Application of the LCA method to estimation of the level of environmental load associated with recovery of lead from recycled materials

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Introduction

Due to the content of heavy metals and toxic compounds the used lead-acid rechargeable batteries are classified to hazardous wastes and are marked with the 160601* code according to effective regulations in force [4]. Hence, they must be handled in line with the effective rules of environment protection and ecology, where recovery and recycling of materials and substances is the primary measure [1, 5]. Out-of-service lead and acid rechargeable batteries may be considered as a source of many valuable elements, where primary extraction and production of them needs much higher expenses on materials and power as well as other financial means then recovery of them from recycled scrap.

Any manufacturing activity is associated with adverse impact onto natural environment [6]. To carry out ecological balance of recycling technologies one can apply the method of *Life Cycle Assessment* (LCA). That method enables determination of potential environmental impact during the entire lifetime cycle of any specific technology in question.

The LCA method can be applied to estimate environmental impact of the recycling technologies that enable recovery of lead from waste batteries. The analysis of life cycle provides information that may mitigate adverse effect of the involved technological processes onto environment.

Phased of Life Cycle Assessment

Requirements to correct execution of the Life Cycle Assessment are listed in the group of ISO standards from the 14040 to 14049 series. These standards comprise guidelines to carry out the procedure of LCA analysis and to construe its results.

According to the content of the PN-EN ISO 14044 standard the LCA analysis should comprise four stages [2]: determination of the objective and scope, analysis of the set of inputs and outputs, assessment of the life cycle impact and interpretation of results.

Stage I – determination of the objective and scope

The first stage of the LCA analysis consists in determination of the position occupied by the investigated object in the environment. Definition of the investigation objective and scope enables detailed description of the investigation object [2]. The objective of the life cycle assessment for a recycling technology is evaluation how much the technology affects natural environment.

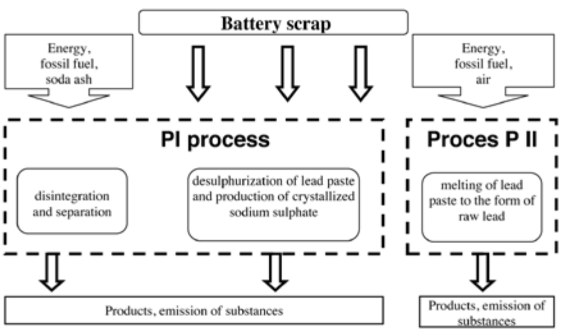

Fig. 1. System boundaries and elementary processes typical for recycling of battery scrap [7]

The investigation scope was limited to the recycling technologies of waste acid and lead rechargeable batteries from the moment when battery scrap is delivered to the treatment plant until the final product of the plant is obtained in the form of raw lead.

The system of scrap utilization includes such operations as mechanical disintegration of battery scrap, desulphurization of lead paste, production of sodium sulphate and raw lead.

The analysis of ecological balance covers also auxiliary processes, such as recovery of polypropylene, deposition of waste polyvinyl chloride (PVC) and slag in dumps (Fig. 1).

The mandatory activity consists in selection of a functional unit that should serve as a reference for normalization of input and output data. Adoption of such a unit enables also comparison between the obtained results. For the LCA method applied to analysis of the recycling technologies the functional unit was adopted as 1 ton of processed battery scrap.

Stage II – analysis of the set of inputs and outputs

The second phase, referred to as *Life Cycle Inventory* (LCI) consists in data acquisition for all identified impacts of the object in question. The information that must be considered as the input for the system relate to exhaustion of natural reserves, utilization of land, raw materials, consumables and energy carriers. The system output should define emission of pollutants, other wastes and recycling by-products. Table 1 summarizes all information that has been identified for the investigated process. The analyses that are carried out as the second stage of the LCA process lead to compiling of a list with all impacts exerted by the process onto natural environment.

Table 1

Balance sheet for material and energy contribution into the production process of raw lead from scrap of waste batteries

Input data – materials, fuel, electric power, heat	
Battery scrap	input charge for the process
Soda ash	necessary for the desulphurization process
Consumption of electric power	for disintegration, desulphurization and melting
Output data	
Raw lead	major product
Sodium sulphate	produced from recovered electrolyte
Polypropylene	extracted from hydro-separation and saleable for further processing
Wastes and emission to air	
Zn, HCl, H_2S, H_2SO_4, CO_2, SO_2, Pb, Cu, Sb, Se, combustion dust, other dust, CO, NO_2	emission to air due to the processes of scrap disintegration and desulphurization with further production of or raw lead
Polivinyl chloride (PVC)	waste product from the process of hydro-separation, deposited in dumps
Slag	originated from melting of desulphurized lead paste, deposited in dumps

Assessment of the life cycle impact

Assessment of environmental impact is the third compulsory stage of the LCA method. It enables evaluation of results from the completed analysis and deeper understanding of the result importance.

Assessment of the ecological balance can be carried out with use of various methods. For European conditions the researchers recommend such techniques as CML, IMPACT 2002+, ReCiPe and EDIP. They differ from each other in categorization of impacts and the methods how the same categories are parameterized, which may lead to different analytic results for the same process. The analysis that is disclosed in this study was carried out with use of SimaPro v. 7.3.2. software with preliminary selection of two analytic methods typical for European conditions, i.e. Eco-Indicator99 and IMPACT 2002+.

The first of the mentioned method assumes determination of three final points that are considered as ecological impact into human health, the ecosystem quality and exhaustion of natural resources. Results of that analysis shall be presented for selected impact categories that have been distinguished of that method in the number of eleven. [8, 9].

Table 2 summarized categories of hazards and impacts typical for the Eco-Indicator99 method

Table 2

Assignment of LCI data to individual impact categories and final points for the Eco-Indicator99 method [10]

Impact categories	Unit	Hazard categories
Global warming	DALY	**human health**
Depletion of the ozone layer		
Photochemical smog		
Ionising radiation		
Cancerogenic factors		
Substances with adverse impact onto the respiratory system		
Acidification	PDF•m²•year	**ecosystem quality**
Eutrofication		
Ecotoxicity		
Exhausting of natural resources	MJ surplus	**consumption of natural resources**
Use of land		

DALY – *Disability Adjusted Life Years*
PDF•m²•year – *Potentially Disappeared Fraction*
MJ – megajoule

In order to present how recycling technologies of scrap from acid and lead rechargeable batteries affect natural environment the author of this study selected such categories that are typical for the adopted investigation method. Due to the level of achieved results the particular attention should be paid to the following categories:

- climatic changes due to the production process of sodium sulphide and melting of lead paste leads to emission of two primary indicators of CO_2 and NO_2 representative for the global warming effect
- acidification, since combustion of fossil fuels that is employed for the technology in question is associated with emission of pollutants, chiefly sulphur compounds and consequential acidification is a result of excessive emission of pollutants, e.g. SO_2 and NO_x
- ecotoxicity is understood as a group of adverse effects onto living organisms resulting from their contacts with chemicals emitted to air, water and soil. Since the recycling technology of old batteries entails the hazard that compounds of heavy metals may be released to environment, the category of ecotoxicity has been included into the eco-balance analysis
- photochemical smog (smog of the Los Angeles type, white or pale); occurrence of photochemical smog is chiefly associated with sulphur oxides (SO_x) and nitrogen oxides (NO_x). Since metallurgical industry emits high amounts of these compound the related category has been included into this analysis
- cancerogenic factors – the author suggests to include that category to the analysis due to trace emission of cadmium compounds that takes place during melting of lead paste
- substances with adverse impact onto the respiratory system. The group comprises chiefly sulphur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide (CO) and dust. Since the technology in question entails emission of all these mentioned groups of compounds the author suggests including that category to the analysis of ecological balance.

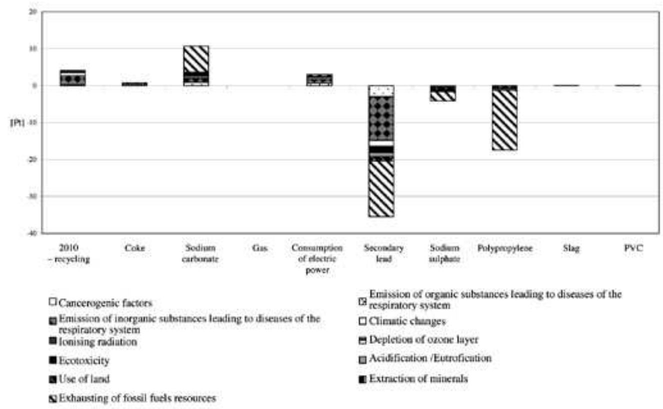

Fig. 2. The effect of the recycling process carried out for 1 ton of waste lead and acid rechargeable batteries and investigated for 11 categories of impacts typical for the Eco-Indicator99 method

However, the impact factors with less than 1% of contribution in the totalized result of the analysis were exempted from the analysis. Results are expressed in eco-points (environmental points – Pt) that stand for the ration of the total load to the environment to the number of inhabitants for European conditions multiplied by one thousand). It means that 1000 Pt stands for the annual load to the environment by a single European citizen.

Te completed analysis (Fig. 2) demonstrated that the highest potentially adverse effect onto natural environment due to recycling of 1 ton of old batteries results from consumption of sodium carbonate (-11 Pt) and consumption of electric power (-5 Pt). Reuse of wastes, e.g. polyporpylene from battery casings, makes it possible to make savings on fossil fuels that would be indispensable for primary manufacturing of plastic. The calculations carried out with use of the Eco-indicator99 method revealed that the recycling process, beside obvious environmental benefits due to reuse of wastes (polypropylene, sulphuric acid) and production of lead from recovered materials, has also adverse impact onto the environment, determined at the level of 5 Pt. It results from chemical composition of wastes that are subjected to the recycling process and that fact that they comprise 75% of lead and 8% of sulphur. For all processes distinguished for the recycling technology the most beneficial effect for natural environment was identified for the category associated with exhausting of fossil fuels. The achieved result is the effect resulting from reuse of wastes. The recycling process of acid and lead rechargeable batteries entails emission of such pollutants as carbon dioxide, nitrogen and sulphur oxides, dust substances and cadmium that are released to air.

In turn, the IMAPCT 2002+ assumes distinguishing of 14 categories of effects (impacts) and 4 categories of hazards that include human health, ecosystem quality, climatic changes and consumption of natural resources (Tab. 3).

Table 3

Assignment of LCI data to individual impact categories and to final points for the IMPACT 2002+ method [10]

Impact categories	Unit	Hazard categories
Cancerogenic factors	DALY	human health
Factors other than cancerogenic ones		
Ionising radiation		
Impact of inorganic compounds onto the respiratory system		
Impact of organic compounds onto the respiratory system		
Depletion of the ozone layer		
Ecotoxicity (in water and terrestrial environments)	PDF•m²•year	**ecosystem quality**
Eutrofication		
Use of land		
Acidification		
Global warming	equivalen CO_2 in kg	**Climatic changes**
Extraction of mineral resources	Primery energy w MJ	**consumption of natural resources**
Non-renewable energy		

DALY – *Disability Adjusted Life Years*
PDF•m²•year – *Potentially Disappeared Fraction*
MJ – *megajoule*

Normalization of the hazard categories consists in division of the impact from a unit emission by the total (overall) impact from all substance of each category per a single person and for European conditions.

The IMPACT 2002+ method was developed as superposition of several other techniques, such as Eco-indicator99, CML, IPPC and IMPACT 2002+. Figure 3 shows results from application of the IMPACT 2002+ method to the analysis of the recycling technology.

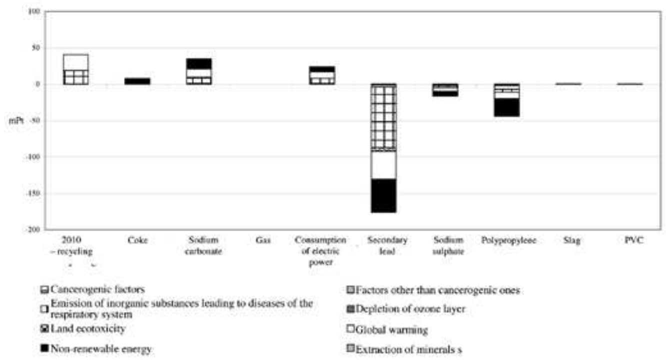

Fig. 3. The effect of the recycling process carried out for 1 ton of waste lead and acid rechargeable batteries and investigated for 11 categories of impacts typical for the IMPACT 2002+ method

The completed analysis demonstrates that no impact was identified for the categories "acidification" and "eutrofication" for water environment. The highest ecological benefits are estimated for the category "inorganic substances leading to diseases of the respiratory system" (43.9%) and for the category 'non-renewable energy' (37.5%). The impact of the recycling technology onto the field of global warming was estimated at much lower level (7.57%), as well as for ecotoxicity in the terrestrial environment (2.69%) and for factors other than cancerogenic ones (1.41%). The analysis neglects the categories with totalized impact less than 1%.

Interpretation of life cycle

Interpretation is the last phase for the LCA method. Its key goal is to scrutinize results from the ecological balance and to make comparisons against the assumed objective and scope [2, 11]. This phase serves as a basis for formulation of final conclusions, explanation of boundary limits and setting up of guidelines that shall be helpful for mitigation of adverse environmental impacts.

The achieved results may be also supportive for taking decisions related to reduction of adverse ecological influence from manufacturing processes for a specific product. Identification of elementary processes as well as all inputs and outputs makes it possible to undertake measures aimed at reduction of raw material and energy consumption as well as to efficiently handle and reuse substantial amounts of by-products and wastes.

The analysis of ecological balance was carried out with use of the Eco-Indicator99 and IMPACT 2000+ method applied to the recycling technology for waste acid and lead rechargeable batteries. Its results enable drawing up the following conclusions: total environmental impact of the recycling technology estimated by means of the Eco-Indicator99 technique is -38.29 Pt whilst the same impact determine with use of the IMPACT 2000+ approach is -121 mPt (-0.121 Pt).

Discrepancies between results obtained from two methods may result from differences in weighting techniques for individual methods and adoption of different parameters for characterization of the same impact categories. For instance the impact category associated with extraction of minerals for lead production is 0.051 MJ surplus/kg in case of the Eco-Indicator99 method, whilst the same parameter for the IMPACT 2000+ technique is as high as 7.35 MJ surplus/kg, i.e. it adopts the values that is ca. 144 times higher than for the first approach.

However, the both methods confirm that the most important factor that affects natural environment is lead, the basic component of lead and acid rechargeable batteries.

Conclusions

The completed analysis of ecological balance enabled determination how much the recycling technology of old lead and acid rechargeable batteries affects natural environment, where the impact was determined for the adopted functional unit, i.e. 1 ton of battery scrap. The analysis made it possible to find out which recovered raw materials should reused and are beneficial for the environment and which ones are deposited in dumps and adversely affect selected components of the ecological balance.

It is clear that the analysis disclosed in this study is incapable of reflecting all leads to natural environment for all possible technologies that are used for recycling of acid and lead rechargeable batteries in our country. But anyway, it enables determination of the most typical environmental loads associated with recycling of these hazardous wastes. It must be emphasized that recovery and reuse of waste material and substances is always much more beneficial for natural environment than various processed of waste neutralization since neutralization is always burdensome for nature.

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