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ARTICLE

Transition to the circular economy in the metallurgical sector: an implementation framework

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Abstract

This study proposes a theoretical framework for implementing the circular economy in the metallurgical sector, highlighting the necessary processes for such implementation. Circular practices and governance aligned with the ReSOLVE framework were identified within B3 listed companies in the Corporate Sustainability Index through documentary research and a survey. A multiple case study and interviews were conducted with three B3 Corporate Sustainability Index companies already adopting the circular economy. Based on benchmarking, a theoretical framework was developed, considering the reality of the metallurgical industry, for which a technical visit and interview with the administrative director were conducted. The fundamental processes for transitioning to the circular economy include the engagement of leaders and top management; awareness, training and engagement of employees; identification of gaps in the production process; monitoring indicators; and communication and transparency with stakeholders. The study contributes to the proposal of an applicable framework that managers can use to advance toward circularity.

Keywords: Circular Business. Organizational sustainability. Metallurgical industry.

Transição para a economia circular no setor metalúrgico: um framework de implantação

Resumo

Este estudo tem por objetivo propor um *framework* teórico para implantação da economia circular no setor metalúrgico, destacando os processos necessários para tal. Práticas circulares e de governança alinhadas ao *framework* ReSOLVE foram mapeadas junto às empresas do Índice de Sustentabilidade Empresarial da B3, por meio de pesquisa documental e aplicação de uma *survey*. Um estudo de caso múltiplo foi conduzido com três empresas do Índice de Sustentabilidade Empresarial da B3 que já adotam a economia circular, com as quais aplicaram-se entrevistas. A partir do benchmarking foi elaborado o *framework* teórico, considerando o reconhecimento da realidade de uma indústria metalúrgica, na qual foi efetuada visita técnica e realizada entrevista com o diretor administrativo. Os processos fundamentais para a transição para a economia circular compreendem o engajamento dos líderes e da alta direção; sensibilização, capacitação e engajamento dos colaboradores; identificação de *gaps* no processo produtivo; monitoramento de indicadores; e comunicação e transparência com os *stakeholders*. Os achados revelam que o setor metalúrgico apresenta potencial para geração de novos negócios circulares a partir do reaproveitamento de aparas de materiais metálicos. O estudo contribui com a proposição de um *framework* aplicável, cujas diretrizes podem ser utilizadas por gestores que desejam avançar rumo à circularidade.

Palavras-chave: Negócios circulares. Sustentabilidade organizacional. Indústria metalúrgica.

Transición a la economía circular en el sector metalúrgico: un marco de implementación

Resumen

El objetivo de este estudio es proponer un marco teórico para la implementación de la economía circular en el sector metalúrgico, destacando los procesos necesarios para ello. Las prácticas circulares y de gobernanza alineadas con el marco ReSOLVE se mapearon con empresas del Índice de Sostenibilidad Corporativa (ISE B3) mediante la investigación documental y la aplicación de una encuesta. Se llevó a cabo un estudio de casos múltiples con tres empresas del ISE B3 que ya han adoptado la economía circular, con las que se realizaron entrevistas. A partir del *benchmarking*, se elaboró el marco teórico, teniendo en cuenta el reconocimiento de la realidad de una industria metalúrgica, en la cual se realizó una visita técnica y una entrevista con el director administrativo. Los procesos fundamentales para la transición a la economía circular incluyen el compromiso de los líderes y la alta dirección; la sensibilización, formación y compromiso de los empleados; la identificación de lagunas en el proceso de producción; el seguimiento de los indicadores; y la comunicación y transparencia con las partes interesadas. Las conclusiones muestran que el sector metalúrgico tiene potencial para generar nuevos negocios circulares a partir de la reutilización de chatarra. El estudio contribuye proponiendo un marco aplicable cuyas directrices pueden ser utilizadas por los gestores que deseen avanzar hacia la circularidad.

Palabras clave: Negocios circulares. Sostenibilidad organizativa. Industria metalúrgica.

Article submitted on January 08, 2024, and accepted for publication on July 12, 2024.
[Translated version] Note: all quotes in English translated by this article's translator.

DOI: https://doi.org/10.1590/1679-395120240004x

INTRODUCTION

The metallurgical sector is of significant importance in the Brazilian economic scenario. Although traditional, the metallurgical activity faces environmental and market pressures due to technological advances and aspects related to sustainability, which promote and encourage changes in the industry. The expectation is that the sector will seek to apply new technologies with a view to sustainable production processes and high-performance products (Carvalho, Mesquita & Cardarelli, 2017).

In this context of searching for sustainable solutions, the circular economy (CE) has been gaining strength in recent years. It is a regenerative system that aims to reduce the input of raw materials, the generation of waste and the emission of gases by slowing down and closing the material and energy cycles (Geissdoerfer, Savaget, Bocken & Hultink, 2017).

In organizations, its implementation occurs through the adoption of Circular Economy Business Models (CEBMs), which incorporate value into the business, minimize and even eliminate waste of resources and capabilities (Lacy, Long & Spindler, 2020). CEBMs can be classified in different ways, according to their environmental strategies (Manninen et al., 2018). Different CEBMs can, for the most part, be categorized by ReSOLVE (Lewandowski, 2016), a CE framework proposed by the Ellen MacArthur Foundation (2015) and which encompasses six actions: regenerate, share, optimize, loop, virtualize and exchange.

Due to the nature of the raw materials, the metallurgical sector has great potential for adherence and growth in a CE system. Steel, one of the main raw materials in the metallurgical industry, is 100% recyclable and plays a relevant role in the adoption of CE (Brazil, 2021). The longevity, functionality, reduced maintenance and the great potential for recovery and recycling of metallic materials place the sector in the spotlight. It is estimated that with CE strategies it is possible to significantly reduce the materials consumed in the sector's activities (Association of Metallurgical, Metalworking and Related Industries of Portugal, 2018).

Despite the potential benefits of CE for the sustainability of the metallurgical sector, this production system still lacks studies that consolidate associated principles and practices (Merli, Prices & Acampora, 2018). Considering that the restricted dissemination of CE practices is a barrier to their implementation (Sehnem, Kuzma, Julkovsky, Frare & Vazquez-Brust, 2021), this study aims to propose a theoretical framework for the implementation of CE in the metallurgical sector, answering the following research question: What processes are necessary to promote the implementation of CE in companies in the metallurgical sector?

The mobilization of specific sectors for CE facilitates awareness and engagement of stakeholders, in addition to helping to orchestrate stakeholders to create new business models (Sehnem et al., 2021). When considering good circular and governance practices of companies that are part of the B3 Corporate Sustainability Index (ISE B3), this study is based on practical cases, seen as motivators for a change in attitude towards CE by decision makers (Tapaninaho & Heikkinen, 2022). The core processes mapped by the research comprise successful experiences of other organizations and provide fundamental learning for the advancement of CE (Batista & Francisco, 2018), in addition to contributing to the establishment of governance, considered essential for the circular transition (Van Langen et al., 2021).

In addition to this introduction, this study is composed of four other sections. The second section presents the theoretical framework that underpins the collection and analysis of data; the third section describes the methodology applied to develop the study. Next, the fourth section presents the results of the research and discusses them with the literature. The article then closes with the final considerations section, in which the main findings are reviewed and the limitations and recommendations for future studies are highlighted.

THEORETICAL FRAMEWORK

Circular economy, sustainability and ESG: concepts and interactions

Companies' involvement with sustainability is growing, however, the linear production model adopted by most organizations is recognized as unsustainable (Nikolakis et al., 2024). The implementation of more responsible and sustainable practices by companies requires broad changes in their ways of operating (De Angelis & Ianulardo, 2024). In this context, the Circular Economy (CE) is an alternative for greener production, which ensures the transition to sustainability practices (Nikolakis et al., 2024). For Kandpal, Jaswal, Gonzalez and Agarwal (2024), the paradigm shift includes not only the circular system, but also the integration of environmental, social and governance practices, which constitute ESG (Environmental, Social, and Governance).

The incorporation of ESG strategies and CE practices into operations, associated with investments for long-term sustainability, are emphasized as business needs by Ramakrishna and Ramasubramanian (2024). Sustainability is understood as an interconnected and balanced relationship between the economy, social performance and the environment (Geissdoerfer et al., 2017), while the concept of CE, despite having gained momentum among academics and practitioners in the last decade, means different things to different people (Kirchherr, Reike & Hekkert, 2017).

The Ellen MacArthur Foundation (2015, p. 2), for example, indicates that "a circular economy is restorative and regenerative in principle. Its goal is to maintain products, components, and materials at their highest level of utility and value at all times, distinguishing between technical and biological cycles" — this being the best-known definition of CE (Geissdoerfer et al., 2017). Based on the similarities found between the various CE concepts identified in the literature, Kirchherr, Yang, Schulze-Spüntrup, Heerink and Hartley (2023, p. 4) present the following definition:

> The circular economy (CE) is a regenerative economic system that requires a paradigm shift to replace the concept of "end-of-life" with reduction, alternative reuse, recycling and recovery of materials throughout the supply chain, with the aim of promoting value maintenance and sustainable development, creating environmental quality, economic development and social equity, for the benefit of current and future generations. It is enabled by an alliance between stakeholders (industry, consumers, policy makers, academia) and their innovations and technological capabilities.

Although EC does not have a clear and defined concept in the literature (Nosková, Prochazkova & Zemanova, 2024), the circular system is based on three principles: i) preservation and increase of natural capital through stock control and selection of high-performance technologies and processes; ii) optimization of resources through circulation of components and materials for the longest period of time (includes design, maintenance, reuse, recycling, among others); iii) promotion of system effectiveness, to reduce externalities related to mobility, housing, noise and other environmental impacts (Ellen MacArthur Foundation, 2015).

Stakeholder involvement is considered fundamental to CE (Ghisellini, Lazarevic, Bird & Liu, 2024); when stakeholders articulate and interact in the production chain, there are opportunities to close cycles that generate win-win results (Silva & Sehnem, 2022). This scenario highlights, in the interaction between the constructs of CE and ESG, the pillar of governance. Structured governance established among stakeholders is essential for the circular transition to happen (Van Langen et al., 2021) and, for this reason, this study focuses on governance in terms of ESG. Interaction between parties is important to achieve zero waste (Wade, Meath & Griffiths, 2022) and replace the concept of "end of life" (Kirchherr et al., 2023). Partnerships between companies, business and government commitments (Valeva & Bodkin, 2018), collaborative relationships (Tapaninaho & Heikkinen, 2022) and other social relations influence decision-making (Marques & Manzanares, 2022). Therefore, CE is understood as a production process adopted jointly, with the participation of several actors, and which requires transparency in relation to actions (Todaro & Torelli, 2024).

The circular production system is seen as one of the five trends for the future of ESG (Mascotto, 2020). On the one hand, ESG guidelines help identify business aspects for the adoption of CE; on the other hand, the internalization of circularity can improve the environmental performance of the business, contribute to social credibility and strengthen governance (Patil, Ghisellini, Ramakrishna, 2020). The transition to circularity significantly affects the management of organizations

(Mascotto, 2020). Although CE focuses on environmental issues and social factors, governance cannot be forgotten, since excellence in socio-environmental management requires governance knowledge (Patil et al., 2020).

Due to its characteristics, CE is seen as a driver of sustainability (Manninen et al., 2018), capable of assisting the sustainable management of organizations (De Angelis & Ianulardo, 2024) by being based on principles of natural ecosystems (Ellen MacArthur Foundation, 2015). For Unruh (2010), sustainability is achieved when the principles of nature are applied in the organizational context in a profitable way.

To achieve the benefits of CE, in addition to the governance aspects mentioned, companies must gradually adopt circular economy business models. These models are responsible for guiding the implementation of circular principles in the organizational environment (Lewandowski, 2016), and their characteristics are detailed in the following subsection.

CIRCULAR ECONOMY BUSINESS MODELS

CEBMs are characterized as a new way of capturing opportunities (Weetman, 2019). They are capable of contributing to the company's prestige in society; minimizing damage; restoring the environment on a local scale; reducing production costs; reducing expenses with final disposal of waste and contributing to the longevity of companies (Ormazabal, Prieto-Sandoval, Loyal Puga & Jackfruit, 2018), CEBMs generate employment and income, allowing organizations to enter new markets (Ellen MacArthur Foundation, 2015).

The literature identifies several business model structures whose objective is to create value through adherence to CE principles (Lüdeke-Freund, Gold & Bocken, 2018). CEBMs encompass structures and strategies designed by companies to promote change towards CE (Weetman, 2019) and seek eco-efficiency of activities based, above all, on the application of the 4Rs (reduce, reuse, recycle and rethink) (Kalmykova, Sadagopan & Rosado, 2018).

CEBMs can be classified in several ways, based on their environmental strategies (Manninen et al., 2018). Kalmykova et al. (2018) and Lacy et al. (2020) point out the existence of five CEBMs whose premises are capable of supporting the transition to CE, reducing or even eliminating waste, pollution, and inefficient processes. They are: a) circular inputs or circular supply; b) sharing platforms; c) product as a service; d) extension of product use or second life; e) resource recovery or waste as a resource. These models can be adopted either individually or jointly (Lacy et al., 2020), and a common characteristic is the search for maintaining materials and products flowing in cycles, with a view to recovering materials for reuse, as pointed out by Weetman (2019).

The elements that constitute CEBM derive from circular principles and, for the most part, reflect the ReSOLVE framework (Lewandowski, 2016), proposed by the Ellen MacArthur Foundation (2015). The framework, presented in Chart 1, has a practical approach and brings together a set of six areas of action (Tavares, Ganga, Godinho Filho & Rodrigues, 2023), which can be adopted by companies and governments with the aim of implementing CE practices (Ellen MacArthur Foundation, 2015).

Chart 1
ReSOLVE Framework and Action Examples

Action	Description
Re Regenerate	Use of electrical energy from renewable sources, such as solar, wind, hydraulic and biomass energy.
	Use of biofuels, such as ethanol.
	Adoption of waste segregation, with forwarding for recycling and composting.
	Adoption of reverse logistics for certain materials.
S Share	Adoption of the rental and sharing service for assets such as cars, rooms and similar.
	Acquisition of remanufactured (second-hand) products for internal use.
	Extending the life of materials through maintenance, upgrading, design for durability, etc.
O Optimize	Use of technologies to maximize the use of resources and minimize waste generation.
	Adoption of the closed water cycle in production processes.
	Adoption of continuous improvement principles.
	Optimization of logistics routes to reduce pollutant gas emissions.
L Loop	Adoption of zero waste assumptions, that is, all waste is sold to become input in another production chain.
	Use of waste as a resource through recycling, composting, energy from waste, etc.
	Reintroduction of materials into the production chain to be reprocessed and transformed into new products.
	Use of remanufactured goods.
V Virtualize	Direct dematerialization – digitization of documents and processes, for example.
	Marketing done via e-commerce.
	Adoption of online service channels.
	Use of indicators from big data for decision making.
E Exchange	Replacement of non-renewable raw materials with raw materials of renewable origin.
	Application of new technologies, with a view to operational and energy efficiency.
	Gradual replacement of vehicles powered by fossil fuels with lower-impact electric vehicles.

Source: Adapted from Ellen MacArthur Foundation (2015).

The ReSOLVE framework demonstrates the principles of CE as business actions that can be implemented by organizations (Lewandoswki, 2016), providing practical and real-world applicable results (Mastos et al., 2021) and representing new business opportunities (Kalmykova et al., 2018). It is a leading tool in the CEBM implementation process, considered one of the most important (Tavares et al., 2023) and most used (Jabbour et al., 2019) tools, which reinforces the role of non-academic actors in the conceptual and applicable work of CE (Kirchherr et al., 2017).

The importance of the ReSOLVE framework for the effective adoption of circular practices is highlighted, for example, by Dias, Jugend, Fiorini, Razzino and Pinheiro (2022) and Jabbour et al. (2020). Previous studies use it as a basis for developing findings in different contexts: Sehnem, Pandolfi and Gomes (2019) adopt the ReSOLVE framework to analyze the alignment between sustainability practices of a Brazilian multinational and CE; Jabbour et al. (2020) measure CE actions based on the ReSOLVE framework with the aim of identifying barriers and drivers of CE in Brazilian industries (micro level); Tavares et al. (2023) use ReSOLVE as a basis for proposing a framework that contains benefits and barriers of using additive manufacturing in the transition to circularity; Marcon, Provensi, Sehnem, Campos and Queiroz (2023) analyze the internalization of CE in Brazilian B corporations (BCorps) based on the six strategies, demonstrating the alignment of ReSOLVE with the B Impact Assessment tool.

CE is understood as a more operational system than other concepts already proposed to achieve a more sustainable economy (Jesus, Antunes, Santos & Mendonça, 2019). However, the adaptation of economic and social systems to the circular model (De Angelis, 2022) and practical implementation (Awan & Sroufe, 2022; Kirchherr et al., 2023) are central issues related to CE. Considering that the ReSOLVE framework is a base structure, capable of being adapted to different contexts, it is understood that it aligns with what is proposed by this study and constitutes an adequate starting point towards circularity.

Despite the potential of CE, there are still numerous obstacles to its successful implementation. CE is often confused with other widespread practices in organizations, such as waste management (Pluskal, Shadow, Nevrly, Smejkalová & Pavlas, 2021), reverse logistics (Julianelli, Caiado, Scavarda & Cruz, 2020), recycling (Moraga, Huysveld, Meester & Dewulf, 2021; Ahmed & Lim, 2021; Rahman, Kim & Laratte, 2021) and reuse (Ciccullo, Cagliano, Bartezzaghi & Perego, 2021). The lack of clarity regarding the concept and the hundreds of existing definitions (Kirchherr et al., 2017; Kirchherr et al., 2023) may be related to "confusion" in practice.

Challenges related to complex and sometimes costly infrastructure for waste management and reverse logistics (Barbieri & Santos, 2020) are accentuated in countries of continental dimensions such as Brazil. Other obstacles relate to resistance to change and lack of understanding of the benefits of CE (Ghedam, Raut, Jabbour, Tanksale & Narkhede, 2021). There is also a need for large investments (Ghedam et al., 2021), such as artificial intelligence and cutting-edge technologies (Moreno, Court, Wright & Charnley, 2019).

In terms of criticism, the literature is not clear about the long-term effects of adopting CEBM; it is not yet known how CE can generate different results from those promoted by the linear production system (Millar, McLaughlin & Borger, 2019). The expansion capacity of circular economy projects is also questioned, since most are applied on a small scale (Mboli, Thakker & Mishra, 2020). However, at a macro level there are also difficulties in decision-making and monitoring of CE: academics, public authorities and professionals from different areas still differ in terms of understanding circular definitions and concepts; the low availability of data and the scarcity of tools to support CE monitoring result in a lack of transparency and trust (Sileryte, Wandl & Timmeren, 2023) towards the circular production system. It is therefore necessary to be aware of the challenges of implementing CE so that it is possible to achieve the potential economic and socio-environmental benefits of the circular production system (Chenavaz & Dimitrov, 2024).

METHODOLOGY

This study consists of qualitative research, with a descriptive and exploratory approach. As for the procedures, documentary research, survey, and case study were adopted, the latter guided by the guidelines proposed by Yin (2010), with multiple units of analysis, aiming at data triangulation.

The study sample included companies that are part of the ISE B3 index for 2022, which is composed of 48 Brazilian organizations from different sectors. The companies were chosen for being considered a benchmark in sustainability and ESG in the country, since the index covers five dimensions of analysis: i) human capital; ii) corporate governance and senior management; iii) business model and innovation; iv) social capital; and v) environment (ISE B3, 2021).

The first stage of the study included a documentary search in the 2021 Sustainability Reports of the 48 ISE B3 companies, associated with a search for information on the websites of these organizations. Circular practices aligned with the 6 actions of the ReSOLVE framework, previously presented in item 2.2 in Chart 1, were mapped. The choice of the ReSOLVE framework for this study is justified by the fact that it is a practical tool, widely disseminated and used to guide the implementation of the CE (Tavares et al., 2023). Furthermore, governance practices linked to the ESG principles proposed by the Global Compact (2021) were mapped, namely:

a) Existence of a Sustainability and/or ESG committee.
b) Existence of independent communication and reporting channels for use by stakeholders.
c) Existence of anti-corruption policy and actions.
d) Approval and monitoring of suppliers following social, environmental and human rights criteria.
e) Hiring local suppliers whenever possible.
f) Support for community development, with financial investments and volunteering in social, environmental, educational, social inclusion projects, among others.
g) Partnerships with startups, universities and entities to develop solutions – open innovation ecosystems.
h) Development of training and qualification programs for employees.
i) Diversity and inclusion policies in recruitment, selection and hiring processes.

The practices of the ReSOLVE framework and the principles of the Global Compact (2021) were also used as a basis for structuring a survey. A series of circular and governance practices along the value chain were established based on the literature and the study by Julkovski (2021), aiming to identify the degree of adoption through a five-point Likert scale. The data obtained were analyzed using simple descriptive statistics.

The proposed questionnaire was structured on an online form platform and sent to the 48 companies in the ISE B3. To ensure greater accuracy in completing the questionnaire and providing feedback, employees, directors and CEOs of the companies whose activities were directly related to the areas of sustainability, ESG or CE were mapped. The questionnaire was then sent to these employees via email and LinkedIn, with the social network being the most effective way in terms of feedback. Data collection through the survey began in July 2022 and ended in October of the same year. Responses were obtained from 19 companies, representing 39.6% of the total.

To deepen knowledge about the procedures for internalizing circular practices at an organizational level, the researchers conducted a multiple case study with companies from ISE B3. Six companies were mapped to participate in the case study based on documentary research, which identified evidence of adoption of CE principles at an advanced stage in these organizations.

Through the institutional website, managers linked to the sustainability, ESG or CE sectors were identified to send an invitation to participate in the research via LinkedIn and, later, via email to formalize and explain the research objectives. Out of the six contacts made, three managers from three different companies accepted. Although only three responses were obtained, the interviewees robustly validated the findings from other sources of collection, including the literature, which characterizes the existence of theoretical saturation (Galvin, 2015).

A semi-structured interview was conducted with the three managers, the script for which consisted of 10 open-ended questions and which addressed the following topics: job description and duties of the interviewee in the company; CE practices adopted in the organization; description of the process of adherence and internalization of circular principles in the organization; and critical aspects and challenges for the success of CE in the business.The interviews were recorded with the participants' permission and later transcribed, when they were analyzed using the content analysis technique proposed by Bardin (2016). In the analysis of the results, the interviewees were referred to as D1, D2 and D3 to ensure confidentiality.

The pre-analysis stage involved organizing the transcripts and skimming the interviews; in the material exploration stage, the researchers coded the material based on a posteriori analysis categories, grouping the statements of the three interviewees considering the identification of common themes. The data were analyzed in Microsoft Word documents, and the codings were summarized and discussed based on the literature.

The data from the three data collection sources were triangulated to highlight the points of convergence and the most relevant practices mapped by the research, reinforcing the reliability of the data. From then on, with the aim of formulating the framework aimed at the metallurgical sector, benchmarking was used, considering for this purpose a metallurgical industry located in the state of Santa Catarina.

Benchmarking allows an organization to identify and recognize good practices adopted by other companies, competitors or not, that present superior performance, in order to incorporate such practices to improve its own performance and maximize its competitiveness (Carlini Junior & Vital, 2004). In this research, functional benchmarking was adopted, which from the point of view of the parameter is configured as a benchmarking of best practices, where the aim is to compare the frequency and the extent of good practices (Albertin, Kohl & Elias, 2015).

The metallurgical industry used as a parameter for the framework proposal was chosen for convenience, due to the accessibility of one of the researchers to it, associated with the acceptance of the managers to participate in the study. The company in question is classified as medium-sized and, in the region where it is located, is an important generator of jobs (there are approximately 350 employees) that contributes to the local economic movement. The organizational reality was recognized by the researchers based on a technical visit, when a semi-structured interview was applied to the administrative director with the objective of understanding the stages of the production process, raw materials used, and opportunities for improving sustainable aspects and internalizing the CE.

PRESENTATION AND DISCUSSION OF RESULTS

Practices aligned with the circular economy

The data resulting from the documentary research reveal the existence of consolidated practices aligned with circularity, while also demonstrating the existence of gaps in some aspects, with opportunities for development and for the adoption of new solutions in business. It is worth noting that, during the documentary research, practices whose adoption presented evidence were considered, therefore, actions presented as future goals of the organization were not included.

It was observed that the practices related to the Regenerate action of the ReSOLVE framework are those with the highest level of adoption by ISE B3 companies, followed by the practices related to the Exchange action. On the other hand, the actions with the lowest level of adoption are related to Sharing. Finally, the circular practices focused on the Optimize, Loop and Virtualize actions are at an intermediate stage of adoption. It is worth noting that the practices identified are not specific or exclusive to a given sector, and it is possible to identify them in companies that operate in different sectors.

Governance practices have proven to be relevant to the context of circularity, since they directly or indirectly influence environmental, social and economic aspects, and tend to contribute to the creation of favorable environments for the transition to CE. Considering the nine governance practices adopted in this analysis, each organization adopts, on average, 79.6% of them. Three governance practices were identified in 100% of the organizations, namely: existence of communication channels for reporting and complaints; existence of anti-corruption policies and actions; and concrete actions to support the development of communities impacted by the organization's activities.

Regarding the data collected by the questionnaire, the results show that sustainability and governance practices linked to human resources management and infrastructure support activities are those with the highest percentage of full adherence. Among the actions with more than 80% of companies with full adherence are: eradication of forced labor, elimination of discrimination in employment, employee training and development programs, construction of healthy work environments, and combating corruption. Practices linked to operations, services, and acquisition and purchasing activities, in turn, showed the most significant rates of absence and/or initial stage of adoption, indicating gaps and opportunities for improvement, for example, in the adoption of the closed water cycle, in the use of shared assets, and in the acquisition of second-hand (remanufactured) products.

In terms of the ReSOLVE CE framework, the survey data reveal that, among the responding ISE B3 companies, the actions related to Virtualize are those that present the most advanced stage of adoption, since the practices are consolidated, on average, in 51.4% of the organizations, followed by Regenerate and Optimize (on average, 47.4% and 42.1% of the companies have consolidated practices, respectively). As in the documentary research, actions related to Share are those that present the lowest rates of consolidated practices.

Complementing the analysis of primary survey data, through interviews with D1, D2 and D3, it was possible to observe an emphasis on waste reuse and recycling practices. In the context of waste management, companies work together with cooperatives and specialized partner companies aiming not only at better use of waste, but also at valuing the people involved in the recycling chain, bringing to light issues related to collaborative partnerships, intrinsic to governance. There are also mentions regarding the importance of employee training and transparency in communication with stakeholders.

The search for replacing virgin raw materials with sustainable raw materials or those originating from recycling is another practice highlighted – in this case, specifically by D2 and D3. The climate change agenda is also a concern that integrates commitments and practices of the organizations surveyed, especially with regard to reducing greenhouse gas emissions. Another sustainable action mentioned by D3 concerns the adoption of energy from renewable sources.

The data triangulation presented in Chart 2 highlights the points of convergence of the different data collection sources, with regard to practices aligned with the ReSOLVE framework, as well as ESG practices, with a focus on governance. To construct the aforementioned Chart, the most relevant practices were identified, that is, those that stood out in terms of percentage of adherence among ISE B3 companies; in the specific case of the interviews, practices cited by at least two of the three interviewees were considered.

Chart 2
Data triangulation

Mapped Evidence	Documents	Survey	Interviews
Key practices aligned with the ReSOLVE framework	• Use of energy from renewable sources. • Waste segregation. • Waste recycling. • Adoption of the closed water cycle. • Application of new technologies, aiming at operational and energy efficiency.	• Use of energy from renewable sources. • Waste recycling. • Control of greenhouse gas emissions. • Use of digital platforms to purchase products.	• Recycling and waste management. • Replacement of virgin raw material with recyclable raw material. • Control of greenhouse gas emissions.
Main ESG practices aligned with the principles of the Global Compact	• Performance of the sustainability and/or ESG committee. • Independent communication channel. • Anti-corruption policies and actions. • Supplier management. • Support for community development. • Training and qualification of employees. • Diversity and inclusion policies.	• Performance of the sustainability and/or ESG committee. • Independent communication channel. • Anti-corruption policies and actions. • Training and qualification of employees. • Diversity and inclusion policies. • Communication and transparency with stakeholders.	• Training and qualification of employees. • Cooperation partnerships. • Supplier management. • Communication and transparency with stakeholders.

Key: ESG – Environmental, Social and Governance.
Source: Elaborated by the authors.

It is possible to observe convergence between data sources regarding the adoption of practices related to waste management, especially regarding the segregation and recycling of materials. It can be inferred that waste management is one of the main topics worked on by organizations when it comes to sustainability and CE. The use of energy from renewable sources and the control of greenhouse gas emissions also stand out, evidenced in at least two data sources, denoting a commitment to the climate change agenda.

In terms of ESG, especially in the context of governance, the fundamental role of employee training and development is evident in all data collection methods. In this context, it is understood that organizations are made up of people who need to be aware and prepared to understand, assist and develop sustainable, ESG and circular practices in their daily professional lives. With a trained work team, the journey towards positive social, environmental and economic impacts becomes more assertive.

Dynamics of CE internalization

Considering the perceptions expressed by the interviewees, it was clear that the journey towards CE begins with the recognition of socio-environmental responsibility by the organization, which, encouraged by the vision and engagement of its leaders, promotes reflections. These reflections, in the cases analyzed, started from the search for solutions for waste management.

From then on, the process of structuring teams begins, with the possibility of hiring external consultants and specialists for support. Barriers of distrust are overcome by engaging employees through training, awareness-raising and a clear definition of a purpose. Although it is clear that the internalized culture of sustainability and the vision of leaders have a significant influence on the engagement of people, who come to understand the purpose and support the CE process, as mentioned by D1, training programs and actions to disseminate internal information are highlighted and understood as important in this process. In the perception of the interviewees, these actions are fundamental, since people, in general, need to understand why they are taking a certain action, what the gain of a certain change is, in order to truly engage.

The interviewees also unanimously emphasize that establishing collaborative partnerships is essential for the internalization of both sustainable and CE aspects, and that a systemic view of all operations is essential. Customers, consumers, partner companies, suppliers, startups and the distinct management areas that make up the same organization are cited as partners in the search for improvements in sustainability and ESG aspects, as well as for the development of solutions and new technologies, with emphasis on the creation of open innovation environments.

Regarding this, D1 pointed out: "Partnerships are very important, right? So we have been working on developing projects and technologies, I won't say always, but most of the time in partnership with our clients". D2 pointed out the following: "We have an ESG academy for our partners. So, it's a website where we make several online training courses available. Finally, to D3: "[...] and the other [learning] that I usually say is how important collaboration is. It's collaboration between us, collaboration between areas, and collaboration between companies".

Clear communication with stakeholders is also part of the dynamics. Based on the preparation of sustainability reports, actions are monitored, tracking the level of development and evolution, year after year, of practices linked to sustainability. Although they operate in very different economic activities, the CE dynamics of the organizations in the case study are similar and convergent in several aspects, demonstrating the ability of circularity to adapt to different contexts.

The research findings reveal that the fundamental processes for the gradual transition to CE are: a) defining a clear purpose for the business; b) engaging leaders and senior management; c) structuring an internal team responsible for CE, which can count on the support of consultants; d) raising awareness, training and full engagement of employees; e) identifying gaps in the production process, aiming at reducing waste and maximizing the use of raw materials; f) establishing cooperation partnerships to implement sustainable actions applicable in the organization; g) monitoring the actions performed through indicators; h) communicating and being transparent with stakeholders; and i) projecting new businesses based on metal waste materials from the production of the metallurgical industry.

Discussion of results

Although the dissemination of circular practices is still limited (Sehnem et al., 2021), all ISE B3 companies have some type of practice linked to one of the six actions of the ReSOLVE framework. This fact is evidenced by the three data collection sources adopted, which emphasizes the possibility of adapting circular practices to different realities and organizations (Nandi, Hervani & Helms, 2020), and indicates that the circular production system has permeated discussions within organizations and is already present in the value chain.

Among the six actions of the ReSOLVE framework, it is observed that practices related to Regenerate are the most intensively adopted. The positioning regarding Regenerate stands out especially in the context related to waste valorization, reuse, and recycling. It is common for companies to incorporate circular practices gradually (Rebellato & Sehnem, 2018), starting with simpler actions, of which the organization has greater knowledge. In the case of waste management, the existence of national legislation – such as the National Solid Waste Policy (PNRS), established by Federal Law No. 12.305 (2010) – can be a factor influencing the higher adoption percentage. This scenario observed in ISE B3 companies demonstrates that the characteristics of implementing circular practices differ among Brazilian companies: Marcon et al. (2023), for example, found that among Brazilian B Corps holding B certification, the actions with the highest adoption percentage were related to the Virtualize action of the ReSOLVE framework. However, it is important to emphasize that isolated practices do not, in fact, reflect the mindset change necessary for the circular transition.

The fact that governance-related actions are widespread among the companies surveyed reflects an environment conducive to a gradual transition to CE, since circularity depends on the interaction between different actors (Jesus, Antunes, Santos & Mendonça, 2012). Governance aspects strengthen the transition to circularity, especially with regard to cooperative partnerships with other companies and startups for the development of solutions and new technologies (Jesus et al., 2012). Bauli (2019) has already observed in his study that cooperative relationships are fundamental for CE. In this sense, D3 was emphatic in pointing out that "for a circular economy to happen, I have no doubt that there must be a partnership". Thus, the research highlights and corroborates the statement by Langen et al. (2021), that the transition to CE depends on governance established among the actors.

Furthermore, it is identified that certain practices can be categorized within the ReSOLVE framework, such as recycling and reusing materials (Regenerate); renting and sharing vehicles (Share); controlling pollutant gas emissions (Optimize); using remanufactured goods (Loop); eliminating the use of paper through the adoption of digital documents (Virtualize); and applying technologies aimed at energy efficiency (Exchange), which impact the economic aspect of organizations and the capture of value (Geissdoerfer et al., 2017).

The synergy between sustainable practices and CE is also observed in the responses of the interviewees in the case study. When asked about the main sustainability and CE practices adopted by the organizations, we identified the mention of circular and governance actions that strengthen circularity. According to D1, "[...] this work exists with the cooperatives; they help the cooperatives to develop processes, to improve their structure to increase productivity and member remuneration". D2 points out: "[...] today we already have a use of about 95% of our waste here, but there is some kind of valorization, right? So it goes to recycling or is sold as scrap". Finally, D3 indicates that "[...] in our annual reports we even present the volume of resin waste produced with plastic waste, and how much of it is from other products that we also managed to develop circularity". And, further: "In this part of climate change, we have our KPIs for reducing emissions and even for becoming carbon neutral".

It can be seen, therefore, that circular practices, aligned with the ReSOLVE framework, contribute to improving the environmental, social and economic aspects of organizations, which monitor this evolution through the evaluation of key indicators. Among the six actions of the ReSOLVE framework, the practices categorized under Regenerate stand out in this research for their influence on the pillars of sustainability, especially with regard to recycling and reuse of materials: environmentally, the reduction in the extraction of raw materials and the minimization of waste are observed; socially, support and partnerships with recycling cooperatives are identified, contributing to the generation of income and social inclusion; while economically, the valorization of waste as a raw material and the possibility of new businesses and market entry are envisaged.

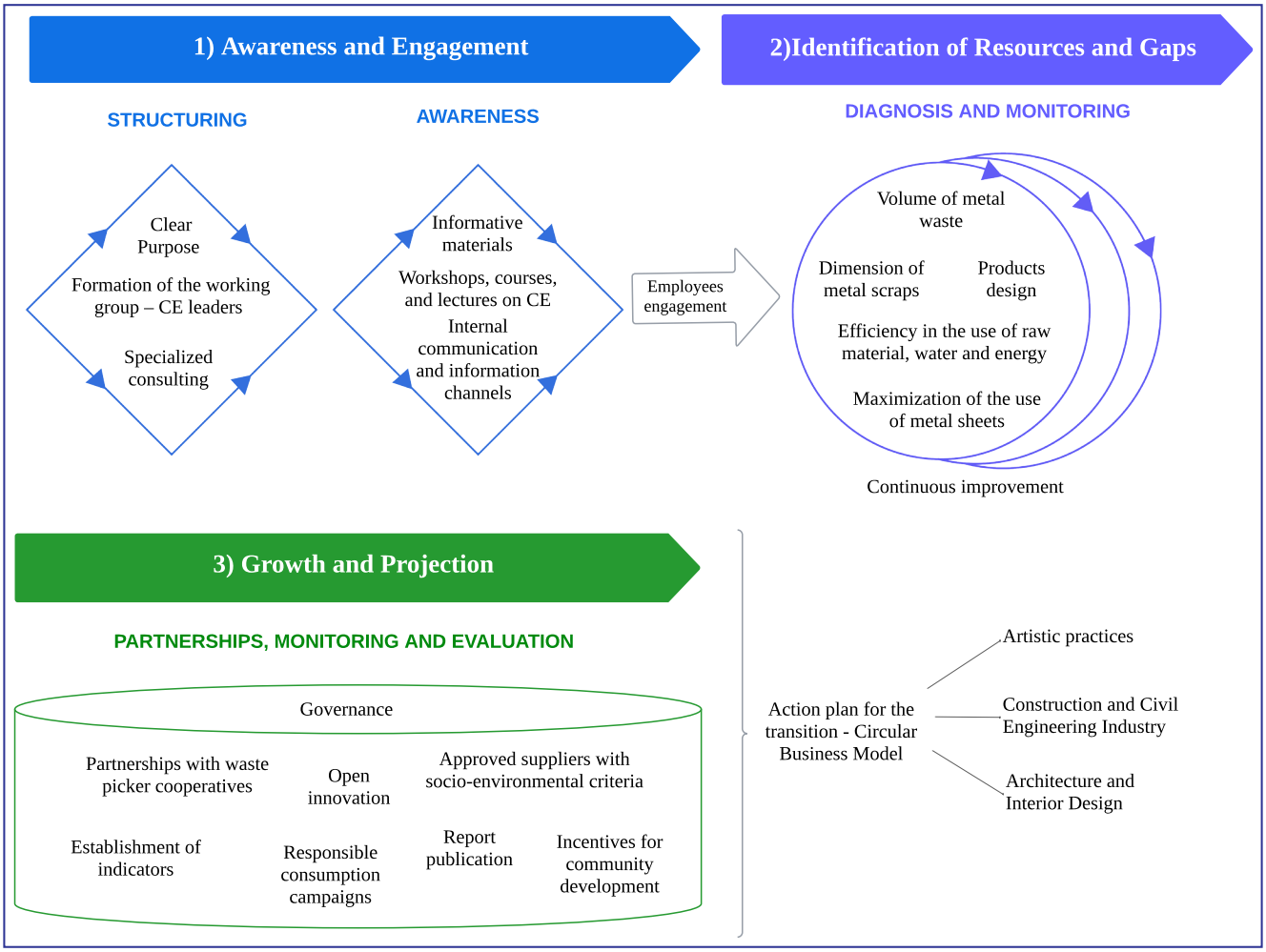
The research also clarifies and reinforces the synergies between governance and the adoption of circular practices. The articulation of partnerships with suppliers and customers, the engagement of leaders and employees, open innovation ecosystems, and incentive policies are examples of governance capable of influencing and collaborating in the adoption of CE practices. In addition, the systemic vision indicated as necessary to achieve sustainability (Rogers & Hudson, 2011) and circularity (Ellen Macarthur Foundation, 2015; Kirchherr et al., 2017; Bianchi & Cordella, 2022) is emphasized by the multiple case study. There is convergence in the three cases interviewed regarding the importance of analyzing operations in a systemic way, including environmental, social, and governance aspects, in order to obtain quality solutions. Finally, it is observed that, in fact, the organizations that are part of ISE B3 have sustainability and CE as commitments. The display of various practices related to these two concepts denotes a gradual change in behavior towards a more sustainable bias, as pointed out by Pego (2020).

The successful experiences investigated by the case study reveal the existence of numerous challenges for the implementation of CE, while proving that it is possible to adapt circular practices in different contexts. Through the engagement and resilience of leaders and employees, CE occurs, and organizations achieve better sustainability rates. In this context, the research results presented so far were used as a basis for benchmarking in the metalworking industry, emphasizing the importance and usefulness of learning from successful cases in the market, especially for the implementation of CE, as highlighted by Batista and Francisco (2018).

Proposition of the theoretical framework

The proposed theoretical framework, visualized in Figure 1, is based on the best practices triangulated in Chart 2, resulting from the benchmarking process. The stake is composed of three main pillars: 1) Awareness and engagement; 2) Identification of resources and gaps; and 3) Growth and projection. Raising awareness and engaging the company's management, managers, leaders and other employees in the same purpose will be decisive for the success of circularity in the organization. The lack of consensus on what CE is is a major barrier to its success (Sileryte et al., 2023), and this awareness seeks to overcome resistance to change (Ghedam et al., 2021) by promoting the understanding of circularity. In this initial phase, it is also important to structure the internal team that will monitor the actions linked to CE, as well as to discuss the possibility of hiring a specialized consultancy to support the beginning of the transition.

Figure 1
Theoretical framework for transition to the circular economy in the metallurgical sector



Source: Elaborated by the authors.

Metallic materials used as raw materials in the metallurgical industry have a high capacity for recycling and reuse. It is important to map the resources used and the gaps in the production process. Reducing waste of raw materials and resources is an important action, and it is necessary to evaluate the production process daily to map points where waste may be occurring. Water and electricity are also resources that can be managed and optimized.

During production, metal sheets are often cut, resulting in the generation of scraps, which are usually sold. Products, parts or similar items can be produced with the scraps generated and used in the organization's production process. It is also possible to identify waste that is useful for other industries, which allows for the establishment of partnerships to develop the circular economy not only within the company itself but also in the value chain.

As evidenced by Marjamaa, Salminen, Kujala, Tapaninaho and Heikkinen (2021), the transition to CE requires the involvement of stakeholders at all levels of society. In this case, in addition to partnerships with other companies, universities, startups, suppliers, customers and employees themselves can be partners in proposing solutions aimed at sustainability and implementing the circular economy. A university, for example, can provide the expertise needed to assess the economic viability of a new circular business.

In research aimed at identifying suggestions for the use of metal waste, opportunities were observed in the visual arts, in the production of metal sculptures, in architecture and interior design, and, mainly, in the construction industry. The production of furniture such as chairs, benches, and tables, due to the characteristics of the metal, can be molded into the most different shapes and used in both indoor and outdoor environments. This furniture has become common in architectural projects largely due to the popularization of the contemporary industrial style (Gouveia, 2021), denoting the potential of this market niche. It is reiterated that, most likely, such options are viable for cases of reduced volumes of metal shavings. There is the possibility of reusing larger volumes of these materials in the construction industry, as an additive in mortars and concrete mixes, for example (Power, 2023).

The growth and projection of a business from a circular perspective depend on structured governance and require monitoring. Therefore, it is essential to establish monitoring indicators that reveal progress towards CE. Indicators tend to help keep the team motivated and always seeking continuous improvement, creating an environment of internal cooperation. With a view to transparency with stakeholders, the publication of reports that bring together social and environmental initiatives and economic results is of great value.

It is important to highlight that the proposed framework lists processes and procedures mapped by research evidence. Each organization has specificities that need to be considered in a transition project to CE, and during the process of executing an action plan, new needs may be identified, which highlights the importance of having an internal CE coordination team that monitors the processes on a daily basis and reports on such demands.

It is worth noting that CE lacks a systemic vision, and although the metallurgical industry offers great opportunities related to recycling and reuse of metallic materials, the adoption of waste management in isolation does not imply the adoption of circularity in processes. The National Solid Waste Policy (Federal Law No. 12.305, of August 2nd, 2010) establishes in a regulated manner the responsibility of organizations in the management of their waste. Therefore, CE emerges as an alternative to add greater value to waste.

The ways of implementing CE are still unclear and inconsistent (Friant, Vermeulen & Salomone, 2020), and this study seeks to fill this gap for companies in the metalworking sector. The great challenge, as pointed out by Mboli et al. (2020), is the expansion of CE projects beyond the micro scale addressed by this study. In any case, our findings reinforce the assertion of De Angelis and Ianulardo (2024), that CE can contribute to sustainability management in organizations, and demonstrate that circularity in the metalworking sector goes beyond what is proposed by the ReSOLVE framework, encompassing the following process flow:

- Diagnosis and planning: assessment of the value chain and analysis of the material flow.
- Design for circularity: development of sustainable products and selection of recycled and recyclable materials.
- Circular production processes: process optimization and recycling and reuse in the production process.
- Circular business models: servitization and return systems.
- Partnerships and collaboration: collaboration with suppliers and customers and joint recycling initiatives.
- Policies and regulations: compliance with waste management, recycling and emissions regulations and incentives for circular practices.
- Education and awareness: employee training and local community and industry engagement.

FINAL CONSIDERATIONS

With the aim of proposing a theoretical-empirical framework adapted to promote the implementation of CE in the metallurgical sector, the research findings allowed us to identify the fundamental processes for the gradual transition to CE. It was observed that governance presents itself as a fundamental structure for CE. Through structured governance, it is possible to create an environment favorable to circularity, with interaction and cooperation between the various actors in the value chain, aiming at the creation and execution of sustainable solutions. Within the scope of stakeholders, leaders, employees, customers and suppliers are mapped as priority stakeholders for the success of circularity in organizations.

The study contributes to the literature and practice by providing a practical and adaptable model for companies wishing to begin the transition to CE, which is especially valuable given the scarcity of such models in existing research. For practitioners, the proposed framework outlines steps and presents clear considerations for integrating CE into their operations, aiding decision-making and strategic planning.

The main theoretical contribution of this research is the expansion of the discussion on sustainability in practice, with the differential of multiple data sources. The study also contributes to the understanding of the necessary governance structures, the identification of strategic stakeholders, and reiterates the adaptable nature of CE practices. The study positions governance as a central pivot to enable circularity, which is a significant theoretical contribution, as it highlights the systemic nature of CE adoption, in which governance structures influence the transition.

In managerial terms, the practical examples presented in the study reinforce the possibility of adapting sustainable and circular practices in companies from different economic sectors. Both the cases analyzed in depth and the proposed framework are possibilities to support managers in future decision-making, especially for organizations that wish to start planning to join the CE.

Among the practical implications of the study for the identified priority stakeholders, the following stand out:

a) Leaders and managers: leaders play an indispensable role in the transition. Their positioning in favor of sustainability and circularity has the ability to disseminate and strengthen the organizational culture. Benchmarking is highlighted as a useful and applicable tool by leaders and managers in the context of CE, being an important source of information and knowledge, capable of assisting in adapting operations management to CEBM (Jabbour et al., 2019).

b) Employees: Employees are important agents of intra-organizational change. They can act to propose improvements to the CE implementation process. By engaging them, the metalworking company can strengthen its organizational culture and reinforce its sustainable and circular positioning.

c) Customers: customers may value and prioritize the acquisition of products from metallurgical industries that adopt circular practices. This may generate an increase in demand for products with these characteristics, encouraging the transition to CE in companies in the sector.

d) Suppliers: Suppliers have the opportunity to engage in circular practices by cooperating with companies in the metalworking sector. Offering recycled metal, supplying various inputs with sustainable characteristics, and adopting sustainable practices to meet the requirements imposed by metalworking companies are some examples. When metalworking industries seek sustainable suppliers aligned with the CE, circular premises go beyond the organizational scope and can achieve more comprehensive results.

Despite the contributions listed and the benefits associated with circularity, caution is needed to ensure that CE is not adopted uncritically by countries, economic sectors, and companies. Many stakeholders and sectors articulate circular discourses that are only aligned with their interests (Friant et al., 2020), without sufficiently examining the implications of circularity in the macro environment. In this sense, managers and entities in the metallurgical sector cannot confuse CE solely with the management of metal waste. Even though good practices are highlighted in this study, they must be adopted in a critical and systemic manner. Creating a culture for circularity is a slow, systemic, and complex process. It is necessary to articulate not only the engagement of employees and suppliers, but also the development of public policies to encourage circularity, tax incentives, and support in the search for financial resources.

The study has some limitations. Among them, the survey response rate stands out, reaching 39.6% of companies, which is lower than expected. Another limitation of the study is related to the diversity of sustainability, governance and CE practices. Despite the efforts made to optimize the data collection instruments by indicating practices aligned with the ReSOLVE framework commonly cited in the literature, the questionnaire developed is not capable of covering all practices linked to a circular production system. The limitation of the small number of interviews is also noteworthy, although the three interviewees robustly validated the results mapped in other sources and served as an additional source to validate elements mapped in other sources – which supports the use of theoretical saturation.

As suggestions for future studies, we suggest the possibility of developing a similar study applied to a specific economic sector of B3, including companies that are not part of the ISE in the sample, to allow for comparability. A second suggestion is to conduct quantitative studies to assess the existence of a correlation between the adoption of governance practices and adherence to the CE. Especially in the context of the metallurgical sector, discussions can be advanced with studies that address in depth environmental, social and economic indicators for measuring the objectives of implementing the CE in organizations in the sector. It is also important that additional studies improve the proposed framework, aiming at expanding the CE beyond the micro scale.

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Nelson Santos Machado: Supervision (Equal); Validation (Equal); Writing- original draft (Equal); Writing- review & editing (Support).

DATA AVAILABILITY

The full dataset supporting the findings of this study is available upon request from corresponding author Tais Provensi. The dataset is not publicly available because it contains information that may compromise the privacy and anonymity of research participants.

ACKNOWLEDGEMENTS

This research was carried out with support from the National Council for Scientific and Technological Development (CNPq), through a productivity grant for Simone Sehnem; from the Santa Catarina State Department of Education, through a grant from the Fund to Support the Maintenance and Development of Higher Education (UNIEDU/FUMDES, public call 471/SED/2021) for Tais Provensi; and from the Coordination for the Improvement of Higher Education Personnel, through a grant from the Postgraduate Support Program for Community Higher Education Institutions (CAPES/PROSUC, Unoesc notice 07/2023) for Tais Provensi and Maiara Lais Marcon.

PEER REVIEW REPORT

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