acid-batteries recycling technology

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**Abstract.** The article presents the results of the eco-balance analysis of the disused lead-acid batteries recycling process. Test-dedicated technology offers the possibility to recover other elements, for example, polypropylene of the battery case or to obtain crystalline sodium sulphate. The life cycle assessment was made using ReCiPe and IMPACT2002 + methods. The results are shown as environmental points [Pt]. The results are shown in the environmental categories, specific for each of the methods grouped in the impact categories. 1 Mg of the processed srap was a dopted as the functional unit. The results of the analyses indicate that recycling processes may provide the environmental impact of recycling technology less harmful. Repeated use of lead causes that its original sources are not explored. Similarly, the use of granule production-dedicated polypropylene extracted from battery casings that are used in the plastics industry, has environmental benefits. Due to the widespread use of lead-acid batteries, the attention should be paid to their proper utilization, especially in terms of heavy metals, especially lead. According to the calculations, the highest level of environmental benefits from the use of lead from secondary sources in the production of new products, was observed in the refining process.

## 1 Introduction

In Poland, there are two methods of processing battery scrap. The first one allows the processing of non-broken up batteries. Technological gases which contain substances requiring high-temperature post-combustion in the dust extraction system, can be considered a technological disadvantage. This complicates the process of exhaust purification and practically prevents the reduction of chlorine emissions.
The second method allows only lead metallurgical fractions to be introduced into metallurgical processing. Plastics are, in turn, processed to produce commercial products. Some of the plastic fractions that do not find an industrial application is stored as waste. Metallurgical processing of lead fractions is performed in electric, vertical, rotary or rotary-pendulum furnaces. The study analysed the recycling of disused batteries using the first method.
Fig. 1 shows a schematic diagram of a recycling system for lead acid batteries for which an eco-balance analysis has been carried out.
The first stage in the recycling of disused lead-acid batteries involves the mechanical break up the batteries, then filtering out the electrolyte and disassembling the battery components. At this stage the hydrodynamic method of separation is used and metallic, plastics, sulphated lead paste, polyethylene and electrolyte fractions are formed.

The lead paste along with the electrolyte is directed to the desulfurization line, where sodium method is used to convert sodium sulphate to lead carbonate using sodium carbonate.

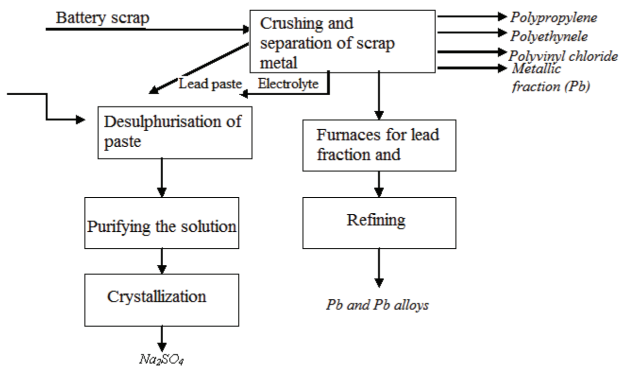


**Fig. 1.** The scheme of scrap metal recycling of lead-acid batteries by using the desulphurization process. [1,2]

As a result, a 2% desulphurized paste and a sodium sulphate solution are formed. This solution, following pre-filtration and purification, is directed to the evaporation and crystallization line. The result is anhydrous sodium sulphate, used in the cosmetic and metallurgical industries [3,4]. The next stage is production of raw lead obtained with the fire processing of desulphurized lead paste together with the metal

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fraction in the tilt-and-turn furnaces. The final stage is the refining process in which the raw lead is melted in the refining boilers and subjected to the process of removing impurities of foreign metals. During the refining process, the slags are formed from which lead is recovered in the tilt-and-turn furnaces [5,6].

The management of disused lead-acid batteries is realized in compliance with by Directive 2006/66/EC of the European Parliament and of the Council [7]. According to the provisions of the Directive, the battery and accumulator management system includes, inter alia, is formed by the recycling companies. Currently, there are 5 companies operating in Poland with such business profile. There are battery manufacturers, users and the entities involved in collecting waste batteries and accumulators. The system also includes the entities introducing batteries and accumulators (3064 entities) onto the market, processing plants (27) and the ones combining both forms of activity (3) [8]. According to the information in the report on the functioning of the recycling system in the country for the year 2015, 81958 Mg of car batteries were put on the market [9].

In the paper [10], the authors describe the results of the eco-balance analysis of the disused lead-acid batteries recycling technology based on typical data from the Italian market. In this paper, similar boundaries have been adopted. This is important as some people believe that the LCA should not cover only the recycling phase.

Unterreiner et al. [11] describes recycling technology for three types of batteries. Authors presented the results of the LCA analysis for three types of batteries, including lead-acid batteries (LCiA) where the evaluation was performed using ReCiPe method. Information about lead-acid-batteries recycling derives from the literature. The authors point out the importance of the lead-acid batteries recycling which can lessen the environmental impact by 50%.

Alistair et al. [12] carried out an LCA analysis among the others for lead-acid batteries. It was found that the manufacture and production stages do not play a dominant role in the environmental impact. On the other hand, high recycling indicators significantly reduce LAB's environmental impact.

Tian et al. [13,14] compared the recycling technology of the five types of lead-acid batteries using national life cycle databases. In addition, they have modelled the costs of these technologies. They highlighted the issue of the sulphur dioxide emission which causes the very high level of the environmental acidification. The result of the economic analysis of recycling carried out for different batteries is similar. The authors point out the need to seal the recycling system of disused batteries in China, since only a portion of the lead is recovered. The share of recovered lead in the lead production in China is only 30%. The authors propose to implement the American recycling system model (e.g. recycle through the network of sulphuric acid producers) and supporting Best Available Technique (BAT) in this area.

Ferget. et. al. [15] point out the high content of lead, rutile and iron compounds in the products derived from waste polypropylene obtained from the recycled lead-acid batteries and the presence of harmful airborne compounds generated by the combustion of polypropylene. These are chlorine and bromine compounds. Despite the possibility of recovery of this material, the level of contamination in the resulting material should be monitored. The tests should be carried out to determine the presence of calcium carbonate, rutile and iron oxide and lead in the form of dioxides and sulphate. The papers [16,17] describe the situation in China concerning the lead-acid batteries recycling system and the level of lead pollution. The need of recycling used up lead has been brought the attention, which will be possible when the battery collection and utilization system is sealed.

## 2 Assumptions for the study

The data used to carry out the eco-balance analysis of the energy materials flow and pollutants emissions is both a real data from the company involved in the lead-acid batteries recycling process and the literature data. It was assumed that only lead-acid batteries from passenger cars are used in the technological process. 1Mg of recycled battery scrap was adopted as a functional unit. A simplified analysis was carried out. It was conducted taking into account the following processes:

1. Processing of battery scrap, desulfurization of lead paste and sodium sulphate crystallization, designated as PI,
2. Re-melting of the desulphurized lead paste to a form of raw lead, labelled as PII process,
3. Refining of raw lead and re-melting into the form of raw lead from other lead materials, labelled as process PIII.

The boundary of the testing system is the recycling of disused lead-acid batteries, from the moment they are delivered to the processing plant until the end-product – refined lead - is received. The additional processes such as: polypropylene recovery, sodium sulphate production, landfill of polyvinyl chloride waste and slag were also included in the eco-balance. The company has the necessary environmental permits and a number of awards related to its pro-ecological undertakings. The technology for which the analysis was carried out is referred to as "Best Available Technique" (BAT) and is included in the guidelines for non-ferrous metal management in Poland.

The quantitative data defining the mass and type of raw materials, wastes and emissions obtained for 1 Mg of disused lead acid batteries will be the basis for the study.

## 3 Methodology

The SimaPro v. 7.3.3. software, dedicated to carrying out eco-balance analysis, was used to estimate the potential environmental impact of lead-acid batteries recycling technology. This tool has a built-in database of seventeen methods used for analyses. The data specific for the European conditions include such methods as: CML2 Baseline 2000 and 2002, ReCiPe, IMPACT2002 +, Ecoindicator99. The study used ReCiPe and IMPACT2002 + methods which were created by combining two eco-balance methods: CML and Ecoindicator99 (Table 1 and Table 2).

**Table 1.** Categories of damage and impact in the ReCiPe method [19].

| Damage category | Unit | Impact category |
|---|---|---|
| Human Health (HH) | DALY | Ozone depletion<br>Human toxicity<br>Particulate matter formation<br>Photochemical oxidant formation<br>Climate change<br>Ionising radiation |
| Ecosystem Quality (EQ) | Species / Year | Terrestrial acidification<br>Freshwater eutrophication<br>Terrestrial and freshwater ecotoxicity<br>Agricultural/urban land occupation<br>Natural land transformation |
| Resources (R) | $ | Metal depletion<br>Fossil depletion |

DALY – Disability Adjused Life Years; Species/Year – extinction of the species during the year; $ - increase in costs resulting from the extraction o of resources.

**Table 2.** Categories of damage and impact of the Impact2002+ method [19]

| Damage category | Unit | Impact category |
|---|---|---|
| Human health | DALY | Carcinogens<br>Non-carcinogens<br>Ozone layer depletion<br>Human toxicity<br>Respiratory organics<br>Respiratory inorganic<br>Photochemical oxidation<br>Ionising radiation |
| Ecosystem quality | PDF*m2 *year | Aquatic ecotoxicity<br>Terrestrial ecotoxicity<br>Terrestrial acidification/nitrification<br>Aquatic acidification<br>Aquatic eutrophication<br>Land occupation |
| Climate change | Kg $CO_2$ eq | Global warming |
| Resources | MJ primary | Non-renewable energy<br>Mineral extraction |

DALY - Disability Adjused Life Years; PDF*$m^2$*year – Potentially Disappeared Fraction; MJ – megajoule

They differ in how they represent the damage category – resources. In the ReCiPe method, the category is expressed by the increase in costs caused by the extraction of resources. In the second method, the category is determined by the amount of primary energy [18].

Unfortunately, SimaPro software does not have built-in methods and databases that take into account Polish conditions. Table 1 shows the damage categories and impact categories that are specific to the ReCiPE method.

The IMPACT2002 + method has identified 14 environmental impacts and 4 damage categories, including: human health, ecosystem quality, climate change and resource exploitation [20].

Table 2 shows the categories specific to the second IMPACT2002 + method used.

## 4 Results and discussion

The results of the analysis presented in Fig. 2 show that the PIII is the most advantageous process in terms of environmental impact.

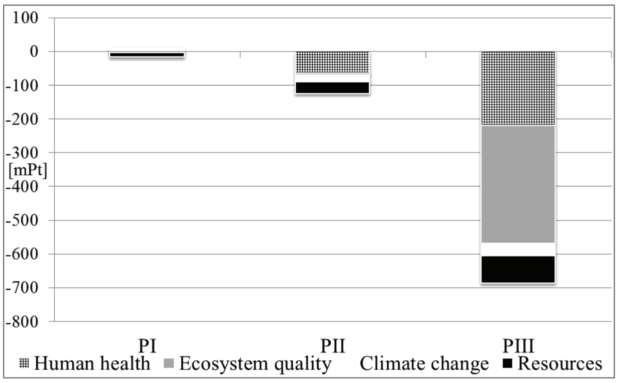


**Fig. 2.** The results of the analysis of the Eco-balance sheet for the processes of PI-PII-PIII in terms of the 4 categories of impact (impact categories). IMPACT2002+ methods.

This is related to the so-called production avoidance. This is due to the use of waste materials to manufacture new items and avoid the use of primary materials. The total level of environmental benefits for the refining process is -700 mPt.

Fig. 3 shows the results of comparative analysis of PI-PII-PIII processes for the damage category - ecosystem quality.

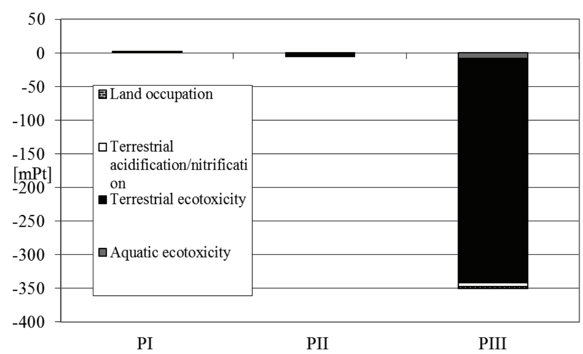


**Fig. 3.** Impact category related to the ecosystem quality for the PI-PII-PIII processes. IMPACT2002+ Method.

Almost 95% of all identified environmental benefits in this group are related to the Terrestrial eco-toxicity category and are (-336.23) Pt. Environmental benefits in this area were identified for PII and PIII processes.

In the category related to acidification and eutrophication of the aquatic environment, no environmental impact was identified. Global warming in the category of climate change is (-44.34) Pt. For each process received values (10.31; -20; -34) Pt. In the group of resource-related factors, the environmental benefits for all non-renewable energy (-13.92; -35.06; -87.49) Pt. On the other hand, for the mineral extraction category, environmental impacts were identified as low, for all processes (-0.05) Pt. Fig. 4 shows the results of the eco-balancing analysis for the storage of polyvinyl chloride (PVC), slag, and the utilizing processes of the waste materials for the production of new materials. This includes waste polypropylene (PP) from the battery casing from which the commercially produced granular material as well as crystalline sodium sulphate resulting from the lead paste cleaning treatment.

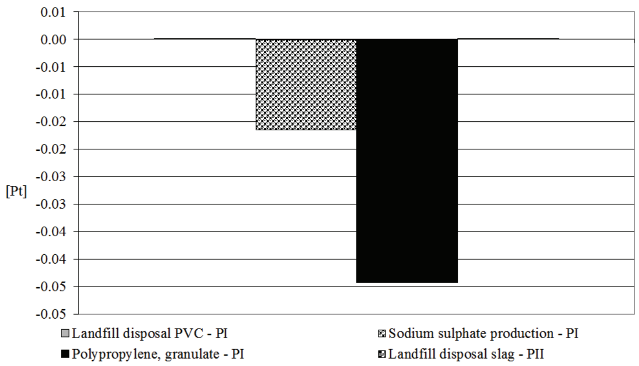


**Fig. 4.** The comparison of the effect of selected waste management in terms of environmental impact categories selected characteristic for the IMPACT2002+ method (PI – PII).

Fig. 5. shows the results of the eco-balance analysis of PI-PII-PIII processes carried out by ReCiPe method. Results for individual processes are as follows: (-2.93 Pt; -29Pt; -87Pt).

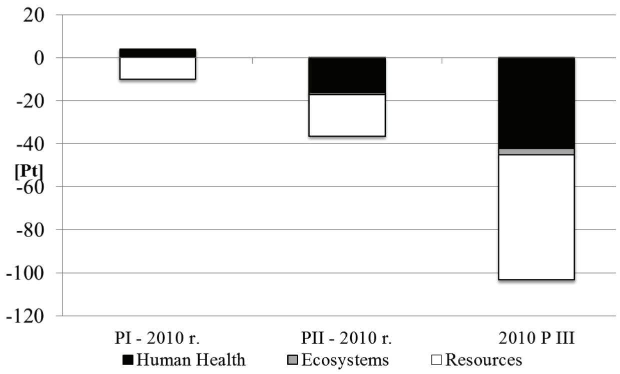


**Fig. 5** The results of the analysis of the Eco-balance sheet for the processes of PI-PII - PIII in terms of the 3 categories of impact.(impact categories). ReCiPe methods.

The environmental benefits have been identified primarily in the *resources* category which represent 55.18% of all identified impacts. The impacts on human health account for 54% of the calculated environmental impacts.

Fig. 6. shows in detail the results of the eco-balance analysis for the categories related to human health. The environmental benefits have been identified for most of the identified processes.

In the particulate matter formation category, negative values have been obtained for PII and PIII (-5.4 and -13.58) Pt. In total, this represents 52.81% of all identified environmental benefits associated with human health.

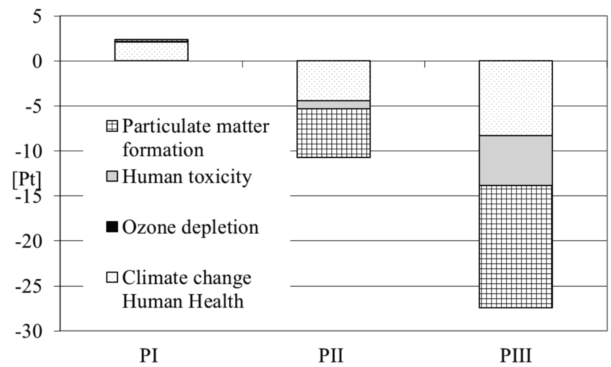


**Fig. 6.** Impact category related to human health for the PI-PII-PIII processes. ReCiPe methods.

The level of total environmental damages associated with dumping the waste in the landfill has reached the following values: for polyvinyl chloride (Pt 0,03) Pt, while the storage of slag which is waste from re-melting the lead paste reaches (0.04) Pt.

The environmental benefits were identified for (PP) production processes (-14) Pt and sodium sulphate production (-5) Pt.

The potential environmental impact of PIII storage processes has not been assessed because no information has been obtained about this.

The results in Fig. 7 show that no environmental benefits can be identified in the waste landfilling process.

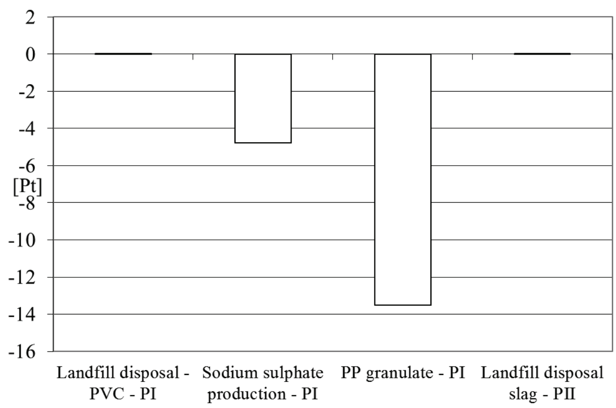


**Fig. 7.** The comparison of the effect of selected waste management in terms of environmental impact categories selected characteristic for the ReCiPe method (PI –PII).

The result of the analysis may be due to the lack of economic use of waste and, the need to obtain raw materials for their production.

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## 5 Conclusions

The total environmental burden estimated for recycling technology of 1 Mg of lead-acid batteries is (-119.60) Pt for ReCiPe method and (-817) Pt for IMPACT2002 + method. The negative outcome indicates the environmental benefits that result from the so-called avoided emissions. This means that, thanks to the use of recycled lead for the production of refined lead, the use of polypropylene from battery casings in a form of granules i.e. base product for production or the production of sodium sulphate, it is possible to utilize potentially harmful components of the battery. Despite the storage of polyvinyl chloride or the non-use of slag, the processes that positively affect the environment are superior to those generating environmental damage. The differences in the results of the analyses carried out by two different methods may be due to distinctions in weighing techniques used in individual methods as well as the use of different characterization parameters for the same impact categories.

The paper highlights the possibility of using environmental analyses to obtain information on the level of environmental damage that could potentially influence the assessment of whether the object under analysis will be perceived as environmentally friendly. Conducting the analyses in these areas will enable to take action aiming at improving the solution to the battery recycling system in the country as well as emphasize the need for extreme caution before actually implementing organizational and technological changes which could have a negative environmental impact.

It should be stressed that there are no papers in Poland regarding eco-balance analyses applied to the lead-acid batteries recycling technology. It should be emphasized that the analyzes carried out were based on the real data, which quantitatively determine the realization of the processes of recycling and utilization of raw materials as well as the waste recovered from disused batteries. The analyses presented in the paper do not reflect all possible technologies of recycling lead-acid batteries in Poland. However, they do allow to identify the most characteristic environmental burdens for recycling such waste. Based on the research conducted on the actual process of processing and disposal of battery scrap, the following conclusions can be drawn:

- the recycling process of 1 Mg of the battery scrap conducted in 2010, brings about environmental benefits of (-119.53) Pt in the ReCiPe method, for the European conditions and (-0.81822) Pt in the IMPACT2002 + method,
- reuse of materials and substances is a source of environmental benefits, while the waste disposal processes (landfill) have a negative impact on the environment,
- in respect to the waste (reuse of lead paste, plastics and sulphuric acid) is an environmentally beneficial activity,
- the process of landfilling non-recyclable waste (polyvinyl chloride) causes environmental damage.

As far as the impact categories are concerned, the dominant effect on the overall level of environmental benefits achieved through the implementation of the actual battery scrap utilization scenario is achieved by the effects of the reduction of resources. This is mainly due to the limitation of the use of primary raw materials for the production of refined lead, polypropylene and sodium sulphate.

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