The Use of Circular Economy Indicators to Improve Sustainability in the Recycling Aluminium Context

Paulo Vitor dos Santos Gonçalves, Rafaela Francisca Moreira Barbosa and Vitor Allan Prats Raspini
Universidade Federal de Santa Catarina
Graduate Program in Production Engineering
Caixa Postal 476, 88040-900, Florianopolis, SC, Brazil
santospaulo.eng@gmail.com, mbarbosarafaela@gmail.com, pratsvitor@gmail.com

Simone Sehnem
UNOESC and UNISUL
Graduate Program in Administration
simone.sehnem@unoesc.edu.br

Lucila M. S. Campos
Department of Production Engineering and Systems
Federal University of Santa Catarina
Caixa Postal 476, 88040-900, Florianopolis, SC, Brazil
lucila.campos@ufsc.br

Abstract

The Circular Economy is an important alternative to capture environmental profit from polluters and increase the competitiveness of productive sectors. This study aims to analyse how the Circular Economy (CE) indicators can contribute to improving the sustainability of recycling aluminium beverage packages in the Brazilian scenario. A literature review was conducted about CE indicators in aluminium-recycling context and a set of CE indicators were found and criticized in the context of sustainability. According to results, beverage packages have alternatives to be more circular, with correct ways to measure improvements and develop the sector, decreasing environmental threats and increasing recycling content. This study provided information to the metal industry, metal users, and the recycling industry of aluminium beverage packaging in Brazil.

Keywords
Circularity, Solid Waste, Beverage Packages.

1. Introduction

Metals are infinitely recyclable in principle, but in practice, recycling is often inefficient or essentially non-existent because of limits imposed by social behaviour, product design, recycling technologies, and the thermodynamics of separation (Reck and Graedel 2012).
The aluminium is used in a variety of products due to its characteristics such as good formability and high corrosion resistance. In this context, the aluminium recycling industry has been expanded through the decades requiring management tools adaptations to this market segment. Therefore, the sustainable management of aluminium has become crucial to the exponential growth in global demand (Soo et al. 2018).

In order to attempt a sustainable management, the concept of Circular Economy (CE) emerges as an alternative system, aiming to decouple economic growth from resource constraints (Ghisellini et al. 2016). According to Reike et al. (2018), the CE concept claims for absolute resource input reduction and a balance among sustainability dimensions. A CE aims to keep products, components and materials at the highest utility and value, wherein this value is maintained through extension of products lifetimes by reuse, refurbishment, and manufacturing as well as closing of resources cycles, trough recycling and related strategies (Bocken et al. 2017).
In this way, indicators can also be used to manage activities, define goals, and visualize the production chain. Specifically concerning CE, indicators can function as a key to improve performance and as a basis for regulatory change (Linder et al. 2017). Thus, this study aims to analyse how the CE indicators can contribute to improving the sustainability of recycling aluminium beverage packages in the Brazilian scenario.

1.1 Objectives

The main objective of this study is to analyse how the Circular Economy (CE) indicators can contribute to improving the sustainability of recycling aluminium beverage packages in the Brazilian scenario.
The paper presents besides this introduction, a section about literature review, and then a section related to the method used. Next, we present the results, discussion of the main results and finally the conclusions.

2. Literature Review

2.1 Background on Circular Economy Indicators

The circular economy consists of a regenerative system in which virgin resource inflows are reduced for the recirculation of materials and components in cycles, and also in which the value of products and materials are maintained for as long as possible (Schilkowski et al. 2019). It is opposed to the linear production system where the material flows are unidirectional, with a beginning and an end of life that leads to disposal in post-consumption (Elia et al., 2017). The circular economy is linked to the understanding of material and energy flows, product design and product life cycle assessment, so that planning these aspects stimulates the closure of production in cycles (Haupt and Hellweg, 2019).
The topic receives increasing attention from researchers, policy makers and decision makers as an alternative to sustainable development (Avdiushchenko and Zając 2019). Furthermore, CE has been endorsed as a policy to minimize burdens to the environment and stimulate the economic system (Moraga et al. 2019). However, one of the core questions around CE is how to measure its progress and performance at different levels (Saidani et al. 2019).
In this way, several studies indicate the use of indicators as an alternative to address the gap on how to measure aspects of the circular economy (Niero et al. 2017; Haupt and Hellweg 2019; Pascale et al. 2021). The use of these indicators is relevant to monitor the transition to a circular economy model and to measure the effects of new policy and circular trends (Vercalsteren et al. 2018). Thus, indicators are needed to ensure that the economy does not only become circular, but also sustainable (Haupt and Hellweg 2019).
The indicators can be distinct between macro, meso and micro level (Vercalsteren et al. 2018). The macro level indicators are useful to support decisions in areas such as sustainable development strategies and environmental policy integration. Meso level indicators focus on the industry, consumption activity or particular material level helping to detect waste of materials, pollution sources and opportunities for efficiency gains in specific sectors or consumption domains. At the last, micro level indicators provide detailed information for specific decision processes at business or local level or concerning specific substance or individual products.

2.2 Aluminium Beverage Package Context and Recycling

The frequency of purchases and high volumes associated with consumer products mean that consumers buy large amounts of packaging – an estimated 207 million tones globally with a value of USD 384 billion each year (Ellen MacArthur Foundation 2015). Packaging represents a large share of the material flows for many materials (Niero and Hauschild 2017). In 2012, aluminium cans represented the second major packaging format (30%) at European level for beer, and nearly half of all cans produced in the EU were destined for the brewing sector (Berkhout et al. 2013). At the global level, packaging represents the second largest source of aluminium scrap (Muchuvá and Elder 2010).

In Brazil, more than one half of the total energy associated with the primary aluminium are hydraulic, a renewable source, while the remaining energy is due to the use of fossil fuels (in thermal power plants, for transportation or for heat and work production) (Gatti et al. 2008).
Aluminium beverage cans are the most recycled packaging material because of the high value of the scrap and ease of collection, unlike other materials; aluminium retains its properties throughout the process. Furthermore, the recycling rate of this type of packaging is higher than others because of the high value of the scrap metal and the technologies available for sorting and recovery aluminium waste materials (AlSaffar and Bdeir 2008).
Aluminium cans are one of the packaging types considered in the initiative, which have shown good circularity potential, in particular to enter a closed-loop supply (Stewart et al. 2018). Niero and Olsen (2016) showed that a closed product loop system, producing new cans from used beverage cans (UBC) has lower impacts than using mixed aluminium packaging scrap as a source. Stewart et al. (2018) demonstrated that new business models can implement circular economy strategy, emphasizing environmental and economic aspects, promoting circularity in aluminium beverage cans.
In this way, recycling of aluminium beverage packages can also contribute to preserve natural resources and aligned with the concepts of circular economy and sustainability. Moreover, the recycling advantages of aluminium cans are straight linked to correct package disposal and the reduction of aluminium primary production (Gatti et al. 2008), minimizing environmental impacts, improving economic aspects and, hence, creating new jobs.

3. Method

This work undertook a systematic literature review to identify papers of circular economy indicators and indexes in the aluminium recycling chain. To achieve this purpose, we followed two methods that complemented it selves. The method followed by Tranfield et al. (2003) comprises three steps (planning, execution, and reporting) and a snowballing procedure was outlined according to Wohlin (2014) that use four phases (start set, iterations, authors, and data extraction). These phases were integrated according to Figure 1.

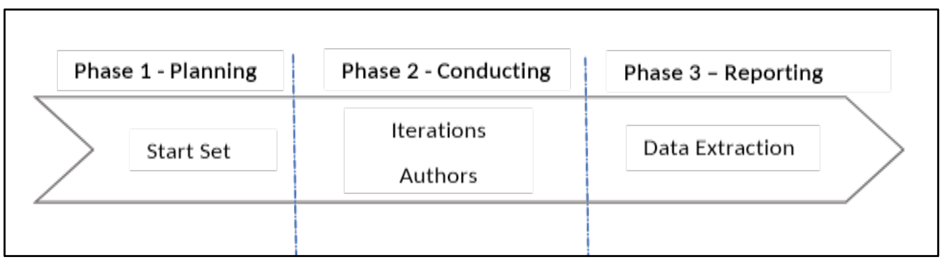

Figure 1. Stage of Research

The planning stage proposed by Tranfield et al. (2003) defines keywords of interest and a protocol according to the proposal review. Thus, according to Wohlin (2014), the step called start set identifies papers that started the snowballing method. To achieve the methods, papers were extracted from the digital databases Scopus using two different strings. First, was used “circularity” and “aluminum can*” or “aluminium can*” resulting in three articles; and then, was used “circularity” and “solid waste” and “index” or “indicator*”, resulting in four papers. So, these strings brought seven papers that were used to start the conducting stage.
Tranfield et al. (2003) establish the conducting stage as the search and the selection of articles that follows the theme. In the conducting stage, the authors reviewed the title and abstract examined before deciding to use it as reference and the second phase of snowballing (iterations) was set. From the set of results, it was selected papers using as criteria of inclusion ones that mentioned circular economy indexes and/or indicators, aluminium beverage, or recycling aluminium cans on their keywords. It did not include papers with no interaction of the proposed theme and keywords. This elongated the research to more eleven papers. From this, a research was made thought the most cited authors to identify other potential papers, following Tranfield et al. (2003) guidance. A bunch of more five works was further in this investigated research and added up to twenty-three papers and then, the second stage was finished. The full text of the remaining twenty-three papers were read and works that did not fit the proposed theme were excluded based on the same exclusion criteria used on the second phase. Finally, all papers identified went to data extraction, which conducted the research questions posed in topic 4 of this paper. The Figure 2 shows the overview of article screening process with resulting number of articles.

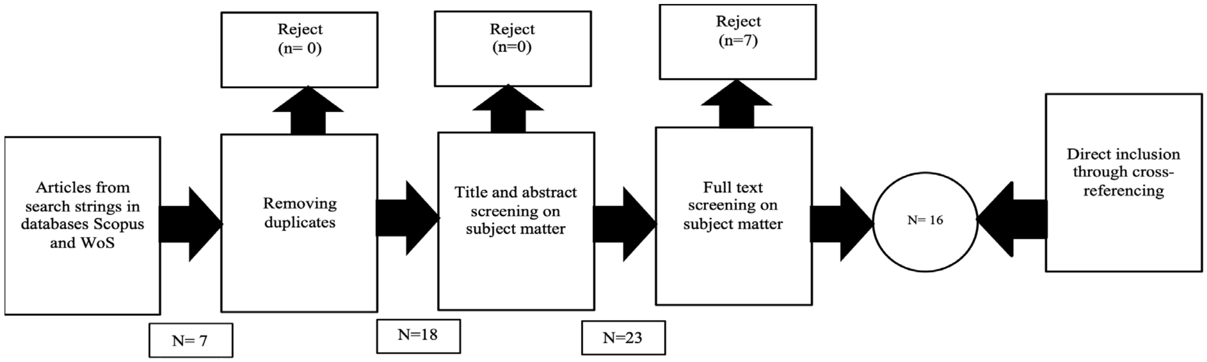

Figure 2. Overview of article screening process with resulting number of articles

4. Results and Discussion

This section presents the results considering the reporting stage mentioned on methods. The first part provides a descriptive analysis of the field research. Then, we present some analyses regarding the indicators selected based on the circular economy concept. The third and last part discusses improvement implications in aluminium beverage cans recycling in Brazil.

4.1 Descriptive Analysis

The data extraction phase, from a total of 16 articles selected to the reporting stage, reached information about the year of publication, sector, the country where the paper was developed, and the methods (index, indicators or another approach) that were used to measure circular economy in aluminium beverage packages. The results of the snowball are shown in Figure 3.
The analysed publications cover the years 2008 to 2020. The year 2016 has the largest number of publications, with five papers published. All these papers have in common the use of Life Cycle Assessment (LCA) as a methodology for analysing the aluminium chain in different sectors.
In attempt to discover different sectors of aluminium studies, the research was sectorial divided and the country of the study was considered. A total of nine papers have specified their country of study or application. Brazil appears in a study considering the beverage can sector with an emphasis on the Life Cycle Inventory (LCI) (Gatti et al. 2008)
Niero and Haulschild (2017) focus on the industrial practices in implementing circular economy strategies in the packing sector, which is one of the priority sectors in the European Circular Agenda. Various factors can contribute to material circularity in a recycling system. One of them is the capability of social and legislative motivates or oblige stakeholders to provide necessary infrastructure or initiate public campaigns to stimulate a sustainable culture (Hageluken 2007) and this agenda aggregates a circular economy action plan for a cleaner and more competitive scenario in Europe.
For this and several other reasons, Europe becomes an example of initiatives regarding the entire life cycle of products (Vercalsteren et al. 2018). In addition, Stotz et al. (2017) analyse seven scenarios comprising specific systemic changes that were compared to the current recycling practice of the used beverage cans in the United Kingdom. Detzel and Monckert (2009), in their case study, discuss the LCA framework to environmental evaluation of aluminium beverage cans in the German context while Princigallo et al. (2016) used the same method to study two different systems of aluminium beverage cans in Bologna and Copenhagen. These papers aimed at Europe emphasize the value of action plans to stimulate and support the use of circular economy strategies in each step of the aluminium cans context.

Reference	Country	Sector	Index or Indicators	Methods/Approaches
Niero & Hauschild (2017)	Denmark	Packaging	Material Circularity Indicator (MCI)	Life Cycle Sustainability Assessment (LCSA)
Ali *et al*., (2020)	Not Specified	Automotive Sector	Manufacturing Indicators and Design Indicators	Life Cycle Impact Assessment (LCIA)
Cullen & Alwood (2013)	Not Specified	Aluminum Chain	-	-
Detzel & Monckert (2008)	German	Beverage cans	Recycling Rate	Life Cycle Assessment (LCA)
Gatti et *al*. , (2008)	Brazil	Beverage cans	Aluminum Recycling Rate and Consumption and Emission Rates	Life Cycle Inventory (LCI) of aluminum beverage cans in Brazil
Grimaud e*t al*., (2016)	France	Cable Recycling Process	10 Indicators Selected for the LCIA	Life Cycle Impact Assessment (LCIA)
Harst et *al*., (2016)	Not Specified	Recycling sector	Recycling Rate, Incineration rate and landfilling rate	Life Cycle Assessment (LCA)
Haupt e*t al*., (2016)	Switzerland	Municipal Solid Waste	-	-
Niero & Olsen (2016)	Not Specified	Packaging	Recycling Rate	Life Cycle Assessment (LCA)
Niero *et al*., (2016)	Not Specified	Aluminum Chain	% renewable energy and % recycled content	Cradle to Cradle (C2C) and Life Cycle Assessment (LCA)
Niero *et al*., (2017)	Not Specified	Beverage packaging	Material Reutilization (MR) Recycled Content (RC) and %of the product considered recyclable	Life Cycle Assessment and Cradle to Cradle
Princigallo e*t al*., (2016)	Bologna and Copenhagen	Beverage cans recycling	-	Life Cycle Costing (LCC) and Life Cycle Assessment (LCA)
Scipioni e*t al*., (2012)	Not Specified	Beverage packaging	CED - Cumulative Energy Demand	Life Cycle Assessment (LCA) and Life Cycle Impact Assessment (LCIA)
Soo e*t al*., (2019)	Not Specified	Aluminum Remanufacturing	Material Circularity Indicator (MCI)	Life Cycle Modelling (LCM)
Stotz e*t al*., (2017)	United Kingdom	Beverage Cans	Material Circularity Indicator (MCI), Circular Economy Performance Indicator (CPI) and Eco-Indicator99	Life Cycle Assessment (LCA)
Warrings & Fellner (2018)	Austria	Packaging and household non-packaging	Recycling Rate, Recovery Rate, Oxidation Rates,	Material Flow Analysis (MFA)

Figure 3. Results from the snowball method

4.2 Circular Economy Indicators Selected

The CE is, as long as we are known, about resource scarcity, environmental impacts, economic and social benefits, and closing the loops which mean to keep materials, components, products, etc. on their highest level of utilization (Lieder & Rashid, 2016). So, aluminium cans are often used to illustrate the benefits of comparing and using frameworks or indicators in intend to find CE strategies on the closed-loop aluminium can supply.
Thereby, Niero and Hauschild (2017) used the Material Circularity Indicator (MCI) on aluminium cans recycling as an indicator that measures how well a product performs in the context of the circular economy, allowing companies to estimate how advanced they are on their journey from a linear model to a circular model. The inputs to calculate MCI refers to four main aspects: i) recycled content, ii) utility during use stage, iii) destination after use and, iv) efficiency of recycling.
The same discuss is used by Soo et al. (2019) about MCI in aluminium recycling cans. The authors complement the CE as a key to ensure that products reached the end-of-life (EoL) within the economy as long as possible through creating further value. In the concept defined by Stotz et al. (2017), EoL is a recycling performance in accordance with the equal share method to account impacts both on the recyclability and the recycled content (RC). This paper also emphasizes in common with the two authors cited above that the circularity of any aluminium system can be express by the total material losses throughout the entire process chain and the MCI refers to a closed material loop to produce new aluminium beverage cans.
While technological innovation alone will not be able to increase the efficiency of the materials circularity, other factors determine the full exploitability of aluminium cans life cycle. One of them is an indicator called recycling

rate (RR) that depends on consumer behaviour, embedded in a recycling culture (Stotz et al. 2017; Niero and Olsen 2016). Basically, recycling rate is one of the most used indicators in circular economy for monitoring progress in waste recycling. Only in this research, eleven papers cited recycling rate as a key to improve strategies in recycling aluminium can.

As regularly applied with complementary methods to assess material circularity, Life Cycle Assessment (LCA) is a scientific methodology that has been successfully used to quantify the potential environmental impacts of beverage packing in aluminium cans (Van der Harst et al. 2016; Saleh 2016; Simon et al. 2015). Studies combined LCA with Material Flow Analysis (MFA) in order to support local solid waste management decision making by assessing the performance of different waste policy measures in terms of archived recycling rates (Stotz et al. 2017; Turner et al. 2016; Sevigné-Itoiz et al. 2014; Detzel and Monckert 2008). These studies concluded that the combination of MFA and LCA is a prerequisite to move from a linear to a circular economy and they also created a Circular Economy Performance Indicator (CPI), which expresses the quality-recycled material to its virgin counterpart.

Many methods have been reported and used to include recycling, e.g., LCA and MFA, as alternative to have a complete process analysis. Haupt et al. (2016) assay Swiss aluminium and tinplate waste management system based on MFA in addition to determine RR and Content Rates (CR). Harst et al. (2016) cited in their research six methods could be use in aluminium can disposal and polystyrene (PS) cups. Its results in three indicators in treatment management: recycling rate, landfilling rate and incineration rate. These results stress the importance to consider other impact categories besides the most commonly used global warming impact.

Other two methods combining with each other were used Niero et al. (2016) related two different methods in their research: Cradle to Cradle (C2C) and LCA. In terms of C2C, twenty different scenarios were developed and compared, arising the indicators % renewable energy (RE) and % recycled content (RC). The RE refers to the share of renewable energy in final energy consumption and RC is the amount of recyclable materials recovered for recycling. For the beverage packing sector of aluminium cans two papers proven the use of the proxy non-renewable indicator called Cumulative Energy Demand (CED) more usefully to obtain preliminary estimation of the environmental impacts due different options (Niero et al. 2016; Scipioni et al. 2012).

Such as integrated pattern, the essence of circular economy can be seen at Warrings and Fellner (2018) paper of Austrian aluminium packaging industry. Austria keeps higher indexes of recovery rates (ReR), recycling rate (RR) and Oxidation Rates (OR) for aluminium packaging. The following ORs were applied to determine losses of aluminium packaging and non-packing during the combustion process while ReR subsequently used in conjunction with the waste quantities processed to determine the absolute aluminium recovery quantities and RR has a very considerable influence of 82% on the total recycled quantities come from rigid packaging and non-packaging material.

4.3 Improvement Implications in Aluminium Beverage Packages Recycling in Brazil Context

According to Abal (2019), the sector from packages is the major consumer of aluminium in Brazil, leaded by the use of aluminium cans in the beverage segment, whose represent an amount of 375.5 thousand tons of cans sold in the country. In addition, in 2019, Brazil recycled about 97% of the total aluminium cans sold in the same year, representing an increase of 14.7% compared to 2018 (Abal 2019). In this circumtances, the use of correct indicators must be enhance the positive aspects regard to recycling aluminium packages, increasing recycling rates, saving resources and implementing new circular models.

The recycling of aluminium saves up to 95% of the energy needed to produce primary metal because the recycling of aluminium requires only 5% of the energy to produce secondary metal as compared to primary metal and generate only 5% of the greenhouse gas emissions (AlSaffar and Bdeir 2008). This aspect indicates that the increase of recycling content is crucial to improve implications and optimize the use of resources, reduce environmental impacts, and save energy, similar to that was promoted by circular economy.

Considering this, the RR indicator (Stotz et al. 2017; Niero and Olsen 2016) should be used in Brazil context to improve circular aspects, however the studies showed that this indicator depends on consumer behaviour. In accordance with Parajuly et al. (2020), the consumers are directly involved in the end of life of a product, implicating in the success of a subsequent resource recovery. Thus, the consumer behaviour should be considered a barrier to implement circular economy strategies and increase recycle index and need to be focused by police makers to create more value in the return of aluminium package products and, hence, creating a recycling culture in Brazil context.

On this point, MCI (Niero and Hauschild 2017; Soo et al. 2019) should be clearly employed in the beverage packages and others types of aluminium packages, measuring product performs and supporting this sector to implement circular economy aspects, mainly with the improvement of crucial factors like destination after use.

Brazil lacks correct alternatives to designate waste, reporting 29 million tons forwarded to landfills or dumps (Abrelpe 2020). The incorrect dispose of packages results in water pollution, soil depletion and waste of resources, implying in threats to the environment and economic losses due to not using the materials in the recycling process, closing the loop.

In accordance with Haupt et al. (2016) and Harst et al. (2016), recycling and landfilling rate are also essential to enhance waste management treatment, leading to a better control of materials flow and life cycle assessment from beverage packages, supporting new strategies to measure the amount destined to waste management system. Therefore, those indicators should be necessary to change the current situation of incorrect destination, assisting governments, entrepreneurs and society to monitor the path of the materials and avoid environmental impacts. Furthermore, increase the recycling rate and decrease the total designated to landfill represents an advance to a more circular system, saving resources and energy. Additionally, CED (Niero et al. 2016; Scipioni et al. 2012) can contribute to estimate environmental impacts, stimulating the sector to elaborate a correct LCA and C2C in beverage packages and other aluminium packages to establish a diagnose of the products and developing alternatives of reuse, repair and recycling due to improve of the products life cycle information.

Finally, the improvement in the sector keeps on setting and developing indexes of ReR, RR and OR, comparable to the study of Warrings and Fellner (2018) in Austria. The above article considers this index to be a suitable instrument for correctly measuring Al recycled in different stages of recovery. Thereby, beverage packages and other aluminium packages have alternatives to be more circular, with correct ways to measure improvements and set goals to develop the sector, decreasing threats and increasing recycling content, mainly.

5. Conclusion

This study contributed to provide information to the metal industry, metal users and the recycling industry of aluminium beverage packaging and cans in Brazil. The major issue analysed was the lack of practices in all aluminium chain in Brazil arising from concepts of circular economy. Another challenge is the need for public policies that encourage companies to adopt circular practices The European Agenda commonly cited in papers used in this research could be a directive in public policies for companies and also consumers from others countries.

Based on this, a consolidated public policies or economic plan considering sustainable and circular economy practices could provide a more optimized process on the secondary chain of aluminium in Brazil. This clearly demonstrates that it should be important to discuss which indicator based on circular economy has a highly performance considering specifics scenarios.

The uses of others databases can provide a better view of more indicators or indexes in the aluminium recycling chain and consequently complete the snowball research.

Additionally, it would be certainly boosting a framework considering the most used methods in packaging and beverage cans sector and their respective indicators.

The study carried out presents as a theoretical contribution the presentation of the panorama of publications allusive to the theme Circular Economy (CE) indicators and its contribution in improving the sustainability of the recycling of aluminium packaging for beverages in the Brazilian scenario.

It shows an important theoretical gap in the recording of evidence about circular economy indicators that may be useful for recycling aluminium packaging. Industry class entities, such as the Brazilian Aluminium Association - ABAL, Revista Alumínio and Alcoa Brasil recognize the potential that aluminium has to be recycled and reintroduced into the production chain. There are already several initiatives underway in the context of production chains. But there is still a need for articulation of different stakeholders so that it is possible to create a culture of returning packaging to its origin and assimilating the premises of shared responsibility for solid waste management provided for in Brazilian legislation.

References

Abal, (2019), “Latinhas campeãs”, Retrieved from https://abal.org.br/sustentabilidade/reciclagem/latinhas-campeas/, Latest access in 14 January 2021.

Abal, (2019), “Statical information”, Retrieved from http://abal.org.br/en/statistical-information/, Latest access in 14 January 2021.

Abrelpe, (2020), “Panorama dos Resíduos Sólidos no Brasil”, Retrieved from https://abrelpe.org.br/panorama-2020/, Latest access in 13 January 2021.

Ali, A.K., et al. (2020), “Symbiotic Circularity in Buildings: An Alternative Path for Valorizing Sheet Metal Waste Stream as Metal Building Facades”, *Waste and Biomass Valorization*, Vol. 11, No. 12, pp. 7127–7145.

AlSaffar, K. A., Bdeir, L. M. H. (2008), "Recycling of Aluminum Beverage Cans", *Journal of Engineering and Sustainable Development*, Vol. 12, No. 3, pp. 157-163. and economic assessment of production, use and recycling of aluminium cans: Bologna

Avdiushchenko, A. and Zając, P. (2019), "Circular Economy Indicators as a Supporting Tool for European Regional Development Policies", *Sustainability*, Vol. 11 No. 11, p. 3025.

Berkhout B., et al. (2013), "The Contribution Made by Beer to the European Economy", Retrieved from https://brewersofeurope.org/uploads/mycms-files/documents/archives/publications/2013/FullReport20140123.pdf, Latest access in 15 January 2021.

Bocken, N.M.P., et al. (2017), "Taking the Circularity to the Next Level: A Special Issue on the Circular Economy: Taking Circularity to the Next Level", *Journal of Industrial Ecology*, Vol. 21 No. 3, pp. 476–482.

Detzel, A. and Mönckert, J. (2009), "Environmental evaluation of aluminium cans for beverages in the German context", *The International Journal of Life Cycle Assessment*, Vol. 14 No. S1, pp. 70–79.

Elia, V., et al. (2017), "Measuring circular economy strategies through index methods: A critical analysis", *Journal of Cleaner Production*, Vol. 142, pp. 2741–2751.

Ellen MacArthur Foundation, (2015), "Circularity indicators: an approach to measuring circularity", Retrieved from https://www.ellenmacarthurfoundation.org/assets/downloads/insight/Circularity-Indicators_Methodology_May2015.pdf, Latest access in 07 January 2021.

Gatti, J.B., et al. (2008), "Recycling of aluminum can in terms of Life Cycle Inventory (LCI)", *The International Journal of Life Cycle Assessment*, Vol. 13 No. 3, pp. 219–225.

Ghisellini, P., et al. (2016), "A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems", *Journal of Cleaner Production*, Vol. 114, pp. 11–32.

Hagelüken, C. (2007), "The challenge of open cycles – Barriers to a closed loop economy demonstrated for consumer electronics and cars", *R'07 World Congress* – Recovery of Materials and Energy for Resource Efficiency 1–11.

Harst, E., et al. (2016), "Comparison of different methods to include recycling in LCAs of aluminium cans and disposable polystyrene cups", *Waste Manag*, Vol. 48, pp. 565–583.

Haupt, M. and Hellweg, S. (2019), "Measuring the environmental sustainability of a circular economy", *Environmental and Sustainability Indicators*, Vol. 1–2, p. 100005.

Haupt, M., et al. (2017), "Do We Have the Right Performance Indicators for the Circular Economy? Insight into the Swiss Waste Management System: Circular Economy: Do We Have the Right Indicators?", *Journal of Industrial Ecology*, Vol. 21, No. 3, pp. 615–627.

Lieder, M. and Rashid, A. (2016), "Towards Circular Economy implementation: A comprehensive review in context of manufacturing industry", *Journal of Cleaner Production*, Vol. 115, pp. 36-51.

Linder, M., et al. (2017), "A Metric for Quantifying Product-Level Circularity: Product-Level Circularity Metric", *Journal of Industrial Ecology*, Vol. 21 No. 3, pp. 545–558.

Moraga, G., et al. (2019), "Circular economy indicators: What do they measure?", *Resources, Conservation and Recycling*, Vol. 146, pp. 452–461.

Muchová, L. and Eder, P. (2010), *End-of-Waste Criteria for Aluminium and Aluminium Alloy Scrap: Technical Proposals*, Publications Office, LU, available at: https://data.europa.eu/doi/10.2791/43228 (accessed 13 January 2021).

Niero, M. and Hauschild, M. Z. (2017), "Closing the Loop for Packaging: Finding a Framework to Operationalize Circular Economy Strategies", *Procedia CIRP*, Vol. 61, pp. 685–690.

Niero, M. and Olsen, S. I. (2016), "Circular economy: To be or not to be in a closed product loop? A Life Cycle Assessment of aluminium cans with inclusion of alloying elements", *Resources, Conservation and Recycling*, Vol. 114, pp. 18–31.

Niero, M., et al. (2016), "Closing the loop for aluminum cans: Life Cycle Assessment of progression in Cradle-to-Cradle certification levels", *Journal of Cleaner Production*, Vol. 126, pp. 352–362.

Parajuly, K., et al. (2020), "Behavioral change for the circular economy: A review with focus on electronic waste management in the EU", *Resources, Conservation & Recycling: X*, Vol. 6, pp. 100035.

Pascale, A., Arbolino, R., Szopik-Depczyńska, K., Limosani, M. and Ioppolo, G. (2021), "A systematic review for measuring circular economy: The 61 indicators", *Journal of Cleaner Production*, Vol. 281, p. 124942.

Princigallo, R., et al. (2016), "Comparative environmental and economic assessment of production, use and recycling of aluminium cans: Bologna vs Copenhagen", In: *Atti del X Convegno dellla Rete Italiana Life Cycle Thinking, sostenibilità ed economia circolare*, pp. 352-359.

Reck, B. K. and Graedel, T. E. (2012), "Challenges in metal recycling", *Science*, Vol. 337, No. 6095, pp. 690-695.

Reike, D., et al. (2018), "The circular economy: New or Refurbished as CE 3.0? — Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options", *Resources, Conservation and Recycling*, Vol. 135, pp. 246-264.

Saidani, M., et al. (2019), "A taxonomy of circular economy indicators", *Journal of Cleaner Production*, Vol. 207, pp. 542–559.

Saleh, Y. (2016), "Comparative life cycle assessment of beverages packages in Palestine", *Journal of Cleaner Production*, Vol. 131, pp. 28–42.

Schilkowski, C., et al. (2020), "Quantifying the circularity of regional industrial waste across multi-channel enterprises", *Annals of Operations Research*, Vol. 290, No. 1–2, pp. 385–408.

Scipioni, A., et al. (2013), "Significance of the use of non-renewable fossil CED as proxy indicator for screening LCA in the beverage packaging sector", *The International Journal of Life Cycle Assessment*, Vol. 18, No. 3, pp. 673–682.

Sevigné-Itoiz, E., et al. (2014), "Environmental consequences of recycling aluminum old scrap in a global market". *Resources, Conservation & Recycling*, Vol. 89, pp. 94–103.

Simon, B., et al. (2015), "Life cycle impact assessment of beverage packaging systems: focus on the collection of post-consumer bottles", *Journal of Cleaner Production*, Vol. 112, pp. 238-248.

Soo, V. K., et al. (2018), "Sustainable aluminium recycling of end-of-life products: A joining techniques perspective", *Journal of Cleaner Production*, Vol. 178, pp. 119–132.

Soo, V.K., et al. (2019), "Life Cycle Modelling of End-of-Life Products: Challenges and Opportunities towards a Circular Economy", *Procedia CIRP*, Vol. 80, pp. 607–612.

Stewart, R., et al. (2018), "Exploring the Implementation of a Circular Economy Strategy: The Case of a Closed-loop Supply of Aluminum Beverage Cans", *Procedia CIRP*, Vol. 69, pp.810-815.

Stotz, P.M., et al. (2017), "Environmental screening of novel technologies to increase material circularity: A case study on aluminium cans", *Resources, Conservation and Recycling*, Vol. 127, pp. 96–106.

Tranfield, D., et al. (2003), "Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review", *British Journal of Management*, Vol. 14, No. 3, pp. 207–222.

Turner, D. A., et al. (2016), "Combined material flow analysis and life cycle assessment as a support tool for solid waste management decision making", *Journal of Cleaner Production*, Vol. 129, pp. 234–248.

Vercalsteren, A., et al. (2018), "Indicators for a circular economy", Retrieved from https://circulareconomy.europa.eu/platform/en/knowledge/indicators-circular-economy, Latest access in 13 January 2021.

Warrings, R. and Fellner, J. (2018), "Current status of circularity for aluminum from household waste in Austria", *Waste Management*, Vol. 76, pp. 217–224.

Wohlin, C. (2014), "Guidelines for snowballing in systematic literature studies and a replication in software engineering", *Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering*, Association for Computing Machinery, London, England, United Kingdom, pp. 1–10.

Biographies

Paulo Vitor dos Santos Gonçalves is a Ph.D. student in Production Engineering at Universidade Federal de Santa Catarina (UFSC). He holds a master in Environmental Sciences at Universidade do Estado do Pará (UEPA) and he has bachelor as Environmental Engineer, also at UEPA. Currently, Paulo is a researcher at the Laboratory of Environmental Management and Assessment (LGAA - UFSC).

Rafaela Francisca Moreira Barbosa has a bachelor in Production Engineer at Universidade do Amazonas (UNAMA). She has a MBA in Project Management at Fundação Getúlio Vargas (FGV). Currently, she is a master student in Production Engineering at Universidade Federal de Santa Catarina (UFSC) and she is also a researcher at the Laboratory of Environmental Management and Assessment (LGAA - UFSC).

Vitor Allan Prats Raspini has a technician in Electrotechnics from the Instituto Federal de Santa Catarina (IFSC). Currently, he is undergraduate student in Production Engineering from the Universidade Federal de Santa Catarina (UFSC) and he is also a researcher at the Laboratory of Environmental Management and Assessment (LGAA - UFSC).

Simone Sehnem has an under graduation in Agribusiness at Universidade do Oeste de Santa Catarina - Campus de São Miguel do Oeste (2005), and also an under graduation at Administration at Universidade do Oeste de Santa Catarina - Campus de São Miguel do Oeste (2010), she has a master in Administration at Universidade Federal de Santa Catarina (2007) and doctorate in Administration at Universidade do Vale do Itajaí (2011). Currently she is Associate Professor at UNOESC and UNISUL. She has experience in Administration, focusing on Administration, acting on the following subjects: sustainability, performance, strategic management, strategic and environmental management, circular economy.

Lucila Maria de Souza Campos is Associate Professor and currently head of department at Department of Production Engineering and Systems (EPS), at Universidade Federal de Santa Catarina (UFSC). She is also accredited as a teacher and supervisor in the Professional Master in Management Systems of the Universidade Federal Fluminense (UFF). She was visiting professor at Royal Holloway University of London (2015-2016) in the area of Sustainability. She holds the titles of Doctor (2001) and Master (1996) in Production Engineering by Universidade Federal de Santa Catarina and Bachelor in Production Engineer (1993) by Universidade Federal de São Carlos. She is also Permanent Professor of the Graduate Program in Production Engineering (PPGEP/UFSC) since 2010 and coordinator in the mandates 2013-2015 and 2017-2019. She teaches and researches in Production Engineering, with emphasis on operations management, environmental management and sustainability. Her research interests include EMS, sustainability indicators, lean manufacturing, green manufacturing, and circular economy, among others.