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Assessing circular economy in Brazilian industries through the analytical hierarchy process

Avaliando a economia circular nas indústrias brasileiras pelo processo de hierarquia analítica

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ABSTRACT

Sustainable development has been pursued by organizations around the world ever since environmental and social issues were introduced into institutional agendas. In the various sectors of the economy, the factors that influence sustainable decisions are multidisciplinary and systemic, and address the concept of Circular Economy (CE). This study aimed to develop a method to measure the level of commitment of companies and sectors to CE. The method allows investigating institutional factors associated with sustainable development and assessing the depth of CE practices. A circularity index is originated that can assist decision makers in the development of specific strategies, investment plans, and policies to guide organizations towards the achievement of a CE. The proposed method was then applied to 75 Brazilian companies recognized for their sustainability initiatives, analyzing practices associated with CE actions, as well as their depth. The results, using the Analytic Hierarchical Process (AHP), indicate that the sectors analyzed do not have a significant difference among them and that the majority of the companies analyzed (80%) do not practice any circular action despite claiming the opposite. Therefore, CE is still incipient in Brazil. The application of the proposed method to a large sample showed its potential for global use, and that it can also be employed to guide actions of single companies or entire sectors towards sustainable development using a CE path.

Keywords: circularity index; circularity levels; circularity measurement; sustainable development.

RESUMO

O desenvolvimento sustentável tem sido buscado por organizações em todo o mundo desde que as questões ambientais e sociais entraram nas agendas institucionais. Nos diversos setores da economia, os fatores que influenciam as decisões sustentáveis são multidisciplinares, sistêmicos e abordam o conceito de economia circular (EC). O objetivo deste estudo foi desenvolver um método para medir o nível de comprometimento de empresas e setores com a EC. O método permite investigar fatores institucionais relacionados ao desenvolvimento sustentável e avaliar a profundidade das práticas de EC. Foi gerado um índice de circularidade que pode auxiliar os tomadores de decisão no desenvolvimento de estratégias, planos de investimento e políticas específicas capazes de orientar as organizações para o alcance da EC. A metodologia proposta foi então aplicada a 75 empresas brasileiras reconhecidas por suas iniciativas de sustentabilidade, analisando-se as práticas relacionadas às ações de EC, bem como sua profundidade. Os resultados, utilizando o Processo Analítico Hierárquico (PAH), mostram que os setores analisados não apresentam diferença significativa entre si, e que a maioria das empresas analisadas (80%) não pratica ação circular alguma, apesar de afirmar o contrário. Sendo assim, a EC ainda é incipiente no país. A aplicação do método proposto em uma grande amostra mostrou seu potencial de uso global, podendo também ser empregada para orientar ações de empresas isoladas ou de setores inteiros na direção do desenvolvimento sustentável, por meio da EC.

Palavras-chave: índice de circularidade; níveis de circularidade; medição da circularidade; desenvolvimento sustentável.

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Introduction

Economic development, as described in neoclassical economics, has been questioned by society due to its unsustainable model with growing demand for raw materials, means of extraction and manufacturing that have a high demand for water and energy, and great generation of waste both during production and after use. The waste generated leads to economic and environmental damage, with negative impacts on natural resources and human beings.

Ghisellini et al. (2016) explain that this linear pattern focuses mainly on the efficient allocation of resources, disregarding their limited nature. A Circular Economy (CE) prescribes an economic model regulated according to the laws of nature, with networks of components interacting through the exchange of material and energy flows, with recycling, and biomimetic standards. CE seeks to transform waste into resources and return them to production and consumption systems closing cycles, with different levels of material and product recovery, increasing the efficiency of resource use (Niero and Olsen, 2016; Witjes and Lozano, 2016; Murray et al., 2017; Parchomenko et al., 2019).

However, incentives for preventing pollution and adopting CE are at an early stage. Only a small number of countries have taken preliminary measures for its implementation (Colling et al., 2016; Ghisellini et al., 2016; Ratnasabapathy et al., 2021) and research on aspects of CE and its implementation is still limited (Witjes and Lozano, 2016).

China has advanced in the implementation of a CE. With the development of specific programs and legislation (Yang et al., 2019). According to Ghisellini et al. (2016), CE in China is the result of a national policy strategy (top-down approach), which is reflected in the instruments used, which are mainly "command and control" and not based on the market, as in European, Japanese, or American policies. In the latter, the transition appears to be taking place as a bottom-up approach, based on initiatives by environmental organizations, civil society, NGOs, among others.

The European Union has also evolved considerably in the practice and development of CE programs, such as the European Commission's communication, "Towards a circular economy: a zero waste program for Europe", which culminated in several reports aimed at private and public organizations, and the third sector. In practice, a study about tire recycling in France shows that the cost/benefit of implementing CE guides recycling, and consumer perception is also taken into account, as well as how easy it is for an end-of-cycle product to be returned to the market (Lee et al., 2021).

In Brazil, however, there are few studies and initiatives associated with CE. The issue of waste is the most discussed, being regulated by the National Solid Waste Policy (PNRS), which emphasizes recycling (Colling et al., 2016). In practice, most of the waste generated is disposed of in landfills (about 94% of all waste generated in Brazil) or recycled. PNRS does not encourage incineration and there is no public policy based on environmental education or the total cost of waste generation and disposal (da Silva, 2018). As for organic waste recycling, waste from the Brazilian fishing industry was the object of research on the CE, and significant disposal of nutrient material was detected. This is important waste in the ecosystem in which it is inserted, demanding attention and investments for its adequate disposal (Machado et al., 2020). Another topic addressed is the growing electronics industry, which has an impact on the material supply chain. It was found that the level of CE practices including processes in the post-use phase that reduce environmental impacts is very low (da Costa et al., 2020).

It is important to highlight that CE transcends the idea of waste recycling. It seeks to integrate economic activity with the environmental responsibility of using natural resources in the development process (Murray et al., 2017). CE initiatives can be implemented at different levels, starting from a value chain approach, from a business perspective, for the global economy (Niero and Olsen, 2016, Ethirajan et al., 2021).

CE practice at the business level occurs through innovation in the ways of producing and relating, and this often requires restructuring the business model. A business model is how the company does business, and how it converts resources and capabilities into economic value (Teece, 2010; Agrawal et al., 2021). For this, the company uses different forms of capital (physical, financial, and intellectual) (Beattie and Smith, 2013). The essence of a business model is to define how the company delivers value to customers, attracts customers, and converts payments into profit (Teece, 2010).

A CE program in a company implies the implementation of different strategies to bring circularity to the production system and also to cooperate with other companies along the supply chain in search of an effective circular pattern (Winkler, 2011). The main strategies in this direction are associated with rethinking business models, and the company's production processes (cleaner production with prevention of pollution, reduced use of toxic substances, among others) (Winkler, 2011; Ghisellini et al., 2016), as well as supply chains (supply and reverse logistics), to achieve and maintain operational efficiency. Products need to be designed with various stages of use and economically viable value recovery activities, as part of closed-loop supply chains. To this end, product life cycle management systems and product and part monitoring at various stages of the life cycle must be used (Lieder and Rashid, 2016).

In summary, CE is an alternative model to traditional economics, with an emphasis on cleaner production, industrial ecology, and life cycle management. The United Nations Environment Programme (UNEP, 2006) highlights the characteristics of CE, such as low energy consumption, low emission of pollutants, and high efficiency.

In this sense, CE is, by design, restorative (aims to repair damage by designing better systems within the industry itself), with biological-like material flows, as well as technological evolution, designed to circulate material without discarding it into the biosphere. The objectives are to "design" waste, return nutrients, and recycle durable items, using renewable energy to fuel the economy (Murray et al., 2017; da Silva et al., 2021). The transition to CE basically happens through innovation (technology, product design, and revenue models) and social and institutional change. One example is the transition to what has become known as the sharing economy. But this is not possible without information technology to link service providers and users (Potting et al., 2017).

Therefore, the CE emerges as a possible strategy to allow companies to be involved in the challenges of sustainability, designing a model of resource management, production, and reprocessing of materials in a closed cyclical system (Murray et al., 2017; Khan and Haleem, 2021). According to Kumar et al. (2021), much of the available literature focuses on the discussion of the philosophical bases of CE and its benefits, and defends the need to invest in research aimed at analyzing issues associated with waste, and the feasibility of implementing CE. Therefore, this study seeks to contribute to filling the gap in the literature about CE experiences, in addition to identifying circular practices. The proposed method can be used to achieve this goal. The method also helps in the implementation of Industry 4.0, not in an isolated way, but by bringing CE as an important step for its establishment, and database construction. Circular practices will help identify suppliers, services, and knowledge organizations at each stage of CE (Luthra and Mangla, 2018; Cui et al., 2021).

Thus, to fulfill the objectives stated above, a literature review was first carried out. In addition, an analysis tool was used to identify significant CE practices from the analysis of the Sustainability Report published by the main companies in the country. The study proposes the measurement of each of the nine stages of CE, to which the mapping of processes can be added, and a database constructed. This work largely contributes to feeding Big Data (Gago et al., 2022), which favors the implementation of Industry 4.0 (Kumar et al., 2021; Wang et al., 2022). For example, the Hewlett-Packard company can predict how much raw material is returning to the company. Since the implementation of Industry 4.0 is oriented toward digital and virtual technologies and centered on services, it is understood that its association with CE can improve the sustainability of supply chains for companies (Jabbour et al., 2018; Gupta et al., 2021).

This study proposes a method for quantitatively assessing circularity in business practices, aiming to fill the gap identified in the literature, identifying and measuring the CE practices in place and how effective they are. The method consisted in analyzing 75 Brazilian companies that take part in a sustainability assessment review.

Method

This study was carried out in two phases following the research objectives. In the first phase, circular practices are identified through a review of the scientific literature. The review was conducted using the Scopus Databases. The descriptors used were: (ALL ("circular economy") AND ("Measurement") AND ("Sustainable Development") AND ("Analytical Hierarchy Process")) AND (((circular AND economy)) AND (measurement)) AND (sustainable) AND (LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018)) AND (LIMIT-TO (DOCTYPE , "ar")). The state-of-the-art review revealed 148 possible articles, 28 of which were good matches for the subject and were used for the CE discussions since they addressed some of the CE steps, such as, for example, reduce, reuse, and recycle (Kumar et al., 2021; 2022), or focused on energy and carbon emissions (Mishra et al., 2021); solar energy (Erol et al., 2021), biomass (Facchini et al., 2021), and e-waste (Alblooshi et al., 2022). However, most of these publications refer to the need to identify barriers to CE implementation (Kumar et al., 2021; 2022; Ullah et al., 2021; Irfan et al., 2022).

The following criteria were used to select the 28 articles:

- had CE as a core subject (12);
- dealt indirectly with CE (9);
- dealt with at least one of Potting's Rs (9) (Refuse; Rethink; Reduce; Reuse, Repair; Refurbish; Remanufacture; Repurpose; Recycle; Recover).

The main analysis categories that emerged from the articles that had CE as a core subject were: identifying barriers to CE implementation; exploring the CE concept and its importance; CE in the context of Industry 4.0 and Big Data; CE applied to energy: solar and photovoltaic panels, barriers to the implementation of solar energy, biomass; waste from electrical and electronic equipment (WEEE) (reuse, recycling, incineration, restoration); water resources; CE applied to life cycle analysis; CE as a competitive advantage; regulation and cooperation in the supply chain; CE barriers in the automotive industry; the need for CE assessment models; the need for a CE-skilled workforce.

In the second phase, circular practices were identified and classified according to the strategies presented by Potting et al. (2017), using the Analytic Hierarchy Process (AHP) method. From a review of the literature published between 2021 and 2022, the incidence of studies based on AHP as a method of attributing value associated with Industry 4.0 and even barriers to the implementation of measures for lean production is high. However, it is low when applied to CE categories, particularly the nine categories suggested by Potting et al. (2017). Various methods such as AHP, BWM, TOPSIS, VIKOR, and COPRAS are available to classify circular practices (Khan and Haleem, 2021). However, AHP and BWM are suitable when circular practices follow a hierarchical structure and can have fewer than nine independent factors.

This step was conducted by analyzing the sustainability reports of the main Brazilian companies, as defined by a publication called Guia Exame de Sustentabilidade (Exame Guide of Sustainability) (Exame, 2018).

Company selection

Sustainability reports (SRs) publicly describe an organization's economic, environmental, and social impacts (Global Reporting Initiative, 2016), and are an important factor in guiding the organization's sustainability (Lozano, 2015). Therefore, SRs, in this study, were employed as sources of information about how an organization approaches sustainability, and were reviewed to find information about potential CE practices. In Brazil, there is an annual publication called Guia Exame de Sustentabilidade (Exame, 2018) that identifies, evaluates, and disseminates the best business practices associated with sustainable development and social responsibility. This Guide's methodology was developed by the Center for Sustainability Studies (GVces) of the Fundação Getúlio Vargas School of Business Administration (FGV-EAESP) (Exame, 2018). Businesses are mapped out based on an analysis of their responses to a questionnaire, which is voluntary and composed of approximately 160 questions. The questionnaire addresses issues about commitments, transparency, and corporate governance, and the economic, financial, social, and environmental aspects of corporate sustainability. In addition, the companies report initiatives associated with their sustainability strategy, showing evidence of the information provided, if required. The responses are submitted to an expert council, which chooses the best company in each sector and the Sustainable Company of the Year. The companies chosen make up the Guide, through reports that highlight the practices. In 2017, the Guide included 173 companies operating in Brazil, of which 75 were highlighted and became the object of this study.

Analysis criteria

The analysis strategy developed here is based on the model proposed by Potting et al. (2017) (Figure 1) to verify the level of circularity within a company's production chain. This model was a result of the literature being integrated with specialist analysis. It was applied to product chains in which transitions to CE are central. In addition, it included the participation of Dutch government officials involved in CE policies, who discussed the conceptual framework and its applications (Potting et al., 2017).

The model shows different types of circularity strategies, organized by levels of circularity (Figure 1). The strategies focus on reducing the consumption of natural resources, minimizing waste production in manufacturing, using smarter products, sharing products, and extending product lifespan, followed by recycling materials through recovery. Finally, there is incineration, in which energy is recovered but is a low circularity strategy (Potting et al., 2017).

According to the model, a higher level of circularity means that the materials remain in the loop for a longer period. As a result, in principle, fewer natural resources would be needed to produce new materials, avoiding resource extraction. Strategies with a high level of circularity require socio-institutional changes along the product chain, with innovation in the product design and revenue model. Low-level strategies rely more deeply on technological innovation. The conceptual model focuses on identifying what needs to be measured, rather than how measurements are to be performed. Its application helps to evaluate the role of innovation in CE transitions. This assessment is essential for the next step, to determine what kind of information would be needed to measure the progress of CE transitions.

All the information collected for this analysis, associated with the practices of social responsibility and sustainable development, were analyzed based on these circularity levels: high (use of strategies R0 to R2), medium (use of strategies R3 to R7), and low (use of strategies R8 and R9). It is important to mention that Brazil does not have specific guides for CE (Oliveira et al., 2018).

Company ranking

This paper analyzed 75 companies, corresponding to different sectors of the economy:

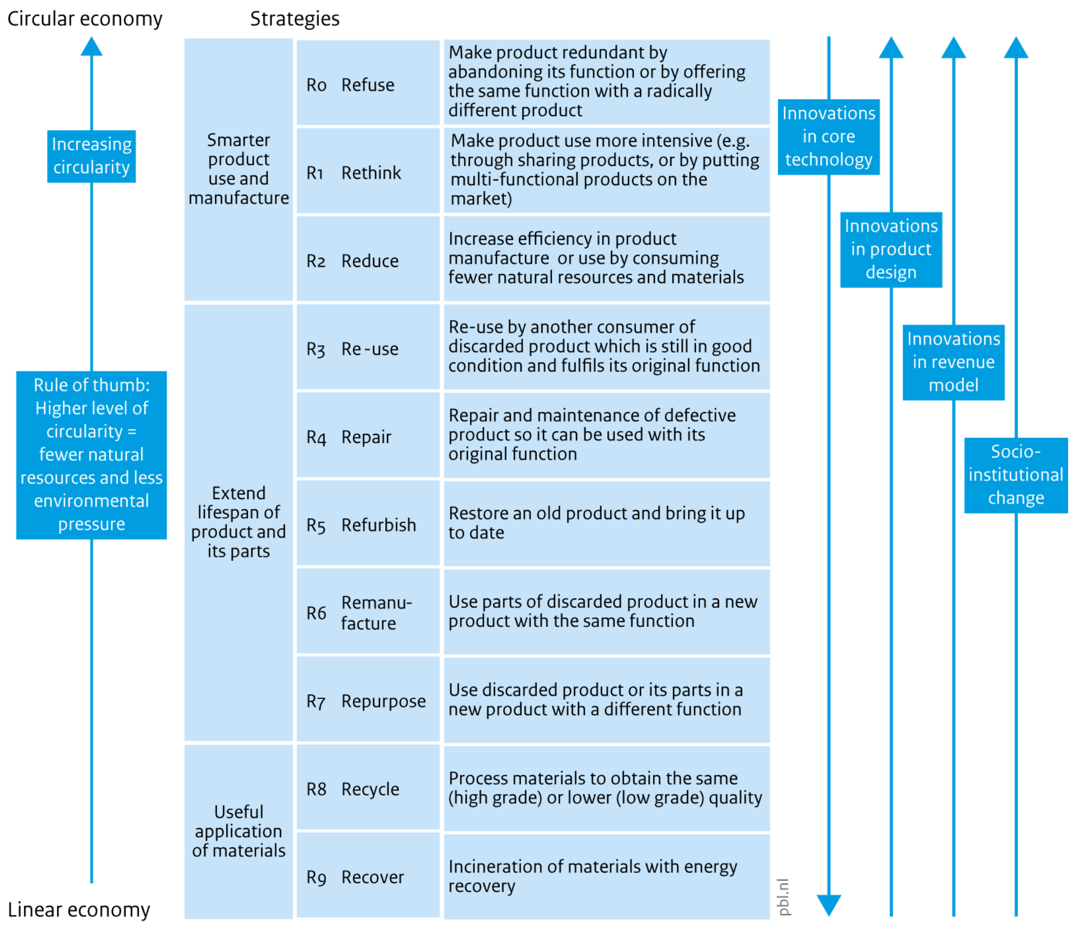
- 8 companies in Agribusiness and Timber;
- 5 companies in Personal Hygiene and Beauty;
- 4 companies in Technology and Information;
- 5 companies in Steel and Mining;
- 3 companies in Food and Beverage;
- 12 companies in Energy and Electricity;
- 4 companies in the Pharmaceutical Industry;
- 6 companies in Health;
- 4 companies in Transport / Logistics;
- 3 companies in Construction;
- 5 companies in Finances;
- 8 companies in Chemical Industry;
- 8 companies from different sectors (tourism, retail fashion, consulting, specific technology).

The companies were ranked using the Analytic Hierarchy Process (AHP), a multicriteria method that proposes to represent the human decision-making process. Applied in solving multicriteria problems, the method is popular in the environmental area (Huang et al., 2011) and was selected due to its ease of use and understanding, and also for allowing the combination of quantitative and qualitative criteria when needed.

Its use allows ranking items, and, therefore, allowed the classification of Brazilian companies regarding CE practices. The method is based on a pairwise comparison of alternatives according to multiple criteria, based on a priority scale (Table 1). For this study, companies are the alternatives, and circularity practices are the criteria. The purpose of the analysis is to determine the company with the best CE practices.

Step 1 Pairwise comparisons

The Saaty comparison scale shown in Table 1 varies from 1 to 9, with 1 meaning the same importance of one criterion in relation to the other (or of an alternative in relation to the other), and 9 meaning extreme importance of one criterion in relation to the other (or of an alternative in relation to the other The circularity criteria of Figure 1 were applied to assess the practices of each company, and the companies were compared in pairs, and different simulated judgments were generated with the aid of the Rstudio computer program as a form of sensitivity analysis. The three levels of circularity in the conceptual model used were considered, seeking to maintain small distinctions of importance among the close criteria. Thus, when comparing R0 and R1, for example, value 2 indicates that the criterion R0 is slightly more important than R1.



Source: Potting et al. (2017).
Figure 1 – Levels of circularity.

Table 1 – AHP pairwise comparison scale used to judge the relative importance of elements.

Intensity of Importance	Definition
1	Equal importance
3	Slightly greater importance of one in relation to the other
5	Greater importance of one in relation to the other
7	Much greater importance of one in relation to the other
9	Absolutely greater importance of one in relation to the other
2,4,6,8	Intermediate values between judgments

Source: Saaty (1991; 1994).

The same is observed for R0 in relation to R2 because they belong to the same category.

This does not occur when comparing R0, R1, and R2 (high circularity) with R8 and R9 (low circularity). In this case, the value is 5, indicating that R0, R1, and R2 are more important than the low circularity levels.

Regarding the definition of the comparison values, it is worth mentioning that, when making judgments, inconsistent comparisons can occur, especially when the number of alternatives is high, and a certain level of consistency is important (Franek and Kresta, 2014). This can be assessed using the consistency index, recommending that the error is of a lower order of magnitude (10 percent) than the measurement itself; otherwise, inconsistency would influence the result (Saaty, 1991; 1994).

Table 2 shows the criteria comparison matrix obtained after a few iterations seeking to improve the consistency index.

The consistency of the assessments, based on the consistency ratio (CR), is calculated by Equation 1.

$$CR = \frac{\lambda max - n}{(n-1)*RI} \qquad (1)$$

Where:

n = order of the comparison matrix

λ_{max} = maximum eigenvalue of the comparison matrix

RI = random consistency index (Table 3).

According to (Saaty, 1991) and as shown in Table 3, the random consistency index (RI) to be used for calculating the consistency ratio in the present study is 1.49; given that 10 compared criteria (elements) were used.

The maximum eigenvalue of the comparison matrix can be calculated by Equation 2.

$$\lambda_{max} = \frac{1}{n}\sum \lambda_i \quad (2)$$

Where λ_i is obtained by multiplying the vector of normalized weights by the criteria comparison matrix (Table 2), according to Equation 3.

$$\lambda_i = (D * Wcn_i)\left(\frac{1}{Wcn_i}\right) \quad (3)$$

Where:

D = is the criteria comparison matrix,

Wcn_i = is the vector of normalized weights.

Based on the comparison matrix (Table 2), the relative weights and normalized weights of each line are calculated. The relative weights are calculated by Equation 4.

$$Wc_i = \sum_{j=1}^{n} a_{ij} \quad (4)$$

Where:

a_{ij} = the weight of criterion i in relation to criterion j.

Normalized weights are calculated by dividing the relative weights of a given criterion by the sum of the relative weights of all criteria, as expressed in Equation 5.

$$Wcn_i = \frac{\sum_{j=1}^{n} a_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij}} \quad (5)$$

In order to stabilize the expected value of the consistency ratio, seeking greater reliability, 500 iterations were performed with simulations of size 200 ≤ T ≤ 100.200. After this stage, the comparison of the alternatives (companies) was carried out.

Step 2 Conversion of grades into weights

To analyze the companies, the circularity practices present, represented by the 10 analysis criteria (R0 to R9), were verified. For those companies that claimed to focus on circularity, transparency was investigated about how the practice was implemented. To this end, grades were assigned according to the evidence of circular practices in the companies (Table 4), which were converted into weights (Table 5). In cases where a company with a score of 0 is compared with another one with a score of 3, for example, for the same criterion, the value of the comparison would be 1/7, and so on.

Step 3 Comparing the companies

Pairwise comparisons of all 75 companies were carried out for each criterion. According to Saaty (1994), the judgment reflects the answers to two questions: Which of the two alternatives is more important in relation to a criterion and with what intensity, using the 1 to 9 scale (Table 1) for the alternative on the left (row) compared to the alternative at the top (column).

Finally, the global performance of the alternatives was calculated and used to rank the companies from the perspective of CE. This procedure generates a value that can be interpreted as an index of circularity in companies, calculated according to Equation 6.

$$A_i = WAn_{ij} * Wcn_i \quad (6)$$

Where:

A_i = circularity index.

WAn_{ij} = matrix of the normalized score of the i-th company for the j-th criterion.

Wcn_i = vector of normalized weights for each criterion.

Table 2 – Base matrix of paired comparison of criteria.

	R0 - Refuse	R1 - Rethink	R2 - Reduce	R3 - Re-Use	R4 - Repair	R5 - Refurbish	R6 - Remanufacture	R7 - Repurpose	R8 - Recycle	R9 - Recover
R0 - Refuse	1	2	2	3	3	3	3	3	5	5
R1 - Rethink	0.5	1	2	3	3	3	3	3	5	5
R2 - Reduce	0.5	0.5	1	3	3	3	3	3	5	5
R3 - Re-Use	0.33	0.33	0.33	1	2	2	2	2	5	5
R4 - Repair	0.33	0.33	0.33	0.5	1	2	2	2	5	5
R5 - Refurbish	0.33	0.33	0.33	0.5	0.5	1	2	2	5	5
R6 - Remanufacture	0.33	0.33	0.33	0.5	0.5	0.5	1	2	5	5
R7 - Repurpose	0.33	0.33	0.33	0.5	0.5	0.5	0.5	1	5	5
R8 - Recycle	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1	2
R9 - Recover	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.5	1

In order to verify which comparisons have the greatest impact on aggregate results, a sensitivity analysis was carried out (Ivanco et al., 2017). This procedure analyzes the impact (variation) of the performance of the alternative (company) as a function of a variation in the relative weight of one of the decision variables (criteria), that is: $S = \partial x / \partial p$, where x represents the overall performance and p the criterion. For the present study, the variations were fixed in the interval $[-1 \leq \partial p \leq +1]$. In this way, the criteria weights were examined between zero (situation in which the variation was -100%) and twice its original weight (situation in which the variation was + 100%).

Thus, in summary, the proposed method for assessing the level of circularity in a company consists of applying the following steps:

Evidence disclosed by a company, such as a sustainability report, is examined to determine the level of circularity practices, listed in Figure 1;

- The grades in Table 4 are assigned to the observed CE practices;
- The grades are converted using Table 5, for pairwise comparisons;
- A pairwise comparison matrix is built, and the AHP method is applied;
- A circularity index is calculated (Equation 6), which can be used as a stand-alone measure of a company's circularity level, or employed to several companies to create a circularity ranking, which can be organized, e.g., by sector.

Table 3 – AHP random consistency index (RI), defined according to the number (n) of elements compared.

n	2	3	4	5	6	7	8	9	10	11
RI	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51

Source: Saaty (1991; 1994).

Table 4 – Grades for verification of evidence of circular practices in companies.

0	The company has no CE actions or this is not clear and transparent.
1	The company intends to implement the practice in the future.
2	The company claims to have CE practices, but with no supporting evidence released.
3	The company has implemented the practice and has shown supporting evidence

Table 5 – Conversion of grades into weights for use in the AHP method pairwise comparison.

Grade	0	1	2	3
0	1	1/3	1/5	1/7
1	3	1	½	1/5
2	5	2	1	½
3	7	5	2	1

Results and Discussion

Considering the theoretical framework established from the literature review and employing the Levels of Circularity analysis model proposed by Potting et al. (2017), the sustainability reports published by the 75 selected companies were analyzed and each circular practice presented was assigned a score.

The initial consistency ratio for the pairwise comparison of the criteria resulted in 0.0856. In order to improve this value, variations in the judgments were tested until the consistency ratio reached a stationary value, as can be seen in Figure 2.

Figure 1A shows that the consistency ratio has a stationary average between 0.0645 and 0.0650, remaining below 0.10, indicating the reliability of judgment. Figure 2B shows the extremes which, remained below 0.10. Thus, the results show that the judgment made was consistent with a high level of reliability.

Following the analysis and based on the conversions from judgments to weights (Table 5), it was possible to conduct a relative comparison of the alternatives, that is, between companies, for each criterion. Table 6 shows examples of these comparisons.

The alternatives (companies) were ranked using the circularity index (Equation 6). Table 7 shows this, where:

$$A_{Company12} = 0.057 * 0.168 + 0.041 * 0.159 + \ldots + 0.009 * 0.017 = 0{,}029.$$

When verifying information about the practices adopted, it was found that most (80%) of the companies analyzed did not have any type of circular action (Figure 3). The effective incidence of circular practices is still very incipient, as well as methods for evaluating these practices, measurement in performance improvement. It is necessary to focus not only on what to do with the waste, but also to understand that waste does not necessarily need to be disposed of, but can return to the supply chain (Colasante et al., 2022; Dalalah et al., 2022; Mishra et al., 2022).

Regarding the ranking by sector (Figure 4), it can be seen that the construction sector reached a higher level of circularity. On the other hand, the health and pharmaceutical sectors have the least circularity. This may be because these sectors have strict health protection laws, which prevent actions of a cyclical nature, such as reducing waste, sharing, and reusing materials.

When analyzing the types of circularity actions practiced by the companies (Figure 5), these are mostly concentrated in the R2 (Reduce) criterion. Many are associated with water resources, water pollution, and availability, inspiring restorative and regenerative actions, both at the center of CE (Abu-ghunmi et al., 2016).

One of the barriers cited by the literature for CE practices is their interdependencies, which involves understanding the process itself and the interaction hierarchy of each of the Rs. Process systematization also favors the basis for the formulation of management policies that help to improve the process as a whole (Wu et al., 2022). According to Barni et al. (2022), it is important to extend sustainability assessment to the entire production chain, which does not appear in the results since the most recurrent circular practices are limited to recycling and reducing the raw material used.

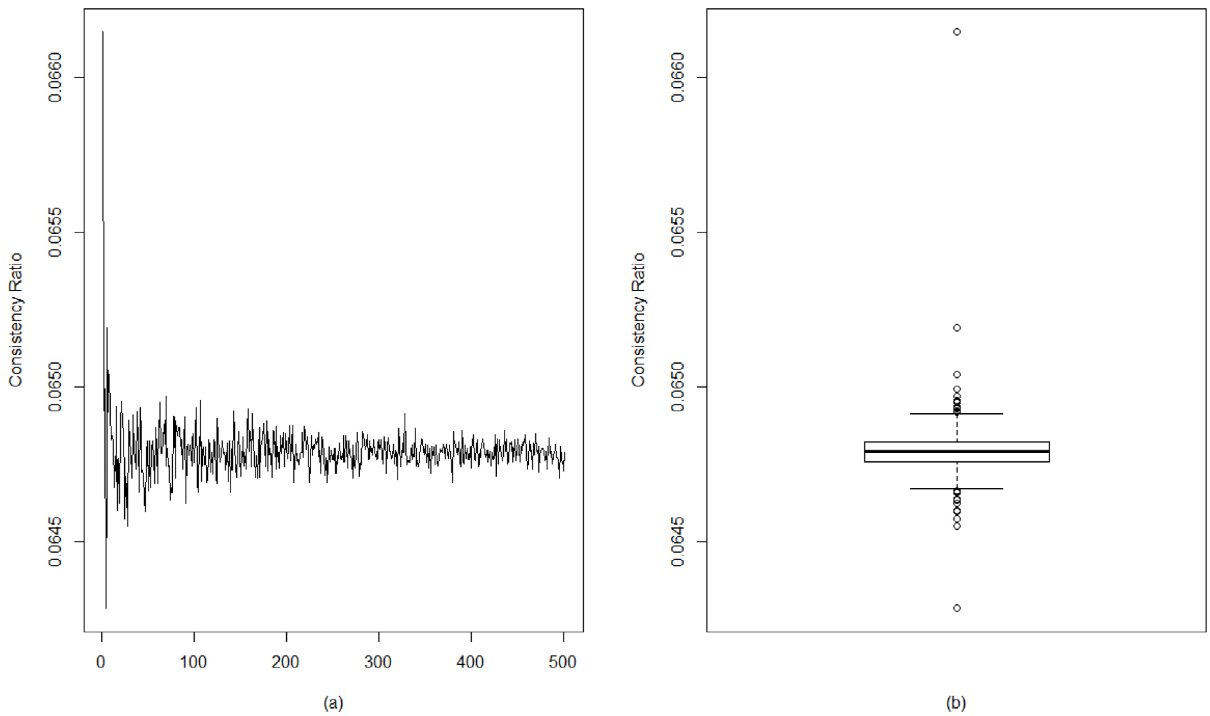


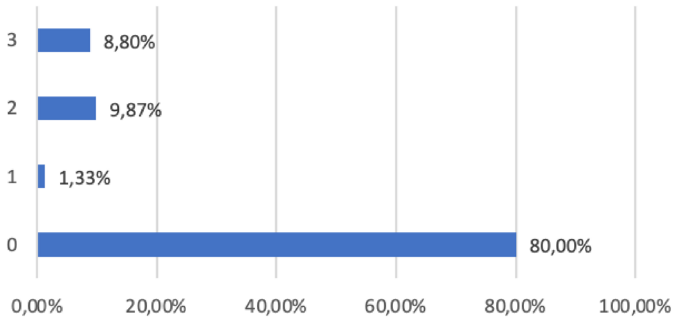
Figure 2 – Simulations of the consistency ratio of judgments.

Table 6 – Pairwise comparison of alternatives (companies) for criterion R2.

R1 - Rethink	Company1	Company2	Company3	Company4	...	Company75
Company1	1.00	0.33	1.00	0.20	...	1.00
Company2	3.00	1.00	3.00	0.60	...	3.00
Company3	1.00	0.33	1.00	0.20	...	1.00
Company4	5.00	2.00	5.00	1.00	...	5.00
...	...	...	...	...	...	...
Company75	1.00	0.33	1.00	0.20	...	1.00

Table 7 – Example of company ranking by circularity index.

Weight Criterion	R0	R1	R2	R3	R4	R5	R6	R7	R8	R9	Circularity Index	Ord.
Company12	0.057	0.041	0.018	0.049	0.011	0.012	0.010	0.009	0.018	0.009	0.029	1
Company14	0.011	0.041	0.014	0.010	0.011	0.060	0.049	0.046	0.018	0.009	0.027	2
Company9	0.011	0.008	0.018	0.049	0.011	0.060	0.010	0.009	0.024	0.009	0.021	3
Company28	0.011	0.008	0.014	0.010	0.057	0.012	0.068	0.009	0.004	0.009	0.021	4
Company21	0.011	0.024	0.018	0.068	0.011	0.012	0.010	0.009	0.004	0.009	0.020	5
Company58	0.011	0.057	0.018	0.010	0.011	0.012	0.010	0.009	0.024	0.009	0.019	6
Company71	0.011	0.008	0.018	0.010	0.011	0.012	0.049	0.064	0.024	0.009	0.019	7



Source: based on the evidence shown in Table 4.
Figure 3 – Circularity practices in companies.

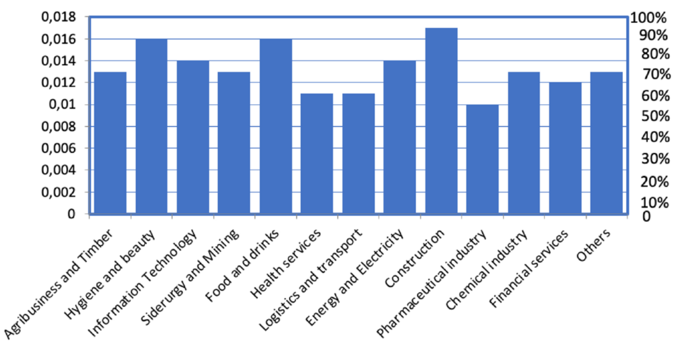


Figure 4 – Ranking by sector according to circularity index averages.

In the second place, there are practices focused on the R8 (Recycle) criterion. According to Potting et al. (2017), recycling generally does not lead to substantial changes in products and faces relatively small obstacles in the regulatory framework of laws and policies. However, more radical institutional change is needed in the entire production chain, when strategies for higher levels of circularity are targeted. Sharing products and services, for example, would require a change in consumer behavior, while manufacturers and retailers would also need to take action to address these issues. Figure 6 shows a summary of the investigated evidence on actions taken by the companies (Table 4).

Concerning Figure 5, taking the R1 (Rethink) criterion as an example, among the 13 companies included in this item (Rethink), only two have supporting and transparent indicators, seven companies claim to have actions, but without evidence, and four state they intend to develop future actions.

In this study, the issue of divergent opinions among decision makers, which are typical of the classic single decision approach, was alleviated through a sensitivity analysis, but also minimized because the judgments were based on evidence disclosed by the companies. As previously discussed, the relative weights of the criteria varied by one level in each direction [$-1 \leq \partial p \leq +1$]. The main results of the sensitivity analysis can be seen in Appendix A. It is possible to observe that the ranking of the alternatives (companies) declines as R0 loses importance (the curves of the alternatives decline as it moves from $x = 0$ to $x = +1$), with the exception of two alternatives that have significant positive variations in their circularity index and, consequently, in their ranking. The ranking of the other companies remains unchanged. Small changes in ranking are also observed due to variations in R4, R5, and R9.

The largest changes are derived from variations in criteria R1, R2, R6, and R8. Thus, it is possible to verify that the ranking for the set of alternatives studied is more sensitive to changes in judgment in such criteria. This evidence is corroborated by Figure 5, as these criteria are the ones with the greatest variation in circularity levels observed among companies.

Another result of the sensitivity analysis is that a company's ranking would greatly benefit if it invested in practices that are not conducted by third parties, especially those that are in criteria of greater relative weight, such as R0. These results confirm much of the literature on CE that focuses on identifying the existing barriers that make circularity implementation difficult for the companies. Many authors highlight the lack of qualified labor (Kumar et al., 2021; Ortiz-Barrios et al., 2022) as one of the main barriers to the implementation of CE, especially at the management level, which is required for the implementation of Industry 4.0 technologies, and integrate them with CE sustainability criteria. According to Luthra et al. (2020), organizations should measure their progress towards sustainable performance, but beyond the focus on operational and economic performance (Verrier et al., 2016; Ali et al., 2022). There are different methods and techniques for different stages of CE (FAHP, Fuzzy), but there are still few studies dedicated to implementing, measuring, and evaluating effective CE practices in an integrated way (Agrawal and Singh, 2022).

Conclusions

In Brazil, few studies have been carried out on CE, and this work proposes to fill this gap by introducing a method to assess the level of circularity of a company and using this method to assess the top 75 companies in the country that claim to have circular practices.

Using the Hierarchical Analysis Process (AHP), it was possible to rank several sectors of the economy according to CE practices. Important points are identified for the structuring and application of circular actions in different sectors, among different business models, which depend on the value chain. By introducing CE, companies need to reassess the value propositions they present to their customers. It was also revealed that most companies scored zero (0) in several criteria, which means that they do not practice circularity, or, if they do, they do not disseminate it.

The investigation adopted a conceptual model structured into levels of analysis, bringing specific elements to categorize the evaluation.

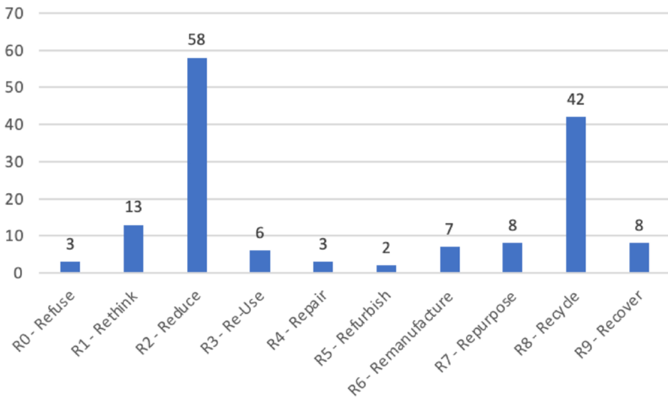


Figure 5 – Types of circularity actions observed among the companies.

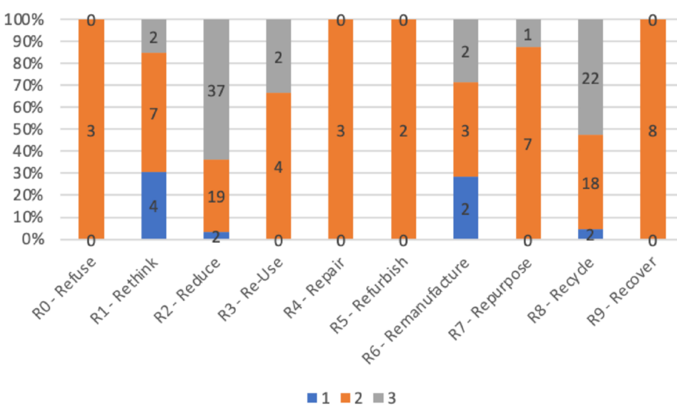


Figure 6 – Number of companies per circularity practice.
1: The company intends to implement the practice in the future; 2: The company claims to have CE practices, but with no supporting evidence disclosed; 3: The company has implemented the practice and shown supporting / confirmatory evidence.

Based on this model, it was possible to verify which actions and to what depth they are being employed by the companies.

The results showed a predominance, among the companies that perform some circularity action, of reduction actions (R2). This means, in most cases, water reuse actions. Many actions in the financial and health sectors could not be associated with the analysis criteria, as these sectors do not have a clear production chain. Even so, these sectors were analyzed indirectly, as they facilitate actions for other sectors and other companies with service provision.

It is understood that Sustainability Reports can be used to compare companies that aim for circularity in their business, as they are tools for the dissemination of indicators and good practices. These reports can help understand, boost, and communicate the CE efforts of organizations, establishing internal goals and managing the transition to more sustainable development. On the other hand, these reports need to be better structured, preferably following recognized methodologies, since many of the reports analyzed did not outline clear indicators, but simply intentions of actions / goals, or actions in progress without any reference to performance.

The results of this research can help companies decide about interventions that prioritize the use of CE practices that are beneficial for each business model, since this study offers structured elements of analysis, which can be replicated by any company or segment that wants to truly implement CE, and, consequently, promote sustainable development.

From a broader perspective, the circularity assessment method proposed herein can be used to guide policies that seek to promote CE, monitor the status, and guide the progress. This could be the subject of further studies, detailing indicators and tools to assist in policy development and implementation.

Contribution of authors:

GOMES, P. R.: Investigation; Project Administration; Methodology; Writing — Original Draft. CARSTENS, L.: Investigation; Writing — Original Draft. VILAS-BOAS, M. C.: Investigation; Writing — Original Draft. KAULING, M. F.: Project Administration; Investigation; Writing — Original Draft. CRUZ, S. T.: Investigation, Writing – Original Draft. DZIEDZIC, M.: Conceptualization; Methodology; Project Administration; Supervision; Writing — Review & Editing.

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