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MANAGEMENT OF DISUSED LEAD-ACID BATTERIES IN THE CONTEXT OF THE ECO-BALANCE ANALYSIS

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Abstract

The article describes the results of the eco-balance analysis of the disused lead-acid batteries recycling technology. The analysis will be made using the life cycle assessment (LCA) method. The analysis was developed using the SimaPro7.3.3. software. The life cycle assessment (LCA) was made using Ecological Scarcity and IMPACT2002 + methods. The results are shown as environmental points [Pt], which reflect the potential level of environmental burdens exerted by the analysed object. The results are presented in the environmental categories, which are grouped in the impact categories. For the Ecological Scarcity method, these are emission into air, water, soil, energy, and natural resources and deposited waste. For the IMPACT2002 + method: human health, climate changes, ecosystem quality and resources consumption. The boundaries of the system under investigation include the processes of mechanical battery scrap processing, desulfurization and crystallization processes (PI), the melting processes to obtain crude lead and refining processes (PII and PIII). As the functional unit, there was accepted 1 Mg of the processed battery scrap. Particular attention was paid to the airborne emission, which adversely affect human health and climate change. The technology for which the tests were conducted offers the possibility to recover other elements, for example, secondary lead, polypropylene and sulfuric acid as crystalline sodium sulphate.

Keywords: *recycling, Life Cycle Assessment, environmental protection, lead-acid batteries, eco-balance*

1. Introduction

Global lead production in 2014 was 11.3 million tonnes. Of this, 56% of lead was from the disused lead-acid batteries (LAB) [6]. In Europe, the production of lead from primary sources has been maintained for many years at 25-30% compared to the production of lead from recycling. In the USA, in the years 2014-2016, the share of Pb in the total lead production was approximately 88% [9]. Unfortunately, in many developing countries, the standards for the proper recovery and utilization of lead from disused products are not maintained. This leads to uncontrolled lead emissions, which adversely affects the condition of living organisms. In Poland, the disposal system for the disused LABs is based on the provisions of the Act on batteries and accumulators [1]. The stages of recycling of disused LABs are presented in the Regulation of the Minister of the Environment regarding the process of recycling and recovery of batteries of the 18 July 2017 on the specific requirements for the processing of the disused car lead-acid batteries [12]. The recycling process should consist of five basic steps:

- sorting disused batteries,
- separation into fractions of lead and its compounds, plastics, electrolyte removal,
- recovery or disposal of the spent electrolyte,
- re-melting of lead fractions and its compounds, refining,
- recycling of plastics.

Many of the articles discussed the environmental impacts of battery recycling. Most of them were based on publicly available data, typical for the European areas. The articles [13, 14] analysed the life cycle of different types of batteries, including lead-acid ones. The Cumulative

Energy Demand (CED) and IPPC methods were used to assess environmental impacts. Most studies use an approach to LCA known as cradle to grave and various combinations of these issues. The article [15], presents a completely different approach to the eco-balance analysis, described as “grave to cradle”. It takes into account the specificity of the recycling process in terms of eco-balance analyses. This article presents a similar approach to recycling where potential waste (spent batteries) is used to produce new materials and products.

2. Life Cycle Assessment Method

Eco-balance analyses aim at determining the impact of the object on the environment. By carrying out the -balance analysis, the main components of the environmental burden arising during the analysed stage of the life cycle of the selected object, should be identified. As a component of the environmental burden, one is to understand as the environmental category to which the dominant environmental impacts are related. The LCA method was used to analyse the recycling of disused lead-acid batteries. The grave to cradle (grave) approach was presented. It is significant that the recycling process can be treated as a process of producing refined lead, where instead of the raw lead, disused waste batteries were used. The LCA procedure is described in the ISO 14040 and 14044 groups of standards [10, 11]. The IMPACT2002 + and Ecological Scarcity methods were used to determine the potential impact of the recycling technology on the environment. The data on electricity production came from the Ecoinvent v2 database.

2.1. Definition of purpose and scope

The recycling aims to utilize materials that can potentially become waste. The lead in lead- acid batteries, due to its properties, can be used repeatedly, without losing its parameters. Therefore, the disused batteries have been treated as a resource for reuse in the production process. This article examines the year of operation of the battery recycling plant. One Mg of disused LABs has been accepted as a functional unit. As a result of the analysis, it will be possible to indicate which of the separated processes (PI, PII, PIII) has the least negative impact on the environment. The accepted limits of the studies include processes:

- processing of the battery scrap, desulfurization of lead paste and crystallization of sodium sulphate – PI process,
- re-melting of the lead paste desulphurised to the form of raw lead – process PII.
- refining process – PIII.

The analyses have taken into account the environmental impact of the emissions into the air in isolated processes. The information needed to determine the flow of materials; energy and pollutants emissions are real data. The system boundaries do not include the LAB transport to the processing plant. This is due to the lack of data. The methods used for determining the environmental impacts are IMPACT2002 + and Ecological Scarcity. The results will be given at environmental points, where the negative value represents an environmental benefit, a positive value – a negative environmental impact.

2.2. Analysis of input and output sets

Battery scrap processing data has been derived from company information, literature data, estimates, and data contained in the EcoInvent database of SimaPro 7.3.3 software. Assuming that the recycling of lead-acid batteries as well as the production of lead is closed loop, each of the material suitable for recycling will be used as recycled material in the production phase. Tab. 1 lists the amounts of materials and energy requirements and emissions associated with the battery recycling technology. These are estimates based on actual data and literature data. While the material flow within the plant is not taken into account.

Tab. 1. The sample inventory table for recycling lead-acid batteries

<table>
<tr><td colspan="6">INPUT</td></tr>
<tr><td colspan="3">Inputs from the technosphere (materials, fuel)</td><td colspan="2">Amount</td><td>Unit</td></tr>
<tr><td colspan="3">Battery waste</td><td colspan="2">34000</td><td>Mg</td></tr>
<tr><td colspan="3">Sodium carbonate</td><td colspan="2">1800</td><td>Mg</td></tr>
<tr><td colspan="6">Inputs from the technosphere (electricity, heat)</td></tr>
<tr><td colspan="3">Gas</td><td colspan="2">1300200</td><td>m^3</td></tr>
<tr><td colspan="3">Electricity</td><td colspan="2">600</td><td>mWh</td></tr>
<tr><td colspan="6">OUTPUTS</td></tr>
<tr><td>Emissions into the air</td><td>Amount</td><td>Unit</td><td>Emissions into the soil</td><td>Amount</td><td>Unit</td></tr>
<tr><td>NO_2</td><td>2000</td><td>kg</td><td>Waste products</td><td>1300</td><td>kg</td></tr>
<tr><td>HCl, H_2SO_4</td><td>4503</td><td>kg</td><td>Outputs to the technosphere</td><td>Amount</td><td>Unit</td></tr>
<tr><td>CO_2</td><td>2275</td><td>Mg</td><td>Desulfurized paste</td><td>16000</td><td>Mg</td></tr>
<tr><td>SO_2</td><td>75</td><td>kg</td><td>Metallic fraction</td><td>7000</td><td>Mg</td></tr>
<tr><td>Pb</td><td>0.8</td><td>kg</td><td>Sodium sulphate</td><td>1800</td><td>Mg</td></tr>
<tr><td>Cu, Sb</td><td>0.20</td><td>kg</td><td>Polypropylene</td><td>3500</td><td>Mg</td></tr>
</table>

Source: Own compilation based on Best Available Techniques (BAT) (3)

The production of auxiliary materials was not taken into account because no technological data was available. Information on electricity production for the purposes of the isolated processes comes from the EcoInventv2 database and relies on data specific to Polish conditions. The impact categories were calculated using the IMPACT2002 + method [4, 7].

2.3. The objects environmental impact assessment and interpretation of the results

Impact assessment is the third mandatory step in the LCA method, which allows evaluating the results of the analysis carried out in order to better understand their significance. The Life Cycle Impact Assessment (LCIA) aims at understanding and evaluating the magnitude and significance of potential environmental impacts for a product system throughout the product life cycle (ISO 14040: 2006). The individual results are converted to indicators, for example for the IMPACT2002 + method it may be global warming (kg CO2-eq). IMPACT2002 + methods were used to assess the impact of the recycling technology of the disused lead acid batteries and the Ecological Scarcity method [4, 7]. In the first method, the results of fourteen categories of influence are converted into four categories of damage (human health, ecosystem quality, climate change, and resources). The Ecological Scarcity method values every ecological charge based on the ratio between the critical and the current annual charge [8]. In order to illustrate the impact of the disused lead-acid recycling technology on the environment, several of the most important impact categories, in terms of the analysis objective, have been selected. Due to the level of results obtained, particular attention should be paid to categories:

- IMPACT2002 + method: terrestrial ecotoxicity, inorganic compounds affecting respiratory diseases, non-renewable energy,
- Ecological Scarcity method: emission into the air, emission into the surface water and waste disposal.

The essential influence on the analysis results have such categories as – terrestrial ecotoxicity – 41% of all identified impacts, then inorganic compounds causing respiratory diseases (32%) and non-renewable energy (16.6%). Global warming is at about 5% of all impacts. The Fig. 1 shows the analysis results for LAB recycling in terms of categories characteristic to the IMPACT2002 + method. Due to the reuse of lead for the production of refined lead, the environmental impact of the process under investigation brings environmental benefits of approximately 816 mPt. Without the re-use of materials, the environmental impact of the described technology would not have a positive impact on the environment. The refining process utilized lead recovered from car batteries. Mining of the ores was avoided, in which lead was present. As shown in Fig. 1. in PIII, the environmental benefits result from avoiding the emission into air of respiratory compromising compounds, which represents 78% of the identified influences in the refining process.

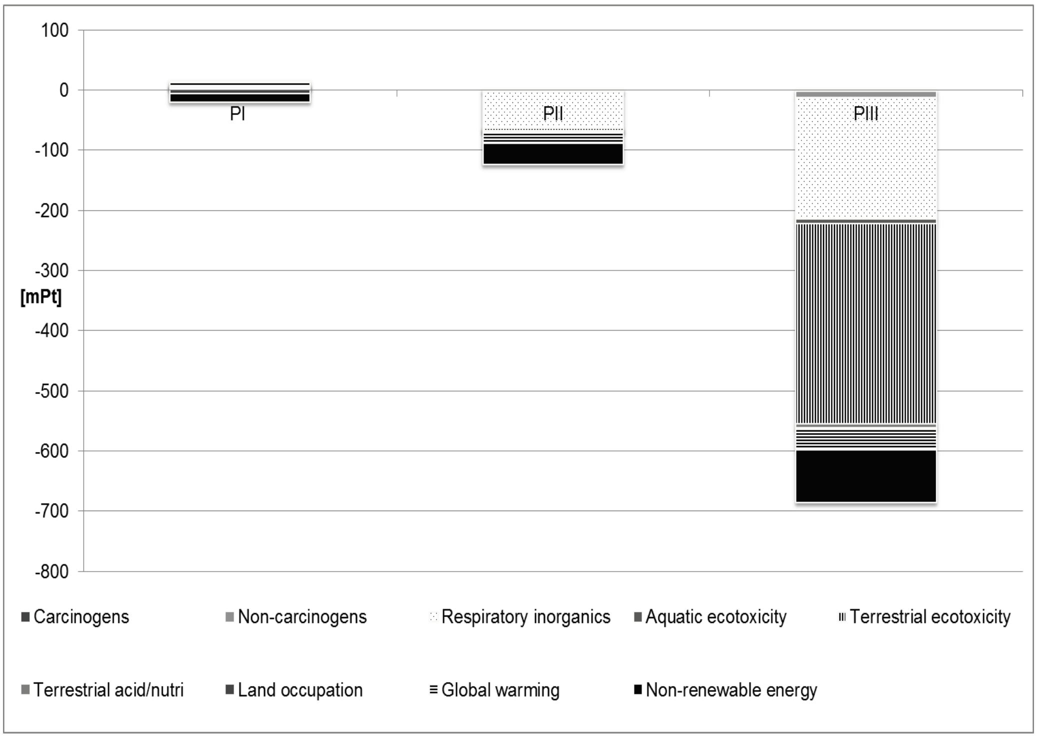

Fig. 1. Eco-balance analysis of the PI-PII-PIII processes. IMPACT2002 + method

Fig. 2 shows the emissions into the air identified for the recycling technology of disused lead-acid batteries. Consequently, by the use of recycled materials to produce new materials it was possible to avoid the emission of aluminium (about 62%). The negative impact of nitrogen dioxide emission (0.0034 Pt) was identified. In turn, carbon dioxide and sulphur emissions were avoided at about 7% relative to all identified emissions to the air. The results shown in Figure 2 show that technology brings the highest environmental benefits in terms of reducing emissions of aluminium, carbon dioxide and sulphur, reaching levels (–0.33 Pt; – 0.44 Pt; – 0.003 Pt), respectively.

The Ecological Scarcity Method determines the environmental impact of the surveyed object by estimating pollutants emission and resources consumption through "environmental factors". The ecological coefficients of the substances used in this method are taken from the environmental protection law or relevant political priorities. The ecological coefficients express the difference between the level of emissions or the consumption of resources and the objectives set in the legal or political provisions. The higher the level of emissions or resources consumption, the greater is the ecological factor expressed in ecological points (Pt). This method can be used to compare products, process and product improvements, to assess the total environmental impact of production sites or final consumption in a given country [2, 5].

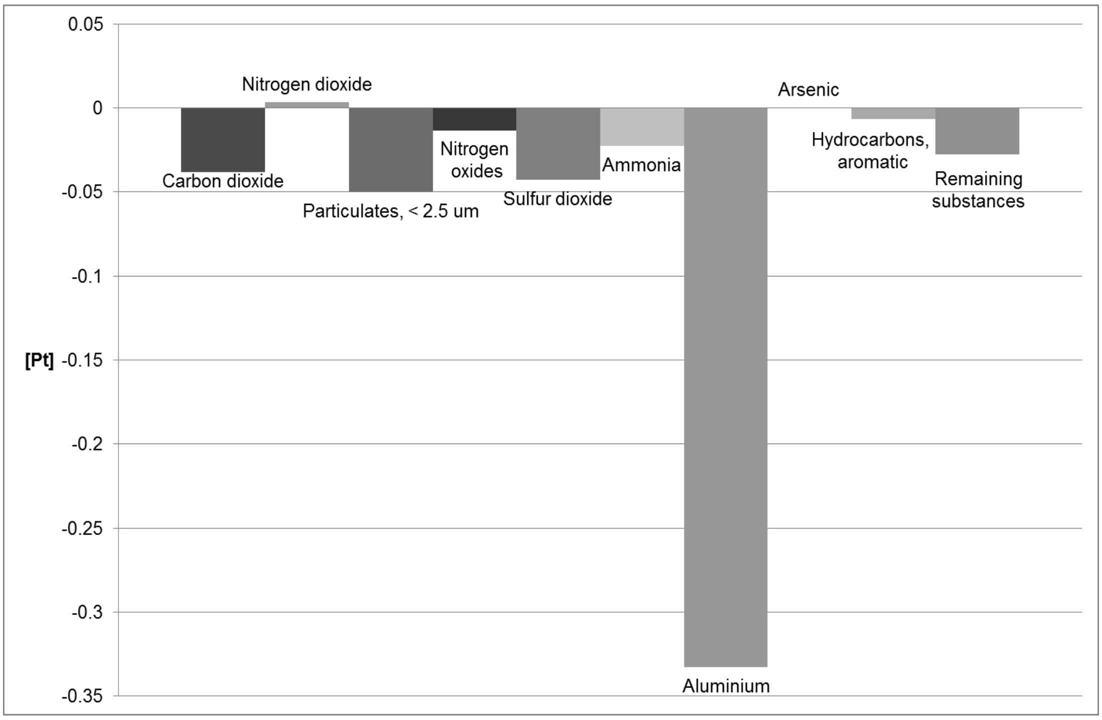

Fig. 2. Level of environmental impacts identified in the recycling process for a cut-off point set at 2%, for the emission into the air, Method IMPACT2002 +

Fig. 3 shows the results of the ecological analysis of PI-PII-PIII processes performed using the Eco scarcity method. The highlighted environmental impacts concern primarily emissions and landfilling. The highest environmental benefits, at 74% of all identified impact categories, are the result of reduced emissions into the air. What is important, the negative impact on the environment in this area was identified only for the PI process. It is at the level of 2.5% (0.072 MPt).

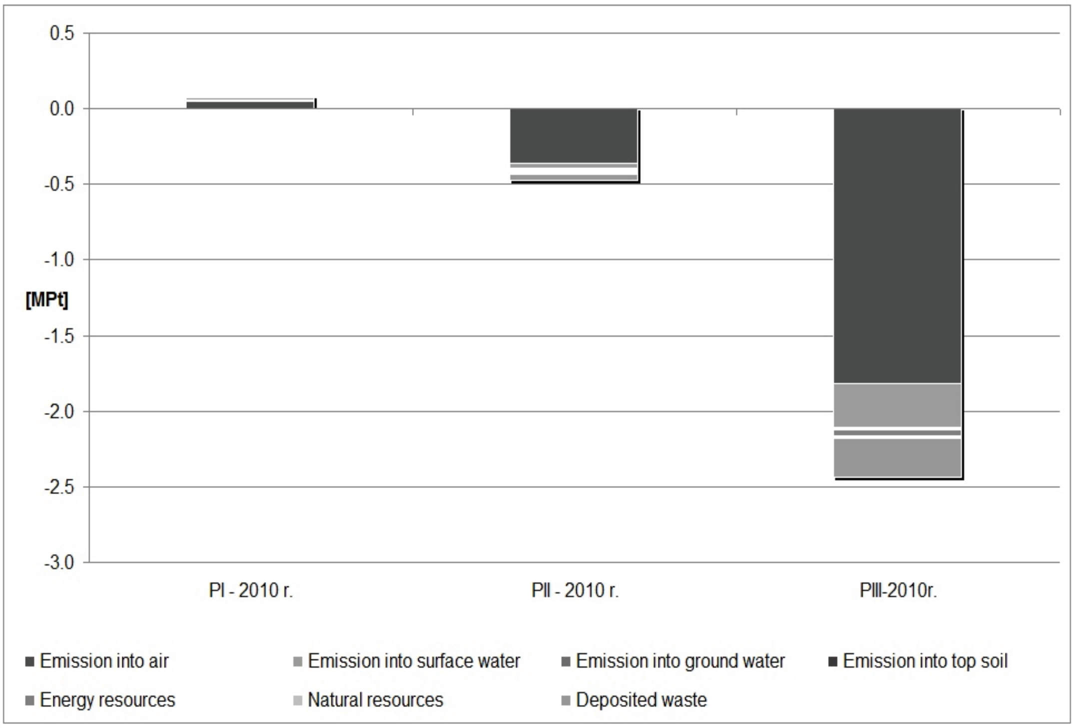

Fig. 3. Comparison of the total environmental indicators for each group of environmental impacts categories characteristic for Ecological Scarcity method

The avoided emissions to surface waters – 11.4% (-0.32 MPt) and waste management – 10.7% (-0.30 MPt) have a significant impact on the overall level of potential environmental burdens caused by recycling technology. For the PI process, a slight positive environmental impact was identified for the energy resources category only (-0.007 MPt). The process most beneficial to the environment is the PIII process - the lead refining process and its level of influence is (-2.44 MPt), i.e. 82% compared to other identified processes. For the PII process environmental benefits have been identified at 16% (-0.48 MPt) and only 2% for mechanical processing of batteries, desulphurisation and crystallization.

Fig. 4 shows the level of emission of substances into the air, based on Ecological Scarcity method. The level of environmental benefits for the emissions into the air has been identified at a high level. These amounts primarily concern the reduction of the emissions into the air of highly toxic and carcinogenic compounds, primarily lead, with a level of avoided emissions accounting for approximately 41% of all identified emissions (-760500 Pt).
The environmental benefits of avoided air emissions characteristic for the recycling process for nitrogen emissions are at 26.5% of the identified emissions (-482364 Pt). The analysis done by the Eco scarcity method has not identified the negative impact of air emissions on the environment.

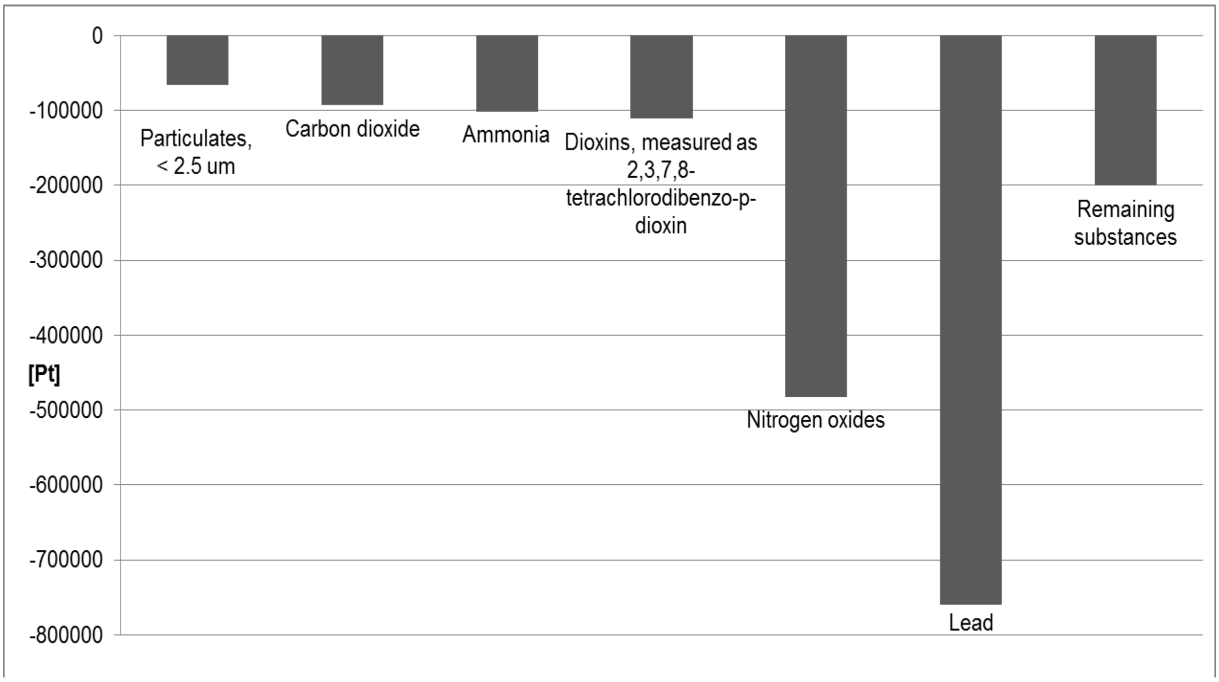

Fig. 4. The level of environmental impacts identified in the recycling process for a cut-off point of 2% for emissions into the air, the Ecological Scarcity method

3. Summary

Taking into account the results of the analyses carried out, it is worth noting that all activities related to the use of materials and recyclables bring environmental benefits. The results are presented with reference to the adopted functional unit - 1 Mg of the recycled lead-acid batteries. The life cycle assessment was made using two methods: IMPAX2002 + and Ecological Scarcity.

The results of the analysis are presented in environmental points and percentage values, which makes it possible to compare them, in order to indicate processes and activities that affect the condition of the natural environment to a higher or lower degree. Consequently, it was found that the most favourable process for the environment is refining process (PIII). The process of obtaining raw lead also does not cause environmental damage. Negative impact on the environment has the first process - mechanical processing of batteries, desulfurization and the production of crystalline sodium sulphate. Although analyses were carried out in two different ways, the similarity in the results obtained can be observed. In both cases, the same processes (PII and PIII) do not generate environmental damage. On the other hand, the PI process causes slight deterioration of the environment. It should be emphasized that while changing the approach from the linear economy to the circular economy (Circular Economy), the use of secondary lead for the production of refined lead and other materials takes on a new meaning. It coincides with the rules of Circular Economy, where potential waste should be treated as products; and allows extending the use of secondary lead, which results in a smaller negative impact on the environment in the area of non-ferrous metals management.

References

[1] *Act of 24 April 2009 on batteries and accumulators* (consolidated text, Journal of Laws No. 2016, No. 0, item 1803, 2016.

[2] Chłopek, Z., Lasocki, J., *Comprehensive evaluation of the environmental hazard caused by the operation of automotive vehicle*s, The Archives of Automotive Engineering, 54(4), pp. 19-36, 2011.

[3] *Guidelines for the Best Available Techniques (BAT)* – Reference Document for the Non-Ferrous Metals Industries, pp. 514-596, 2017.

[4] Goedkoop, M., Spriensma, R., *The Eco-indicator 99: A Damage Oriented Method for Life Cycle Assessment, Methodology* Report, second edition. Pré Consultants, Amersfoort (NL), Netherlands, pp. 10-20, 2000.

[5] http://esu-services.ch/simapro/database/ [accessed 29.09.2017].

[6] International Lead and Zinc Study Group, *World Refined Lead Supply and Usage 2010-2014, 9,* 2015.

[7] Jolliet, O., Margni, M., Cherles, R., et al., *IMPACT2002+: A New Life Cycle Impact Assessment Methodology*, The International Journal Life Cycle Assessment, Vol. 8, pp. 325-330, 2003.

[8] Kowalski, Z., Kulczycka, J., Góralczyk, M., *Ecological life cycle assessment of manufacturing processes* (LCA), Scientific Publishing House, pp. 135, 2007.

[9] Meng, J., *Impact of Macroeconomic Factors on Lead and Zinc.* International Lead and Zinc Study Group (ILZSG), Portugal, pp. 11-12, 2017.

[10] PN-EN ISO 14040 Environmental regulation. Life Cycle assessment. Principles and structure, 2009.

[11] *PN-EN ISO 14044 Environmental regulation. Life cycle Assessments.* Requirements and guidelines, 2009.

[12] Regulation of the Minister of the Environment regarding the process of recycling and recovery of batteries of the 18 July 2017 on the specific requirements for the processing of the disused car lead-acid batteries, used lead-acid automotive accumulators, worn-out industrial lead-acid batteries or lead-acid batteries and installations for recycling lead and its compounds or recycling plastics, Journal of Laws 2017, item 1474, 2017.

[13] Spanos, C., Turney, D. E., Fthenakis, V., *Life – cycle analysis of flow-assisted nickel – zinc, manganese dioxide, and valve – regulated lead – acid batteries designed for demand – charge reduction,* Renewable and Sustainable Energy Reviews, Vol. 43, pp. 478-494, USA 2015.

[14] Sullivan, J. L., Gaines, L., *Status of life cycle inventories for batteries,* Energy Conversion and Management, Vol. 58, pp 134-148, Illinois 2012.

[15] Valero, A., and Valero, A., *A Thermodynamic Approach for Accounting for Abiotic Resource Depletion,* Journal of Industrial Ecology, Vol. 17, Issue 1, pp. 43-52, 2013.

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