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THE ENVIRONMENTAL ASPECT OF RECYCLING END-OF-LIFE VEHICLES

Manuscript delivered, June 2019

Abstract: In Poland every year, about 600,000 cars are processed by the vehicle dismantling stations, which entails the necessity of utilizing a significant mass of waste. Entrepreneurs running the dismantling stations are required to obtain a 95% recovery rate and 85% recycling of the weight of vehicles brought into the company during the year. The article presents the results of the ecobalance analysis of utilizing waste from end-of-life vehicles (ELV). The calculations were carried out in accordance with the assumptions of the LCA method, based on the ReCiPe2016 procedure. The potential level of environmental impacts is analyzed in 23 environmental categories, included in three groups, defining affects on the human health, ecosystems and resources. The results were presented as environmental points [Pt], which reflect the potential level of environmental burdens exerted by the analyzed object. The limits of the tested system include utilization processes of the waste from vehicles. One end-of-life vehicle was assumed as a functional unit. Particular attention has been paid to the emissions into the air that adversely affect human health and climate change. The results of the analysis showed that the properly conducted cars utilization process brings environmental benefits above all in terms related to human health.

Keywords: recycling, Life Cycle Assessment, End-of-Life Vehicles, eco-balance

1. INTRODUCTION

In Poland, the end-of-life vehicle (ELV) utilization system results from the provisions of the Act on end-of-life vehicles [1]. The disassembly process should comprise a few essential stages and should be based primarily on the removal of fuels, operating fluids and refrigerant from the air-conditioning system. Then there is the dismantling of: oil filter, equipment items and parts to be reused, battery, fuel tank, exhaust catalytic converter, car capacitors (only for vehicles manufactured before 1.01.1986), items containing mercury, windscreens, tires, parts containing non-ferrous metals (in the case when they do not go to the shredders) and removal or disposal of elements containing explosives [20].

The important thing is that Poland has the obligation to obtain an appropriate level of recovery and recycling of end-of-life vehicles (ELV), 95% and 85% respectively. For this reason, research is being conducted enabling to achieve an even higher level of vehicle dismantling than before, or the attempts to recycle ASR (automobile shredding residue),
whose level may amount to as much as 12% of scrap metal, which is directed to the shredders [21].

Many papers discuss the problem of environmental impacts of the management processes of the ELV. Most of them were based on publicly available data, characteristic of the European areas. The influence of the ELV dismantling process in the aspect of LCA (Life Cycle Assessment) was analyzed in the paper [4]. What is important, the authors used real data from the vehicle dismantling station for the tests. They estimated the environmental impact of the disassembly along with the segregation and compacting of the waste, which in this form is sold to the recyclers for further processing. The authors presented, in so-called - “gateway-to-gate” analysis, what the stage from the moment of delivering the waste to the dismantling station, until it is transferred to the next company, actually means. In many LCA analyzes - "cradle-to-grave" approach is used. For example, this approach was describes in work [23]. The authors in this studies shows only the phases of production, use and disposal of an electric car based on the technology of Lithium-ion battery and compares it to an internal combustion engine car. In another the article was presented a completely different approach to the analysis of ecological balance, described as a "cradle-to-gate", which focuses mainly on the phases of raw materials acquisition, manufacturing, and transportation from the manufacturing place to the use phase but the use phase is not included in that analysis [23].

The paper [3] analyzes the life cycle for six models of the popular Golf car (Mk1-6), paying attention to the changes in vehicles design, in terms of their material composition. What is important, only the complete re-use of materials derived from ELV was envisaged for the recycling stage. In the papers dealing with the LCA problem, one can find analyzes of the selected utilization stages of the waste coming from ELV. For example, in [17] the environmental burden from the Auto Shredder Residue (ASR) process has been estimated, depending on its material composition changing over the time. The paper [12] presents the results of the eco-balancing analysis of the recycling lead-acid batteries process, in the aspect of impact on human health, the ecosystems condition and the depletion of natural resources. The reuse of car parts and the material flow associated with this process are described in [5]. Very often, due to the lack of necessary data and the complexity of the LCA process for the car, the analysis is carried out with many simplifications of the assumption.

For these reasons, the author proposes to focus on the recycling process and describing the main ecological ones factors that could potentially affect the condition of the environment. This paper presents an approach to the issues of recycling process, in which the waste from ELV can be reused, among the others, as a secondary raw material for the production of new materials (approach from the grave to the cradle).

2. LIFE CYCLE ASSESSMENT METHOD

The eco-balance analyses are aimed at estimating the environmental impact of the object. When performing the analysis, it is first necessary to determine the main components of the environmental burden, characteristic for the considered stage of the lifecycle of the object. The environmental burden component is called - environmental category. Connect-
ed with it are the most important environmental impacts for a given object. In order to analyze the recycling of waste from ELV, the LCA method was used. The author presented the "grave to cradle” approach". It is important that the process of recycling waste from vehicles, in most of the analysis, has been treated as a production process of the secondary materials (ferrous metals, non-ferrous metals, plastics and others). The LCA procedure is described in the group of standards – PN-EN ISO 14040 and 14044 [15,16].

The results of the analysis are presented in the environmental points [Pt]. One environmental point represents a thousandth part of the annual damage to the environment caused by one European resident. Their negative value means an environmental benefit, while a positive value - an identified negative impact on the environment.

The life cycle impact assessment phase was carried out using the ReCiPe 2016 method, in which impact categories are grouped into three damage categories. These are: human health, ecosystems condition and the scarcity of natural resources.

To calculate the quantitative value of the harmfulness of environmental impact on the human health, a DALY (Disability Adjusted Life Years) unit was created for WHO’s and the World Bank’s needs. The environmental impact assessment allows to determine the health impact on a scale from 1 to 10, with 0 meaning no impact, and 10 means death. The impacts related to the state of the ecosystem were distinguished as a separate category of environmental burdens. It expresses the number of species that disappear within a given area during the year due to the adverse environmental impact of various factors. For the damages affecting the consumption of natural resources there were isolated two categories: consumption of fossil fuels and the consumption of metallic raw materials. They are assessed by the increase in costs associated with the extraction of resources and are expressed in monetary value [13].

Human health-related interactions consist of the emissions of substances causing carcinogenic and non-carcinogenic diseases, temperature changes (global warming); depletion of the ozone layer of the stratosphere, ozone formation, emission of ionizing radiation and formation of the fine solid particles. The second category - the ecosystem status - is influenced by: temperature changes (global warming) of the aquatic ecosystems; ozone formation, environmental contamination with toxic substances; acidification and eutrophication as well as land use and consumption of water resources. The last category concerns the scarcity of resources and is associated with the depletion of minerals and fossil fuels [9].

### 2.1. DEFINITION OF PURPOSE AND SCOPE

Recycling aims to utilize materials that can potentially become a waste. It has a positive effect on reducing the use of primary raw materials. For example, one ton of processed aluminium (Al) saves up to 8 metric tons of bauxite, 6300 litres of oil, 14,000 kWh of energy and 7.6 m³ of earth. In addition the average total exhausts emission is about 350 kg of carbon dioxide (CO₂) [2]. Unfortunately the aluminium scrap has a very diverse chemical composition and the presence of harmful impurities in the materials coming from the secondary sources is a major disadvantage compared to primary alloys [2].

Steel components are the main structural material in the analyzed ELV group. It can be seen that at the beginning of the 21st century, the share of the secondary steel production process in the electric furnace increased from 15% to around 50% of the total domestic
production [8]. In 2013, 165.8 million tons of steel were produced in the European Union. 89.9 million tons of scrap were used for this process. This represents 54% of the total production, while in Poland, in the production of 7.9 million tons of steel, there were 5 million tons of scrap metal consumed per year. It is 63.3% of the total domestic steel production per year [18]. Therefore, the waste from disused vehicles was treated as the resources for re-use in the production process. The study analyzed the utilization of one ELV. One ELV unit with a mass of 1017.06 kg was assumed as a functional unit. As a result of the analysis conducted, it will be possible to indicate which group of wastes (ferrous metals, non-ferrous metals, plastics, non-ferrous materials, etc.), have the least negative impact on the environment. The boundaries of research include processes of recycling, reusing and storing selected groups of waste.

The analyzes take into account the environmental impact of the emissions into the air of the separated processes. The information necessary to determine the flow of materials is mostly a real data. The system's borders do not include manufacturing of the vehicles and their transport to the place of processing. This is due to the inability to obtain data. To determine the impact on the environment, the ReCiPe2016 method was used. The results of analyses will be given in the environmental points. Their negative value means an environmental benefit, while a positive value - an identified negative impact on the environment.

### 2.2. ANALYSIS OF INPUT AND OUTPUT SETS

Data regarding the material composition and utilization of the waste from ELV were obtained based on the company information, literature data, estimates and data contained in the EcoInvent v.3.5 database of the SimaPro 9.0 software. Assuming that ELV recycling as well as the production of separate waste groups is a closed loop, any recyclable material will be used as a recycled material during the production phase. This is so-called avoided production. Table 1 presents the numerical values of the ELV material composition. This is an estimated data, based on actual data and literature data.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Amount</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>458</td>
<td>kg</td>
</tr>
<tr>
<td>Cast iron</td>
<td>341</td>
<td>kg</td>
</tr>
<tr>
<td>Aluminium</td>
<td>73</td>
<td>kg</td>
</tr>
<tr>
<td>Copper</td>
<td>27</td>
<td>kg</td>
</tr>
<tr>
<td>Lead</td>
<td>3.10</td>
<td>kg</td>
</tr>
<tr>
<td>Platinum</td>
<td>0.00005</td>
<td>kg</td>
</tr>
<tr>
<td>Plastics</td>
<td>42.37</td>
<td>kg</td>
</tr>
<tr>
<td>Rubber</td>
<td>26.50</td>
<td>kg</td>
</tr>
<tr>
<td>Glass</td>
<td>24.70</td>
<td>kg</td>
</tr>
<tr>
<td>Textilies</td>
<td>19.27</td>
<td>kg</td>
</tr>
<tr>
<td>Liquids</td>
<td>2.12</td>
<td>kg</td>
</tr>
<tr>
<td>Sum</td>
<td>1017.06</td>
<td>kg</td>
</tr>
</tbody>
</table>

*Source: Own compilation based on [3, 11, 14, 19]*
The production stage of auxiliary materials was not taken into account, as no technological data was obtained. The impact categories were calculated using the ReCiPe2016 method [6, 7, 8].

2.3. THE OBJECTS OF THE ENVIRONMENTAL IMPACT ASSESSMENT AND INTERPRETATION OF THE RESULTS

Impact assessment is the third obligatory stage identified in the LCA method. Life cycle impact assessment (LCIA) helps interpret LCA surveys by transferring emissions and extractions of resources to a separate number of environmental impact assessments [10]. This enables understanding and evaluation of the significance of potential environmental impacts for the selected system throughout the LCA cycle [12]. The results of analyzes are converted into indicators, for example for the ReCiPe2016 method, this may be the category of climate change (kg CO2-eq) or the formation of fine particulate matter (kg PM2.5). To assess the impact of ELV utilization the ReCiPe2016 method was used [7]. In the selected method, the results of the twenty-three categories of influence are aggregated into three categories of damage (human health, ecosystem quality and resource scarcity). In order to present the impact of utilizing 1 ELV on the natural environment, several of the most important impact categories were selected from the point of view of the analysis’s objective. Due to the level of results obtained, particular attention should be paid to the categories:

- human health: global warming, Human health (-20.38 Pt), Fine particulate matter formation (-48.98 Pt), Human carcinogenic toxicity (-116.03 Pt), Human non-carcinogenic toxicity (-64.54 Pt) and Water consumption, Human health (-3.12 Pt). In the area of emissions into the air, to sulphur dioxide (SO2) and carbon (CO2) and solid particles (PM <2.5 µm).

The following categories have a major impact on the results of the analysis: Human carcinogenic toxicity - represents 44% of all identified interactions, then human non carcinogenic toxicity affecting respiratory diseases (25%) and fine particulate matter formation (18.77%). The category of water consumption, Human health, appears at the level of approx. 1.19% among all impacts. Fig. 1. presents the results of the analysis for the utilization of ELV, in terms of categories characteristic for the ReCiPe2016 method, in the area of impacts on the human health. Due to the re-use of ferrous and non-ferrous metals (direct shipment to a steelworks or shredder), the environmental impact of the analyzed process brings about total environmental benefits of about -260.84 Pt. Without the re-use of materials, the environmental impact of these activities would not have a beneficial effect on the environment. In the production of steel or aluminium, scrap recovered from ELV was used. Ore extraction was avoided in which these compounds would coexist.
Fig. 1. Effect of the utilizing process of 1 ELV on the categories related to the impact on human health. The ReCiPe2016 method

Figure 2 presents the results of the eco-balance analysis determining the impact of utilizing 1 ELV on the categories related to the state of the ecosystem.

Fig. 2. Effect of the utilizing process of 1 ELV on the categories related to the impact on the ecosystem. The ReCiPe2016 method

The results from the area of impacts on the condition of the ecosystem, compared to the impact determined for impacts in the area of human health, have a significantly smaller level of environmental benefits identified. The total level of impacts in the category of im-
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The environmental impact on the ecosystem state was - 6.51 Pt. It should be emphasized that the discussed ELV utilization process does not have a negative impact on the environment in this group. The highest level of environmental benefits was achieved due to the reduction of emissions of substances affecting global warming. It represents 31.33% of the total impact of the impact identified in this group. Environmental benefits result from the reduction of harmful substances emissions, which is caused by the use of secondary raw materials for the production processes. In the land use category, environmental benefits were identified at 18.58% of all the impacts in this group. They are the effect of reducing the level of obtaining primary raw materials and the use of land for the landfills. A similar percentage was achieved by the impacts of terrestrial acidification (19.35%) from the group of environmental categories and freshwater eutrophication (16.28%).

The total level of beneficial environmental impacts determined in the ELV utilization process, in the group of categories related to the shortage of resources, is presented in Figure 3. It amounted to 0.34% among all identified impacts. The results illustrate the significant advantage of the benefits associated with limiting the use of fossil raw materials (0.3%) over the benefits specified in limiting the exploration of mineral resources (0.04%).

![Fig. 3. Effect of the utilizing process of 1 ELV on the categories related to the impact on the depletion of resources. The ReCiPe2016 method](image)

Fig. 3 shows the level of substances emission into the air, based on the ReCiPe2016 method. The level of environmental benefits for high-level emissions into the air has been identified. These figures relate primarily to the reduction of emissions into the air of the compounds that may affect climate change (carbon dioxide), whose level of avoided emissions is about 23.75% of all identified emissions and amounts to (-18.19 Pt).

The environmental benefits associated with avoided air emissions characteristic to the ELV utilization process, for nitrogen oxide emissions are at the level of 6.2% of the identified emissions (- 4.82 Pt). In the analysis conducted with the ReCipe 2016 method, no negative impact of emissions into the air on the environment was identified. The highest level of environmental benefits was identified in the case of reduction of air emissions for
sulphur dioxide, which was 34.12% of all estimated environmental benefits related to avoided emissions into the air, for the utilization process of 1 ELV.

![Fig. 4. The level of environmental impacts identified in the recycling process for a cut-off point of 1%, for emissions into the air, the ReCiPe 2016 method](image)

The results presented in Figure 5 indicate that the proper utilization of the waste from ELV can bring environmental benefits. The ferrous metals waste is directed, among the others, to a shredder, in which over 80% of metallic fraction are produced, 2.11% of non-ferrous metals and 5.33% of plastic waste [11]. It was assumed that the fraction of the residue after the shredder will not be stored, but its energy recovery will take place. The fraction of ferrous metals recovered in the shredding process is subjected to recycling processes. This group of materials has the largest share in the construction of cars, so as a result, the level of identified environmental benefits for ferrous metals is at the proportionally highest level. It accounts for 82.92% of all identified environmental benefits. The utilization of this group of waste in the recycling process reduces the mass of waste going to the landfills. It also contributes to lower demand for primary raw materials. The environmental benefits of rubber materials (car tires) arise from the fact that they are fed into combustion processes with energy recovery. The remaining part of the waste generated during the dismantling process is subjected to recycling processes. Waste from other waste groups has been transferred to recycling companies.
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3. SUMMARY

As a result of the conducted analyses, it was found that all identified activities related to the ELV utilization process and to using materials and secondary raw materials bring environmental benefits. The results were presented in relation to the adopted functional unit - 1 ELV subjected to the utilization process. Life cycle evaluations were made using the ReCiPe 2016 method. The results of the analysis are presented in the environmental and percentage points, which makes it possible to compare them, to indicate processes that may potentially affect the condition of the natural environment. As a result of the conducted eco-balance analysis, it was found that the utilization process of ELV 1 brings the highest environmental benefits in terms related to human health. Their level is over 97% of all the unidentified impacts. As noted, the lowest level of environmental benefits, amounting to 0.34% of all specified impacts, belongs to the group associated with the depletion of natural resources. The environmental benefits associated with the ecosystem state constitute about 2.50% of the identified positive environmental impacts. The highest level of environmental benefits was identified for the utilization processes of ferrous metal waste (-216.31 Pt), non-ferrous metals (-11.32 Pt), which constitutes 4.34% of all identified environmental benefits and textiles (-21.90 Pt).
11. Information about the results of shredding attempts of 24 November 2016 in Poland.
20. Regulation of the Minister of Economy and Labour of 28 July 2005 on minimum requirements for the dismantling of the station and how to disassemble the vehicles of the year, (OJ 2005 # 143, item 1206 and from 2007, no. 128, item. 892, and with 2010 # 198, item 1317). 16.
ŚRODOWISKOWY ASPEKT RECYKLINGU POJAZDÓW WYCOFANYCH Z EKSPLOATACJI

Abstract: Co roku w Polsce oddawanych jest do stacji demontażu pojazdów około 600 tysięcy samochodów, co niesie za sobą konieczność zagospodarowania znacznej masy odpadów. Przedsiębiorcy prowadzący stacje demontażu, mają obowiązek uzyskać 95% poziom odzysku oraz 85% recyklingu masy pojazdów przyjętych do przedsiębiorstwa w ciągu roku.
W artykule przedstawiono wyniki analizy ekobilansowej zagospodarowania odpadów pochodzących z pojazdów wycofanych z eksploatacji (PWE). Obliczenia przeprowadzono zgodnie z założeniami metody LCA, w oparciu o procedurę ReCiPe2016. Potencjalny poziom oddziaływań środowiskowych analizowany jest w 23 kategoriach środowiskowych, ujętych w trzy grupy, określające wpływ na: zdrowie ludzkie, stan ekosystemów oraz wyczerpywanie zasobów naturalnych.
Wyniki przedstawiono jako punkty środowiskowe [Pt], które odzwierciedlają potencjalny poziom obciążeń środowiskowych wywieranych przez analizowany obiekt. Granice badanego systemu obejmują procesy zagospodarowania odpadów pochodzących z pojazdów. Jako jednostkę funkcjonalną przyjęto 1 pojazd wycofany z eksploatacji. Szczególną uwagę zwrócono na emisję do powietrza, która niekorzystnie wpływa na zdrowie ludzkie i zmiany klimatyczne.
Wyniki przeprowadzonej analizy, wskazały, że prawidłowe przeprowadzony proces zagospodarowania samochodów, przynosi korzyści środowiskowe przede wszystkim w kategoriach związanych ze zdrowiem ludzkim.

Keywords: recykling, cykl życia produktu, pojazdy wycofane z eksploatacji, równowaga ekologiczna