ANALYSIS OF ALUMINUM CAN BY ECO-COSTS AND LIFE CYCLE ASSESSMENTS (LCA)

Dominika SIWIEC[1], Andrzej PACANA[2], Renata DWORNICKA[3]

[1] *Rzeszow University of Technology, Rzeszow, Poland, EU, d.siwiec@prz.edu.pl, ORCID ID: 0000-0002-6663-6621*

[2] *Rzeszow University of Technology, Rzeszow, Poland, EU, app@prz.edu.pl, ORCID ID: 0000-0003-1121-6352*

[3] *Cracow University of Technology, Kraków, Poland, EU, renata.dwornicka@pk.edu.pl, ORCID ID: 0000-0002-2979-1614*

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Abstract

Research on environmental impact assessment in metal production continues to evolve. The developing "chill-on-demand" system is expected to be a revolution in the industry in minimizing negative climate changes. It is used, for example, in industrial cans and storing food products. Therefore, opportunities for this product are still being sought, mainly in the context of the possibility of recycling its steel and aluminum elements (HEU). The purpose of the research was to conduct a life cycle assessment (LCA) of a beverage can with a cooling system and to determine the eco-costs incurred during the life cycle of this product. Life cycle assessment was carried out on the ISO 14040 standard. The analysis was supported by FOOTPRINTCALC 1.2. calculator designed to measure and improve the environmental impact of products. The data were modeled for carbon footprint and eco-costs. The test results showed that the self-cooling beverage can produce in LCA: i) about 101.430 kgCO$_2$e, ii) about 27.64 euros eco-costs, which must be reduced to reduce environmental burdens. Future research will analyze various production scenarios for this type of product.

Keywords: LCA, Eco-cost, self-cooling can, carbon footprint, mechanical engineering

1. INTRODUCTION

From a sustainable development perspective, emissions in all sectors of activity must be drastically reduced to achieve adopted climate goals, such as net zero greenhouse gas (GHG) emissions by 2050. The essential action for effective management is to support the analysis of emissions resulting from individual units' activities and consciously make decisions regarding reducing the carbon footprint (CO$_2$) [1]. This is problematic in the case of metals, of which the variety (mined and used) has continued to grow since the beginning of the Industrial Revolution [2, 3]. At the same time, metals used in low-emission technologies have become important in the industry, contributing to increasing concern about the sustainable development of raw material extraction [1]. This is particularly important because metal production is one of the key industries in the world, and it is one of the most energy-intensive (38% of global energy consumption in industry, 15% of electricity consumption, and 11% of energy consumption). Additionally, the mentioned consumption is based on fossil fuels, which account for, e.g., 19% of the world's coal and carbon products [4, 5]. Recycling rates for metals such as aluminum are relatively high, such as at the end of their useful life exceeding 50%, and can reach as high as 70%. It is possible to achieve increasingly better indicators by using steel scrap for steel production and by balancing the energy of aluminum, which comes from recycling rather than primary aluminum. One of the main sustainability issues includes the intensity of energy consumption and pollution during ore processing [6]. Recycling aluminum and steel elements, e.g., cans used for industrial products such as paints or aerosols is problematic. However, the largest source of use (95%) is for storing food products. The steel recycling rate is growing dynamically, but the number of steel cans has decreased significantly in recent years due to their replacement with lightweight aluminum or plastic cans [7]. The "chill-on-demand" system, a new technology that allows quick sweetening on demand, is increasingly popular in cans [8]. This system may revolutionize reducing negative climate changes, mainly greenhouse gases. This is because of the possibility of using it as a replacement for refrigerators or coolers, which are popular mainly in low-income countries but also often in middle-income countries, even sometimes in wealthy countries. However, there is still a lack of comprehensive analyses covering the life cycle of these products in terms of carbon footprint. As stated by the study authors [9, 10], it is still important to look for favorable solutions for self-cooling cans, considering the possibilities of recycling its elements, i.e., the outer steel and inner aluminum parts (HEU). Therefore, the article aimed to conduct a life cycle assessment (LCA) of a beverage can with a cooling system and determine the eco-costs incurred during the life cycle of this product. The presented methodology will be useful in similar situations in other industries, including machinery [11], steel industry [12], corrosion protection [13], and cleaning [14]. This also influences the change of analytical and predictive approaches [15], which must consider the environmental burden and not only simple direct costs as in DOE [16].

2. MATERIALS AND METHOD

The chill-on-demand system causes, on demand, endothermic desorption of CO_2 previously adsorbed on the activated carbon (AC) bed. He is inside the said drink cans. The exterior of the beverage can is made of galvanized steel. The inner part of the can is made of aluminum, the so-called heat exchange unit (HEU), which contains the mentioned activated carbon and prevents the beverage from contacting the activated carbon. HEU makes the can larger than the traditional one. The button that activates the pressure valve outside the HEU is located at the base of the can. When pressed, CO_2 is released into the atmosphere. Under ideal conditions, it is possible to sweeten the drink to approximately 15˚C [8]. **Figure 1** shows a diagram of the production process of these products.

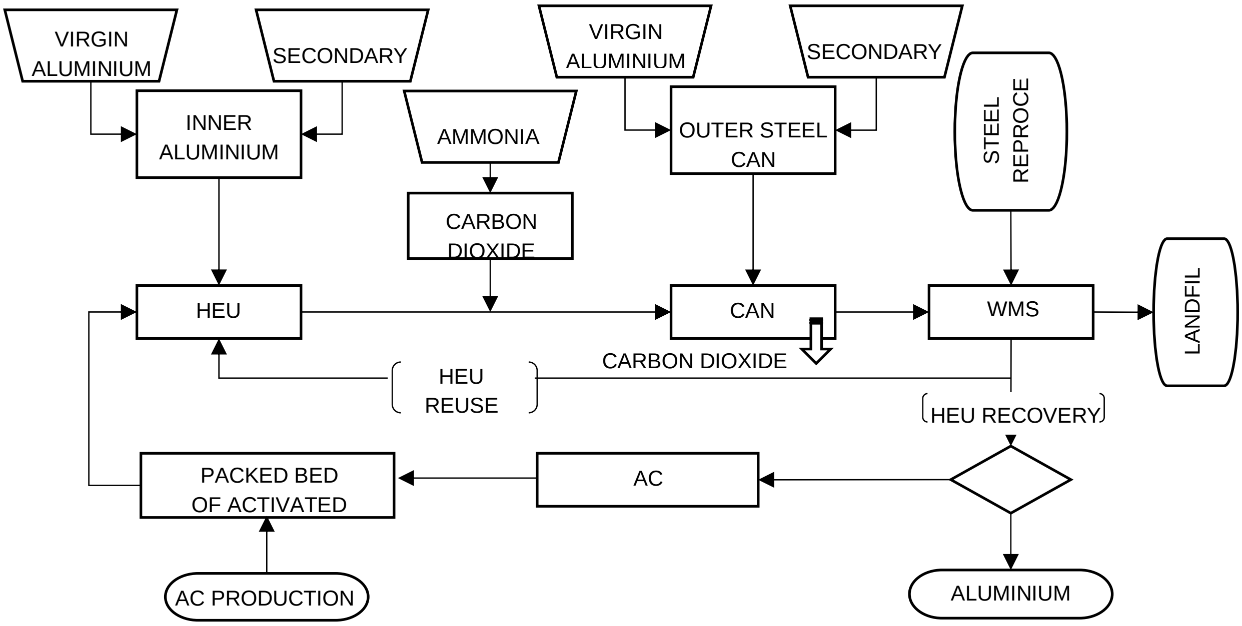

Figure 1 Diagram of the technological process of self-cooling beverage cans.
(own study based on [8])

Life cycle assessment (LCA) was carried out according to the ISO 14040 standard. The analysis was supported by FOOTPRINTCALC 1.2. calculator designed to measure and improve the environmental impact of products. The data were modeled for the carbon footprint and the costs incurred as part of this environmental impact.

3. RESULTS

Because the self-cooling can contain additional elements that allow the drink to be cooled, it is larger than conventional cans. As stated in the article [8, 9], the total volume of this type of can is 510 ml. However, the drink volume stored there is similar to that in traditional cans. Therefore, a functional unit was defined to allow data normalization at 300 ml of chilled drink. It was assumed that the lifespan of the can is one use. Direct loads (including the input data to the model) covering the entire self-cooling life cycle were assumed according to the article's authors [9], as presented in Table 1.

Table 1 Direct loads in the life cycle of a self-cooling beverage can.

Input data	Direct loads
Carbon dioxide (kg)	0.055
Tin-plated steel (kg)	0.029
Aluminum (kg)	0.039
Activated carbon (kg)	0.110
Virgin aluminum (kg)	0.0103
Recycled aluminum (kg)	0.0095
Virgin steel (kg)	0.0180
Recycled steel (tin-plated) (kg)	0.0120
Energy for CO_2 conversion (MJ)	0.0613
Energy for AC compression in HEU (MJ)	0.0864
AC regeneration energy (MJ)	83.20
Transport as a return to a store 40 km away ($kgCO_2eq$)	1.54E-08

Following the study authors [10], LCA analysis is performed according to a scenario in which fossil fuel is considered instead of coconut shells used to generate an alternating current. The energy necessary to charge and compress activated carbon in HEU was also assumed to be an environmental load. The analysis considered the relatively large amount of metals used in the self-cooling can, while materials with low grammage, including those with a low environmental impact, were omitted. Some metals have also been identified separately because they cannot be used in a closed loop, i.e., they cannot be recycled and recovered for reuse. According to the study's authors [9], 70% of the HEU is assumed to be recovered and reused as part of the activated carbon replenishment. The remaining 30% of the HEU is activated carbon, regenerated in an economical furnace (energy consumption of 1 kWh/kg). Then, the aluminum in the HEU is processed again. A similar situation was assumed for the steel material. It forms the outer part of the can and is recycled, according to the studies' authors [9, 17]. It is assumed that recycled materials are mixtures with virgin material. However, carbon dioxide in HEU (for carbonated drinks) is recovered from waste streams from other industrial processes, as in the analyzed approach from gases from ammonia installations. It is emitted into the atmosphere regardless of whether the cooling function is used. According to [9], GHG (greenhouse gas) emissions may be of the same magnitude as the production of carbon dioxide from fossil fuels. In the case of transport, it was assumed that these would be diesel trucks with a load capacity of 27 tons.

According to the adopted assumptions, the can life cycle was assessed, taking into account the impact of carbon footprint emissions. This is one of the most important environmental impacts considered for products, e.g., [18]. Additionally, the so-called eco-costs result from the can's life cycle in terms of carbon footprint emissions. Eco-costs are the environmental burden of a product according to analyses on the prevention of these burdens. Eco-costs are costs that need to be reduced in order to reduce environmental pollution, as well as the depletion of raw materials in the world within a level corresponding to the Earth's carrying capacity [19, 20]. They constitute the sum of the marginal costs of prevention during LCA, as well as the ecological costs of material depletion, energy and transport, and emission costs. Eco-costs are virtual costs that are not integrated with real costs [21, 22]. The model and analysis of the results were developed in the FOOTPRINTCALC 1.2 calculator. Carbon footprint emissions during use were omitted during the analysis due to the lack of reliable data for analysis.

Figure 2 shows the estimated can-originated carbon footprint emissions for selected LCA phases.

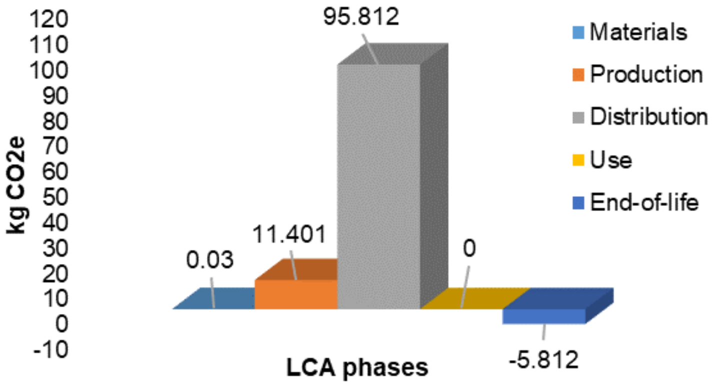

Figure 2 The impact of self-cooling cans during their life cycle on the creation of carbon footprint (kgCO_2e)

According to the adopted assumptions, it was observed that the greatest impact was the distribution phase (approx. 96 kgCO_2e). Much less carbon footprint is created during the production of cans (approx. 11 kgCO_2e). In the end-of-life phase of the can, approx. 6 kgCO_2e. This is due to the recycling of selected materials, such as metal and aluminum. A small share of the carbon footprint was observed in the material acquisition phase (0.03 kgCO_2e). The use phase was omitted from the analysis. Therefore, the final impact of the self-cooling can on its life cycle was estimated at 101,430 kgCO_2e for the carbon footprint. Then, the eco-costs of the self-cooling can, i.e., the costs resulting from its life cycle, were analyzed. The result is shown in **Figure 3**.

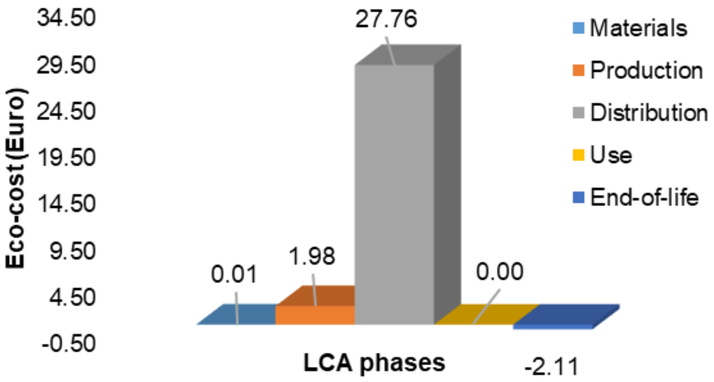

Figure 3 Eco-costs for a self-cooling can (kgCO_2e)

It was observed that savings of up to approximately 28 euros could be achieved in the distribution phase. In the production phase, it is only about 2 euros. As part of the last phase (end of life), it is possible to achieve eco costs of approximately -2 euros. The total eco-cost that needs to be reduced in order to reduce environmental burdens (mainly in terms of carbon footprint) is 27.64 euros. It has been shown that it is good to take improvement actions in the area of can distribution and production. In the same phases of the self-cooling can life cycle, it would be necessary to take cost-saving measures to reduce environmental burdens.

4. DISCUSION AND CONCLUSION

The aim of the analysis was to conduct a life cycle assessment (LCA) of a beverage can with a cooling system and to determine the eco-costs incurred during the life cycle of this product. Life cycle assessment was carried out on the ISO 14040 standard. Calculations were made using the FOOTPRINTCALC 1.2 calculator, designed to measure and improve the environmental impact of products. The data was modeled for carbon footprint and eco-costs.

The main conclusions are as follows.

- the largest share of the carbon footprint occurs in the can distribution phase (approximately 96 kgCO_2e); then during production (approx. 11 kgCO_2e) and obtaining materials (0.03 kgCO_2e);
- in the end-of-life phase of the can, there are approx. 6 kgCO_2e, which are caused by taking into account both the recycling and processing of non-recycled materials;
- with the assumptions made for a self-cooling can, carbon footprint emissions were estimated at 101,430 kgCO_2e;
- the greatest eco-cost savings could be achieved in the distribution phase (approx. 28 Euro).

As shown, the research results indicate critical places in the life cycle of a self-cooling can, such as the area of its distribution and production. Therefore, as part of further research, it is necessary to analyze other solution scenarios for this product. The originality of the proposed model is the ability to verify the entire product life cycle in terms of the creation of a carbon footprint, but also taking into account eco-costs indicating the environmental burden of the product and directions to prevent these burdens.

REFERENCES

[1] SCHLEICH, J., DÜTSCHKE, E., KANBERGER, E., ZIEGLER, A. On the Relationship between Individual Carbon Literacy and Carbon Footprint Components. *Ecological Economics*. 2024, vol. 218, art. 108100. https://doi.org/10.1016/j.ecolecon.2023.108100.

[2] KAGERMANN, H., HELBIG, J., HELLINGER, A., WAHLSTER, W. Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0: Securing the Future of German Manufacturing Industry. *Final Report of the Industrie 4.0 Working Group*. Forschungsunion 2013.

[3] GAJDZIK, B., JACIOW, M., WOLNIAK, R., WOLNY, R., GREBSKI, W. Energy Behaviors of Prosumers in Example of Polish Households. *Energies*. 2023, vol. 16, art. 3186. https://doi.org/10.3390/en16073186

[4] SANJUAN-DELMÁS, D., ALVARENGA, R.A.F., LINDBLOM, M., KAMPMANN, T.C., VAN OERS, L., GUINÉE, J.B., DEWULF, J. Environmental Assessment of Copper Production in Europe: An LCA Case Study from Sweden Conducted Using Two Conventional Software-Database Setups. *Int. J. Life Cycle Assess*. 2022, vol. 27, pp. 255-266. https://doi.org/10.1007/s11367-021-02018-5

[5] IGOGO, T., AWUAH-OFFEI, K., NEWMAN, A., LOWDER, T., ENGEL-COX, J. Integrating Renewable Energy into Mining Operations: Opportunities, Challenges, and Enabling Approaches. *Applied Energy*. 2021, vol. 300, art. 117375. https://doi.org/10.1016/j.apenergy.2021.117375

[6] WIEDMANN, T.O., SCHANDL, H., MORAN, D. The Footprint of Using Metals: New Metrics of Consumption and Productivity. *Environ. Econ. Policy Stud*. 2015, vol. 17, pp. 369-388. https://doi.org/10.1007/s10018-014-0085-y

[7] SIWIEC, D., PACANA, A. A New Model Supporting Stability Quality of Materials and Industrial Products. *Materials*. 2022, vol. 15, art. 4440. https://doi.org/10.3390/ma15134440

[8] ARENA, N., ALPAY, E., KIRKBY, N., LEE, J., CLIFT, R. An on demand chilling system: Activated carbon based desorptive cooling. *J. Clean Prod*. 2018, vol. 176, pp. 937-945. https://doi.org/10.1016/j.jclepro.2017.12.025

[9] ARENA, N., SINCLAIR, P., LEE, J., CLIFT, R. Life Cycle Engineering of Production, Use and Recovery of Self-Chilling Beverage Cans. *J. Clean Prod*. 2017, vol. 142, pp. 1562-1570. https://doi.org/10.1016/j.jclepro.2016.11.148

[10] ARENA, N., LEE, J., CLIFT, R. Life Cycle Assessment of Activated Carbon Production from Coconut Shells. *J. Clean Prod*. 2016, vol. 125, pp. 68-77. https://doi.org/10.1016/j.jclepro.2016.03.073

[11] RADEK, N., PIETRASZEK, J., RADEK, M., PARASKA, O. The influence of plasma cutting parameters on the geometric structure of cut surfaces. *Materials Research Proceedings*. 2020, vol. 17, pp. 132-137. https://doi.org/10.21741/9781644901038-20

[12] ULEWICZ, R., MAZUR, M., KNOP, K., DWORNICKA, R. Logistic controlling processes and quality issues in a cast iron foundry. *Materials Research Proceedings*. 2020, vol. 17, pp. 65-71. https://doi.org/10.21741/9781644901038-10

[13] LIPIŃSKI, T., ULEWICZ, R. The effect of the impurities spaces on the quality of structural steel working at variable loads. *Open Engineering*. 2021, vol. 11, pp. 233-238. https://doi.org/10.1515/eng-2021-0024

[14] RADZYMINSKA-LENARCIK, E., ULEWICZ, M. Polymer inclusion membranes (PIMs) doped with alkylimidazole and their application in the separation of non-ferrous metal ions. *Polymers*. 2019, vol. 11, art. 1780. https://doi.org/10.3390/polym11111780

[15] DUDEK, A., LISIECKA, B., RADEK, N., ORMAN, Ł.J., PIETRASZEK, J. Laser Surface Alloying of Sintered Stainless Steel. Materials. 2022, vol. 15, art. 6061. https://doi.org/10.3390/ma15176061

[16] PIETRASZEK, J., RADEK, N., GOROSHKO, A.V. Challenges for the DOE methodology related to the introduction of Industry 4.0. Production Engineering Archives. 2020, vol. 26, pp. 190-194. https://doi.org/10.30657/pea.2020.26.33

[17] MORRIS, B. The Components of the Wired Spanning Forest Are Recurrent. *Probab. Theory Relat. Fields*. 2003, vol. 125, pp. 259-265. https://doi.org/10.1007/s00440-002-0236-0

[18] KHANAM, T., RAHMAN, A., XU, X., MOLA-YUDEGO, B., MOULA, MD.M.E., PELKONEN, P. Assessing the Awareness and Willingness of European Experts to Reduce Their Carbon Footprint in Everyday Consumption. *Environ. Impact Assess. Rev*. 2022, vol. 97, art. 106889. https://doi.org/10.1016/j.eiar.2022.106889

[19] ČUČEK, L., KLEMEŠ, J.J., KRAVANJA, Z. Accessing Direct and Indirect Effects within a LCA Based Multiobjective Synthesis of Bioproducts Supply Chains. *Comp. Aided Chem. Eng*. 2012, vol. 31, pp. 1065-1069. https://doi.org/10.1016/B978-0-444-59506-5.50044-4

[20] ČUČEK, L., KLEMEŠ, J.J., KRAVANJA, Z. Overview of Environmental Footprints. In: *Assessing and Measuring Environmental Impact and Sustainability*. Elsevier, 2015, pp. 131-193. https://doi.org/10.1016/B978-0-12-799968-5.00005-1

[21] GAWLIK, R. Encompassing the Work-Life Balance into Early Career Decision-Making of Future Employees Through the Analytic Hierarchy Process. *Advances in Intelligent Systems and Computing*. 2018, vol. 594, pp. 137-147. https://doi.org/10.1007/978-3-319-60372-8_14

[22] GAJDZIK, B., WOLNIAK, R., GREBSKI, W., Process of Transformation to Net Zero Steelmaking: Decarbonisation Scenarios Based on the Analysis of the Polish Steel Industry. *Energies*. 2023, vol. 16, art. 3384. https://doi.org/10.3390/en16083384