Circular supply chains and Industry 4.0: an analysis of interfaces in Brazilian foodtechs

Tiago Hennemann Hilario da Silva
University of Southern Santa Catarina Palhoça, Santa Catarina, Brazil, and

Simone Sehnem
University of Southern Santa Catarina Palhoça, Santa Catarina, Brazil and University of Western Santa Catarina Chapecó, Santa Catarina, Brazil

Received 30 May 2023
Revised 19 September 2023
27 November 2023
Accepted 30 January 2024

Abstract

Purpose – This study aims to identify the interfaces between Industry 4.0 (I4.0) technologies and circular supply chains (CSC) in Brazilian foodtechs, focusing on key stakeholders' perspectives to understand the efficiency and sustainability impacts of these integrations.

Design/methodology/approach – Using a qualitative exploratory research design, the study analyzes eight Brazilian foodtechs through interviews and content analysis. It identifies CSC practices and examines the adherence of I4.0 technologies within these enterprises, assessing stakeholder engagement and the implications for CSC optimization.

Findings – Fifteen CSC practices were identified across the foodtechs, with notable integration of three distinct I4.0 technologies. The findings suggest that while I4.0 technologies enhance efficiency in CSC, their adoption is in early stages. Stakeholder engagement emerges as a crucial element for optimizing CSC in the context of Brazilian foodtechs.

Research limitations/implications – This study contributes to the academic discussion on the synergy between I4.0 and circular economy (CE) models, providing empirical evidence of their application in the foodtech sector and highlighting the role of stakeholders in facilitating these integrations.

Practical implications – The findings suggest that stakeholder engagement in circular practices is vital for both supply chain and organizational levels, with potential benefits including improved efficiency and sustainability outcomes. The research also underscores the need for public sector support, including regulatory frameworks and incentives for adopting I4.0 technologies.

Social implications – By demonstrating how I4.0 technologies can support CE practices in foodtechs, the study highlights the potential for these integrations to contribute to more sustainable and efficient food systems, addressing environmental concerns and promoting social well-being.

Originality/value – This study addresses a gap in the literature by exploring the interface between I4.0 technologies and CSC in the emerging context of Brazilian foodtechs, offering insights into the practical and societal benefits of these integrations.

Keywords Stakeholders, Industry 4.0 technologies, Circular supply chains, Foodtechs

Paper type Research paper

RAUSP Management Journal
Emerald Publishing Limited
2531-0488
DOI 10.1108/RAUSP-05-2023-0079

1. Introduction

The first years of this decade have marked a critical period in human history: the return to a "new normal" after the COVID-19 pandemic (World Economic Forum, 2023). Increasingly, climate change and biodiversity loss are on the agendas of both businesses and governments. It is evident that the food system plays a vital role in addressing both challenges (Ellen MacArthur Foundation, 2021). The current production system has driven economic development. However, the productivity gains have come at a high price, coupled with a model no longer suitable for meeting humanity's long-term needs. Moreover, the agri-food sector is responsible for about a quarter of greenhouse gas emissions on the planet (Ellen MacArthur Foundation, 2019).

Only 7.2% of the global economy is circular, which highlights that the system is increasingly dependent on materials from virgin sources. The current economic model is stretching the limits of the planet. Thus, it is essential to transform our relationship with materials to maximize benefits for people (Circle Economy, 2023). To support this transition, a balanced integration of economic performance, social inclusion and environmental resilience is necessary, offering benefits to both current and future generations (Geissdoerfer, Savaget, Bocken, & Hultink, 2017).

Circular economy (CE) and Industry 4.0 (I4.0) have emerged as possibilities for making these crucial transitions. These are two topics currently under discussion among scholars, professionals and policymakers (Gupta, Kumar, & Wasan, 2021). However, the digital revolution has brought many challenges and opportunities for organizations. Nevertheless, the adoption of I4.0 technologies in the CE is still a little-researched topic (Bag & Pretorius, 2022). There is also limited research that examines the impact of digital technology use on the CE in a supply chain context (Khan, Piprani, & Yu, 2022). In this context, increased competition at the supply chain level, variations in customer demand patterns and stakeholder pressures are driving companies to incorporate higher levels of sustainability into their operations (Mani, Jabbour, & Mani, 2020).

Circular practices in foodtechs represent a new phenomenon in the entrepreneurial market. This unit of analysis is also underexplored in academic literature. However, this new model is seen as a significant point for the positive impact of these companies (Rok & Kulik, 2021). Small and medium-sized enterprises with CE initiatives can adapt better to implement new technologies (Chaudhuri, Subramanian, & Dora, 2022).

It is in this context that foodtechs in the food category, popularly known as foodtechs, are situated. Foodtechs are organizations that use technology to enhance the entire food production chain, including production, distribution, supply or postconsumption of food. They can also be defined as companies that enable people to consume healthier, more accessible, fresh, nutritious and environment-friendly food. In this sector, more than 8,400 jobs have been created, and investments have reached approximately 4.66bn Brazilian Reais between 2021 and 2022 (Liga Insights FoodTechs, 2023). These companies were founded with the purpose of fostering an agile and lean business model, capable of creating value for their customers by solving real-world problems and offering a scalable solution to the market. They use technology as their main ally and tool in achieving these goals [Associação Brasileira de Startups (ABSTARTUPS), 2023].

Based on this scenario, this study will use the perspective of key stakeholders in the food producer supply chain. To do so, we rely on the stakeholder theory, focusing on the interests of these stakeholders. Thus, this study aims to identify the interfaces between I4.0 technologies and circular supply chains (CSC) in foodtechs producing food, through the main stakeholders in the sector. The specific objectives are to:

- enumerate circular practices in supply chains;
- verify the adherence of I4.0 technologies in the surveyed foodtechs; and
- examine how foodtechs are responding to the issues raised by stakeholder theory.

Therefore, this study seeks to open up space for critical investigations into this complex relationship between these two still-emerging themes in academia, adding to an already established theory.

Foodtechs that adopt I4.0 technologies in their CSC tend to generate positive impacts for societal development, as they seek to address the three pillars of sustainability (Elkington, 1994). These companies go beyond economic results, also pursuing environmental and social outcomes. In this light, this study is appropriate because it will seek to understand how these two study themes interface in the context of Brazilian foodtechs.

The relationship between these study themes is still in its infancy and requires deeper empirical research. This study is original because it aims to contribute to filling the theoretical gaps identified in previous studies, especially in the Brazilian context of small and medium-sized enterprises. These gaps include the use of blockchain and big data in CSC, understanding how I4.0 and CE can support stakeholders in understanding this new paradigm, as well as identifying the factors affecting the implementation of these theoretical fields in supply chains (Silva & Sehnem, 2022a, 2022b).

The intersection between I4.0, CSC and food technology stakeholders is transforming the way we produce, distribute and consume food, driving sustainability and efficiency across the entire value chain. Especially associated with the intersection between I4.0 technologies and CSC, with adherence to traceability and transparency practices, artificial intelligence (AI) and optimization, additive manufacturing and personalization, sustainable ingredient suppliers, food companies can use automation, robotics and other I4.0 technologies to improve efficiency in sustainable food production, reducing waste and environmental footprint. In addition, technology can be used to optimize logistics operations, ensuring efficient food delivery, especially when implementing CSC that seek to reduce waste. Finally, combining I4.0 technologies in CSC can significantly contribute to sustainability, enabling reduced food waste, efficient use of resources and more sustainable production.

Therefore, the rest of this article is organized beyond this introductory section. Section 2 describes the theoretical framework. In Section 3, the methodology used is presented. In Section 4, the analysis and discussion of the research results are described. Finally, the concluding remarks of this study.

2. Literature review

In this section, the two main concepts comprising this study are presented. First, the topic of CSC will be addressed, followed by I4.0 technologies. Subsequently, the concepts of stakeholder theory, forming the theoretical foundation of this study, will be introduced. Finally, a relationship diagram of constructs that will be used in the analysis of collected data will be described.

2.1 Circular supply chains

To understand CSC, we first present the concept of the CE, which was developed in response to challenges related to natural resource depletion and increasing waste volumes. It is associated with an economic system capable of regenerating in the production and consumption life cycle, where waste is used and repurposed as raw material in the production process (Kirchherr, Reike, & Hekkert, 2017). This practice is essential for improving eco-environmental performance in developing countries (Nascimento et al., 2018).

The CE is inherently restorative, with the goal of keeping goods, components and materials at their highest level of utility, promoting a paradigm shift in how materials and resources are used (Ellen MacArthur Foundation, 2015). Its immense complexity and scope span across various disciplines, making it a vast concept that requires efforts and studies at multiple levels for efficient and effective implementation (Braz & de Mello, 2023).

The CE is closely related to supply chain management, as companies are building sustainable businesses within their networks (Del Giudice, Chierici, Mazzucchelli, & Fiano, 2021). There is a common understanding in the literature that a CSC is significantly different from the traditional model, and several processes need to be added to it, such as material use planning, resource recovery, maintenance product delivery and end-of-life product return (Vegter, van Hillegersberg, & Olthaar, 2020). The CSC can be divided into five stages: design and development, production, delivery, operation and end-of-life cycle (Liu, Song, & Liu, 2023). Thus, many CE practices, such as reuse, remanufacturing and recycling, support closing the loop of CSC (Chen, Yildizbasi, & Sarkis, 2023).

The CE of food presents itself as a model with economic, environmental and health benefits across all its processes because, in a linear process, it degrades the natural resources it depends on and pollutes the air, water and soil (Ellen MacArthur Foundation, 2019). The transition to a food system that builds natural capital, i.e. one that allows nature to thrive, is an essential step in the transition to a CE (Ellen MacArthur Foundation, 2021). The CE emerges as a transformative strategy, aiming to radically reshape the traditional linear model of production and consumption in this sector (Esposito, Sessa, Sica, & Malandrino, 2020). Embracing CE principles becomes strategically significant for foodtech companies, enabling them to gain a competitive edge by prioritizing pollution prevention, managing product life cycles and integrating circular product development practices (Sehnem, Provensi, da Silva, & Pereira, 2022). For this study, the typology by Khan et al. (2022) will be used for mapping circular practices in the supply chain, as presented in Table 1.

2.2 Industry 4.0

The concept of I4.0 was first introduced in 2011 in Germany during the Hanover Fair by a working group of the country's Ministry of Education and Research. The term was created to encompass two meanings: the first as a synonym for a supposed "fourth industrial revolution" and the second as a label for the strategic plan pursued by Germany to strengthen its competitive position in manufacturing products (Culot, Nassimbeni, Orzes, & Sartor, 2020). I4.0 aims at the development of smart factories and products, offering opportunities to enhance production performance and its processes, activities, organizational strategies, business models and skills (Massaro, Secinaro, Dal Mas, Brescia, & Calandra, 2021). These technologies can facilitate interactions among different stakeholders (Upadhyay et al., 2021).

However, this concept is not universally accepted yet (Beltrami, Orzes, Sarkis, & Sartor, 2021). I4.0 is also described as the set of technologies, devices and processes, at various stages of the production process, enabling integrated operations, decentralized decision-making, with minimal human intervention (Castelo-Branco, Cruz-Jesus, & Oliveira, 2019). These technologies may include the Internet of Things (IoT), cyber-physical systems, autonomous robots, additive manufacturing (3D printing), AI, big

Practice	Definition
Technological innovation	Includes Industry 4.0 technologies such as blockchain, big data and artificial intelligence, which can support companies in restructuring their processes to adopt circular economy practices
Circular procurement	Aims to cooperate with suppliers to make green purchases, which do not harm the environment, with products that can be recycled and remanufactured
Circular design	Aims to support companies in minimizing their waste and facilitating recycling and remanufacturing processes, which not only improves environmental performance but also enhances the economic performance of companies
Environmental performance	Relates to companies' ability to protect the environment by reducing waste, energy consumption and toxic waste, from upstream to downstream of the supply chain
Economic performance	Evaluates the ability of companies in producing goods to reduce costs related to material and component supply, recycling and remanufacturing processes, waste disposal, energy and water usage

Source: Table by authors

Table 1. Circular supply chain practices

data analytics, cloud computing, blockchain, autonomous robots, visualization technologies (virtual and augmented reality), among others (Culot et al., 2020; Ejsmont, Gladysz, & Kluczek, 2020).

The goal of I4.0 is to perform processes efficiently and with continuous improvement, integrating information and communication (de Sousa Jabbour, Jabbour, Godinho Filho, & Roubaud, 2018). However, Schwab (2016) describes that I4.0 is not limited to intelligent and connected systems and machines alone, as its scope is broader, encompassing new discoveries occurring simultaneously in different areas, ranging from genetic sequencing to nanotechnology, renewable energies and quantum computing. This author categorized I4.0 technologies into three distinct categories, as described in Table 2.

2.3 Stakeholder theory

In addition to CE and I4.0, another relevant concept for this research is the stakeholder theory. This theory, proposed by Freeman (2010), argues that companies should consider not only the interests of shareholders but also the various groups that are affected by their activities, such as employees, customers, suppliers, community and government. Typically, the focal organization in a supply chain is a stakeholder for many other focal points in its system of interaction. The link between entities is evident as the behavior of an organization and the resistance to demands from all participants in this network (Rowley, 1997).

Category	Technology
Physical	Autonomous vehicles, 3D printing, robotics and new materials
Digital	Sensors, Internet of Things (IoT), blockchain, cloud computing and big data
Biological	Genetics, genomics and synthetic biology

Source: Table by authors

Table 2. Categories of Industry 4.0 technologies

However, Parmar et al. (2010) question how value can be simultaneously created for different stakeholders in this network. Donaldson and Preston (1995) argue that managers need to recognize the different groups to which their organizations are embedded and their interests. In this regard, Freeman and Reed (1983) emphasize that companies engage in negotiation processes with all stakeholders to adjust organizations' expectations in a friendly manner. Increasingly, a growing number of academics and professionals have been exploring concepts and models that facilitate the understanding of the complexities of today's business challenges. Therefore, this theory aims to understand and address three interconnected problems: understanding how value is created and negotiated, how to connect ethics and capitalism and how to manage in a way that resolves the first two problems (Parmar et al., 2010).

This theory has become popular among academics and organizational executives and seeks to understand, within its unit of analysis, the relationships between an organization and the groups or individuals involved (Mitchell, Agle, & Wood, 1997). There are interconnected relationships between an organization and various other agents that affect or may be affected by organizational activities (Freeman & Mcvea, 2001). Stakeholder pressure can motivate organizations to adopt certain environmental sustainability practices (Zhu, Bai, & Sarkis, 2022). Stakeholder theory sees the corporation as an organizational entity through which diverse and numerous participants aim to achieve multiple and not always common purposes among all participants (Donaldson & Preston, 1995).

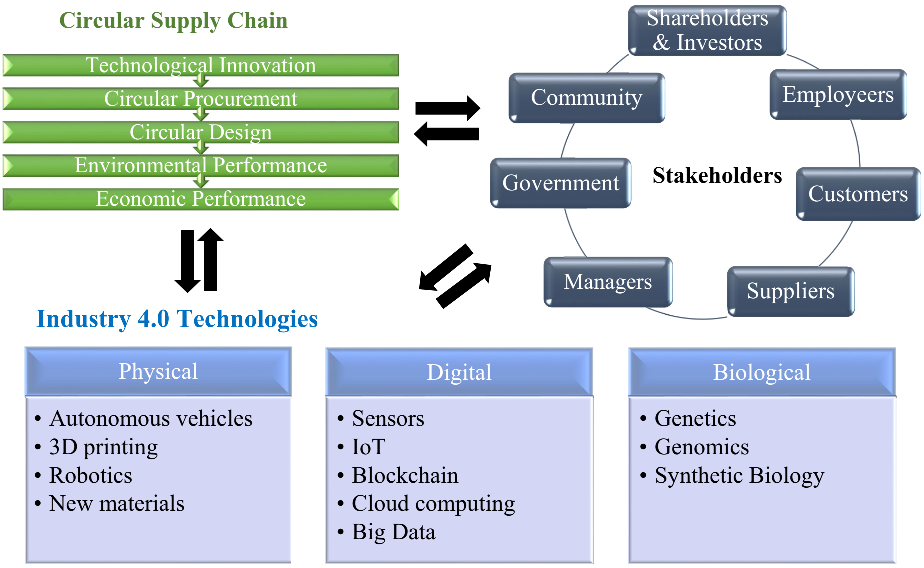
The stakeholders are individuals or groups who possess or claim ownership, rights or interests in the company or its activities. For this study, the typology of primary stakeholders by Clarkson (1995) will be used, as an organization cannot survive without them. These entities include shareholders and investors, employees, customers, suppliers, managers, government and the community (Clarkson, 1995).

With the presentation of the two constructs of this study, CSC and I4.0 technologies, combined with stakeholder theory, Figure 1 illustrates these relationships. In this figure, primary stakeholders of CSC are presented along with the interface of I4.0 technologies. The figure describes the categories of analysis in the study.

Based on the relationship diagram presented in Figure 1, it is possible to visualize the interactions between the categories of analysis of CSC and I4.0 technologies from the perspective of stakeholders. The five categories of CSC, according to Khan et al. (2022) typology, include technological innovation, circular procurement, circular design, environmental performance and economic performance. Each of these categories has the potential to generate value for the organization's stakeholders. The primary stakeholders, including shareholders and investors, employees, customers, suppliers, government and the community, are presented through a closed network, illustrating possible interconnections among these stakeholders within a process.

It is important to consider the needs and expectations of each of these stakeholders when implementing circular practices in the supply chain, as well as adopting I4.0 technologies. At the bottom of the figure, the three categories of analysis of I4.0 technologies, as described by Schwab (2016), are presented: physical, digital and biological. The potential interactions between them are shown by the arrows, highlighting how I4.0 technologies can support the implementation of circular practices in the supply chain, bringing economic and environmental benefits to companies and their stakeholders.

Thus, this relationship diagram underpins the main objective of this study, which is to investigate how I4.0 technologies can support the implementation of circular practices in the supply chain from the perspective of stakeholders. Therefore, in the next section, the methodological procedures used in this study will be described.



Source: Figure by authors

Figure 1. Relationship diagram of circular supply chains, Industry 4.0 technologies and stakeholder theory constructs

3. Research methodology

The originality of this study is grounded in theoretical gaps previously analyzed in the studies by Silva and Sehnem (2022a) and Silva and Sehnem (2022b). In these studies, research topics that had not been extensively explored were identified, and this article seeks to identify the interfaces between I4.0 technologies and CSC in foodtechs, as well as to list circular practices in supply chains and understand the nuances of the adherence of I4.0 technologies. Finally, it aims to provide answers to questions raised by Freeman et al. (2010) in the stakeholder theory:

- understanding how value is created and negotiated;
- how to connect ethics and capitalism; and
- how management is carried out so that the first two issues are resolved.

In addition to the already identified originality, several studies with a similar scope can be mentioned, including Massaro et al.'s (2021) study, which explores how I4.0 can be used to increase the impact of the CE on companies; Batista, Dora, Garza-Reyes, and Kumar (2021) article, which presents a methodological approach to support the qualitative analysis of waste flows in CSC; Tavera Romero, Castro, Ortiz, Khalaf, and Vargas (2021), who describe the relationship between CE and I4.0; Neri et al.'s (2023) analysis of the adoption of digital technologies from I4.0 to support the implementation of CE practices in small and medium-sized Italian companies; and finally, Khan et al.'s (2022) examination of the effect of technological innovation on CE practices, assessing its relationship with environmental and economic performance.

As the object of study, foodtechs are newcomers to the market, typically founded by entrepreneurs with a technological drive and a focus on radical change from their inception. They are usually based on innovations, and these companies can play a crucial role in a community by promoting a higher level of sustainability through their positive impact (Rok & Kulik, 2021). The research for these companies was conducted on one of the largest Brazilian foodtech portals, Startup Scanner (https://startupscanner.com/). This tool is a digital platform by Liga Ventures, providing access to a map of Brazilian foodtechs with solutions for various foodtech areas, and this database is constantly updated. Our research focuses on this specific subset to provide unique insights into how CE and I4.0 are integrated into their operations. These companies play a vital role in driving local innovation and sustainability practices within the food sector.

Data collection took place between November 2022 and March 2023. After this initial stage, a preliminary analysis of the websites and social media of the foodtechs was conducted to assess their adherence to CSC aspects, and subsequently, the companies that agreed to participate in the research were selected. The sample of this study consists of eight foodtechs, whose legal names were kept confidential due to privacy considerations and are identified by acronyms.

This study is predominantly a qualitative exploratory research based on multiple case studies. The primary data collection technique used was interviews, conducted both in person and online. To support this data collection, secondary data available on the companies' social media platforms such as websites, Instagram, Facebook, LinkedIn and YouTube videos were used. Table 3 provides information on the primary and secondary data collected for this study.

Based on the data collected from the interviews and additional information from the secondary data, a qualitative analysis was conducted. The analytical phases of compilation, decomposition, recomposition, rearrangement, interpretation and conclusion, as described by Yin (2010), were followed. The description of the categories is presented in Table 4.

In this section, the methodological approach of this study has been presented. The next section will focus on the results and their analysis.

4. Results and discussion

In this section, the results and analysis obtained in this study are presented. The description of the results follows the sequence of the three research constructs: CSC, I4.0 technologies and strategic stakeholders. In the analysis of the results, the utilization of CSC practices, adherence to I4.0 technologies and the presence of primary stakeholders were identified for each foodtech. These results provide answers to both the overall and specific objectives of the study.

Table 3. Description of research data

	Primary data		Secondary data				
Foodtech	No. of transcribed pages	Interviewee – position	Web page	Instagram	LinkedIn	Facebook	Youtube
XYZ	21	Owner	X	X	X	X	X
APX	16	Operations director	X	X	X	X	X
MMN	24	Director	X	X	X	X	X
SAB	6	Director	X	X		X	
FBN	7	Commercial director	X	X	X	X	
SEI	17	Director	X	X	X		X
MNA	17	Owner	X	X	X	X	
ALL	19	Owner	X	X		X	X

Source: Table by authors

Category	Subcategory
1. CSC – circular supply chain	1.1. TI – Technological innovation 1.2. CP – Circular procurement 1.3. CD – Circular design 1.4. EP – Environmental performance 1.5. PE – Economic performance
2. I4.0 – Industry 4.0 technologies	2.1. PH – Physical 2.2. DI – Digital 2.3. BI – Biological
3. STK – stakeholders	3.1. SI – Shareholders and investors 3.2. EP – Employers 3.3. CU – Customers 3.4. SP – Suppliers 3.5. MN – Managers 3.6. GV – Government 3.7. CM – Community

Source: Table by authors

Table 4. Categories and subcategories of analysis

4.1 Results

Firstly, it was possible to identify CSC practices in the supply chains of all the researched foodtechs, with many of them implementing these actions without even being aware of the concept of CE (foodtechs SAB and SEI). Fifteen CE practices were identified, and they are presented in Table 5. This table describes the practices, the corresponding foodtechs and the identified category(ies), following the typology of Khan et al. (2022) and the foodtech that implemented each practice.

Table 6 presents the I4.0 technologies found in the surveyed companies. It includes the identified foodtech, the analysis category according to Schwab's (2016) typology the identified I4.0 technology, and the practice in which this technology is applied.

Although seven I4.0 technologies were identified in the surveyed foodtechs, only five out of eight companies actually use these technologies in their supply chains and internal processes. Regarding stakeholder engagement, active participation was mainly observed from suppliers, customers, employees and managers, while shareholders and investors had less interaction in the studied sample. Government and community involvement, however, were not identified in both primary and secondary data. Based on these findings, the next section provides a detailed analysis of the results.

4.2 Discussion

The analysis revealed that not all the researched foodtechs are using I4.0 technologies in their supply chains and internal processes. This finding contrasts with the literature suggesting widespread adoption of these technologies to drive the transition to the CE (Davis et al., 2021; Lee et al., 2022). Furthermore, the absence of government and community involvement in the empirical evidence differs from theory. This finding highlights the importance of these actors in supporting the CE and supply chain sustainability (Wang et al., 2021; Thompson et al., 2023).

The study indicates that CE practices and I4.0 technologies adopted by foodtechs contribute to the sustainability and resilience of supply chains. In addition, stakeholder engagement in CSC mapped in the study reinforces the importance of collaboration among

Foodtech	Identified practice	Category
XYZ	Use of eco-friendly packaging, with biodegradable paper that does not require return	1.4 and 1.5
	Utilization of underutilized native food plants in food production. By respecting the interaction between plants and species, the production of these foods does not harm the environment and reduces carbon footprint. The incorporation of biodiversity in agriculture allows for soil and water regeneration while extracting micronutrients from the food. This production process can be scaled up to an industrial level and applied throughout the food supply chain, from production to logistics, processing and commercialization. These types of foods exhibit greater resilience to the impacts of climate change, require reduced pesticide use and offer a rich nutritional profile	1.4
APX	Installation of 210 solar panels for energy generation and the use of two rainwater tanks with a total capacity of one thousand liters for washing the surrounding area of the factory	1.1
	Selective waste disposal according to recycling requirements	1.2
	Knowledge transfer to suppliers through training on agroforestry practices (in a laboratory simulating this culture) and the use of production waste to produce by-products, such as using tomato or orange leftovers to make preserves or jams	1.2
MMN	Low waste generation and utilization of by-products, such as cassava peel, which is sold to suppliers for animal feed, forming a closed-loop supply chain. In addition, the utilization of cassava by-products, such as starch, dough and juice	1.4 e 1.5
SAB	Whenever possible, the use of eco-friendly packaging, even if it comes at a higher cost	1.4 and 1.5
FBN	Offering a bonus for the next purchase when customers return glass packaging	1.4 and 1.5
	Acquisition of suppliers with all necessary regulatory documents and approved through inspection visits	1.2
SEI	Change of fuel for the delivery and collection fleet from diesel to natural gas	1.1
	Purchase of the main raw material, grains, from local producers	1.2
	Use of expired products for animal feed	1.4
MNA	Sustainable design of the manufacturing plant, with water management, solar energy generation, natural ventilation and maximized use of natural lighting	1.3
ALL	Organic product certification through a participatory collective certification, where a group of farmers oversees each other. An official certifying body conducts collective inspections of the entire group	1.5
	Replacement of all plastic packaging with reusable packaging, using their own investment	1.4 and 1.5

Source: Table by authors

Table 5. Identification of circular supply chain practices

stakeholders in achieving sustainable goals. Circular practices for environmental performance and economic performance were present in most of the researched foodtechs. Particularly noteworthy are the use of returnable and biodegradable packaging, even though the added value of these products is higher than standard packaging.

Another highlight is the extensive knowledge of sustainable production techniques, such as soil management, crop rotation, the use of environment-friendly fertilizers through waste composting, among others. These practices are excellent ways to drastically reduce waste generation and reduce the ecological footprint (Al-Sheyadi, Muyldermans, & Kauppi, 2019).

Foodtech	Category	Technology	Practice
XYZ	Digital	Internet of Things (IoT)	Enhanced support for supplier and customer management through mobile applications
APX	Digital	Big data	Support for advanced research
	Digital	Internet of Things (IoT)	Monitoring of local producers through mobile and computer applications, with indicators of regeneration and sustainability
	Digital	Cloud computing	Management of all operations in the cloud
MMN	Digital	Cloud computing	Management of all operations in the cloud. Cloud computing: description on product packaging through QR codes, providing consumers with ingredient traceability and information about the producer's community location
FBN	Digital	Cloud computing	Cloud-based enterprise resource planning (ERP) system
ALL	Digital	Internet of Things (IoT)	Sales through WhatsApp and Instagram, with algorithmic support for product promotion through digital menus

Source: Table by authors

Table 6. Identification of Industry 4.0 technologies

The study identified innovative use of I4.0 technologies, such as the use of QR codes for ingredient traceability and the sale of products through apps such as WhatsApp and Instagram. These practices demonstrate the adaptability of foodtechs and their ability to explore new ways of engaging with customers and suppliers, as well as creating added value to products.

The foodtech LAA provided an example of a closed-loop production in its daily operations: "Our processes, for the most part, are cyclical. For example, we compost, and from the compost, we make fertilizer. The fertilizer is used on the plants, and these plants are either consumed by us or sold. What we lose, such as unsold lettuce, and all the excess from the garden, goes to the chickens. The chickens consume them, and the chickens give us eggs, and the cycle continues. Afterward, we eat the eggs, and the eggshells return to the compost bin, and so on. So, this practice of closing the loops has been present in our reality since the beginning of our business." This example shows how companies will have to reorient themselves around the principles of the CE, especially in their supply chains, abandoning traditional linear methods (Urbinati, Chiaroni, & Chiesa, 2017).

However, the high financial costs of these new technologies still represent a significant challenge for their adoption, especially for small and medium-sized enterprises with more limited resources. This finding is supported by Neri et al. (2023), who describe how the adoption of I4.0 technologies can enable the implementation of CE practices but remains a challenge for small and medium-sized enterprises. Foodtech XYZ highlighted this difficulty by stating, "In the industrial part, there are ways to improve with automation. But industry is quite complicated; it requires a lot of investment." Despite the efforts in using I4.0 technologies in foodtechs, digital practices are still in their infancy, especially concerning interaction with CSC. Digital practices were categorized according to Schwab (2016), with applications, both on mobile phones and computers, categorized as IoT, which connect products and people to the internet, collecting data and generating new information (Ranta, Aarikka-Stenroos, & Väisänen, 2021).

It became evident that in the researched foodtechs, the three problems addressed by the stakeholder theory (Freeman et al., 2010) are present in their daily operations. Regarding the first issue, which consists of understanding how value is created and negotiated, some points of alignment among the companies can be enumerated. First, concerning the interaction of the main participants in the CSC, the value creation of this process still lacks significant improvements. This is because circular practices, despite being considered important and already being practiced in many processes, are still seen as costly for these companies. This economic factor is further exacerbated by the use of I4.0 technologies, as all interviewees considered these technologies to be expensive for implementation and use. Thus, the use of these technologies in CSC is still in its infancy, despite being considered of vital importance for the future of companies.

Regarding the second issue, which concerns the connection of ethics with capitalism, this was strongly evident in foodtechs. I4.0 technologies tend to support this connection because they generate transparency in processes and transactions for all stakeholders. Thus, all links in the food CSC tend to use ethics, always aiming for economic results in the process.

Based on these findings, the third problem of stakeholder theory, which is management so that the first two problems are resolved, becomes challenging for foodtechs, as these companies are still growing, and the profitability of their products is still the main objective. It is evident in the researched companies the engagement of stakeholders, as verified in Foodtech XYZ and MMN, where they describe the need for support from the community, customers, NGOs, among others, as stated: "The local agriculture community, customers, and investors who have this CE mindset, NGOs, organic certification bodies, biodiversity certification bodies, we are already in talks with them." Thus, these responses to the three stakeholder theory questions are summarized in Table 7, describing the issue, the stakeholders involved and the possible answer to the question.

It is evident that CE and I4.0 are being combined to create more sustainable and restorative industrial paradigms. These technologies are seen as important tools for the circular transition in organizations, bringing benefits such as increased transparency and visibility in processes, improved data collection, and greater resource efficiency. Even with limited financial resources, foodtech companies consider these technologies a priority for implementation in their supply chains.

Table 8 presents six interfaces that use I4.0 technologies, but only five of the eight companies surveyed use these technologies. This suggests that there is still a long way to go

Table 7. Summary of findings on stakeholder theory questions

Stakeholder theory questions	Involved stakeholder	Response
How is value created and negotiated?	Main participants in the circular supply chain	Value creation in this area still requires significant improvements due to the high costs of circular practices and Industry 4.0 technologies
Connecting ethics with capitalism	Customers, community, NGOs, among others	Ethics are being strengthened by Industry 4.0 technologies, creating transparency and ethics in transactions
Management to address the first two problems	Engagement of various stakeholders, such as the community, customers and investors	Stakeholder engagement is crucial but challenging, especially for foodtechs seeking growth and profitability

Source: Table by authors

Interfaces	Stakeholders involved	Fundamental authors
Big data supporting research for procuring new suppliers with the aim of increasing circularity in supply chains	3.4 – SP	Castelo-Branco et al. (2019)
Utilization of the Internet of Things (IoT) through applications for purchasing, selling and monitoring suppliers in circular metrics	3.4 – SP	Culot et al. (2020); Ejsmont et al. (2020)
Sharing platforms for data and information through IoT among supply chain members, enabling flexible and responsive evaluation of product life cycles and using available data in the supply chai	3.1 – SI 3.2 – EP 3.4 – SP 3.5 – MN	Zhang et al. (2020)
Virtualization of internal processes through cloud computing	3.2 – EP	Zhang et al. (2020)
Use of mobile devices through IoT for tracking the return of reusable packaging	3.3 – CU	Neri et al. (2023)
Traceability of the entire circular production process through cloud computing	3.2 – EP 3.3 – CU 3.4 – SP 3.5 – MN	de Sousa Jabbour et al. (2018)

Source: Table by authors

Table 8. Interfaces between circular supply chains, Industry 4.0 and primary stakeholders

for these small companies. The table shows the interfaces identified between I4.0 technologies and CSC in the surveyed foodtechs, considering the key stakeholders in the sector. It presents the identified interfaces, the stakeholders involved and the authors who support these findings.

With these findings, it is evident that I4.0 technologies and CE principles are increasingly valued by foodtech companies, despite the financial challenges they face. The implementation of these technologies brings benefits such as greater resource efficiency, transparency in processes and more precise data collection. It is important to note that there is still a long way to go for the implementation of other technologies, but the results obtained show a synergy between CSC and I4.0 through stakeholders. These findings validate the interfaces described in the relationship diagram and address the main objective of the study.

Based on the results presented and considering the proposed relationship diagram, it can be concluded that the surveyed foodtechs are adopting circular practices in their supply chains and are using I4.0 technologies to support these practices. These findings are in line with the analysis categories of CSC and I4.0 presented by Khan et al. (2022) and Schwab (2016), respectively. Regarding the involvement of stakeholders, suppliers, customers, employees and managers were identified as the main participants in the process of implementing circular practices and adopting I4.0 technologies in the supply chain. This corroborates the stakeholder theory, grounded by Freeman (1984), Clarkson (1995) and Mitchell et al. (1997), which emphasizes the importance of considering the needs and expectations of all stakeholders in business decision-making.

The selected companies indeed represent noteworthy examples of circular food supply chains. They have demonstrated effective circular practices without heavy reliance on advanced technologies or extensive involvement from institutional stakeholders. These companies have managed to prioritize sustainability and circularity even in the absence of significant financial resources and institutional support, showcasing their commitment to more environmentally friendly and efficient food supply chains.

5. Conclusions

This study aimed to identify the interfaces between CE and I4.0 technologies in foodtechs through the analysis of key stakeholders in the sector. Six interfaces between the two theoretical fields were identified, with a focus on efficiency in circular production chains, engagement of strategic stakeholders, value creation for foodtechs, and the importance of I4.0 technologies for resource circularity. Based on the analysis of the results, it can be concluded that the surveyed foodtechs have great potential for implementing circular practices in their supply chains, as well as for adopting I4.0 technologies. Although foodtechs are still in the developmental stage, various circular practices are being implemented by the companies, such as the use of recycled packaging, reduction of food waste and prioritization of local suppliers.

These actions indicate a new approach to resource management, introducing an innovative perspective on sustainable development and value creation (Dantas et al., 2021). In addition, collaboration with local suppliers and practices of industrial symbiosis, such as the exchange of materials and resources, contributes to waste reduction and the sustainability of operations (Cagno, Negri, Neri, & Giambone, 2023). This understanding is reflected in sustainable production practices, such as soil management, planting cycles, the use of environment-friendly fertilizers and waste composting. These practices reduce waste generation and decrease the ecological footprint (Al-Sheyadi et al., 2019).

Furthermore, an innovative use of I4.0 technologies was observed, such as ingredient traceability through QR codes and the sale of products through messaging apps. These practices highlight the ability of foodtechs to explore new ways of interacting with customers and suppliers, adding value to their products. A notable example is Foodtech LAA, which demonstrated a closed-loop system in its operations, minimizing waste and maximizing resource efficiency. This example illustrates the need for reorientation toward CE principles, abandoning traditional linear approaches (Urbinati et al., 2017).

Regarding the specific objectives, it was possible to describe 16 CSC practices in the surveyed foodtechs, which addressed the first objective. In the second objective, three I4.0 technologies already used by the companies were identified. Finally, the third objective was achieved by answering the three questions of the stakeholder theory (Freeman et al., 2010) by identifying the stakeholders and interfaces between I4.0 technologies and CSC. Thus, it can be concluded that this study achieved its specific objectives and brought important practical, managerial, theoretical and social contributions to the context of Brazilian foodtechs regarding the interfaces between I4.0 technologies and CSC.

The practical contribution of this research includes evidence that I4.0 technologies can generate efficiency in the circular production chains of foodtechs, even though the acquisition of these technologies represents a significant investment and is still in its early stages in the surveyed companies. In addition, engagement of strategic stakeholders is essential to optimize circular production chains in foodtechs in Brazil, and resource circularity can create value when supported by I4.0 technologies.

The managerial contribution of this research is the realization that the surveyed foodtechs, despite implementing various CE practices in their supply chains, are still in the developmental stage and require more investment in research and their supply chains. An integrated approach combining I4.0 technologies and CE is needed to maximize the sustainability of production chains in foodtechs.

The main theoretical contribution of this study is the combination of two emerging theoretical fields, CE and I4.0, with a consolidated theory, stakeholder theory. This combination of concepts is still underexplored in academic literature, and the research brought these new concepts to light in the context of early-stage Brazilian foodtechs in the implementation of I4.0 technologies and circular practices in their supply chains. The work contributes to filling theoretical gaps identified in previous studies, especially in the Brazilian context of small and medium-sized enterprises (Geissdoerfer et al.; 2017; Gupta et al., 2021; Bag & Pretorius, 2022; Khan et al., 2022; Rok & Kulik, 2021; Chaudhuri et al., 2022; Silva & Sehnem, 2022a, 2022b).

The social contribution of this research is the realization that foodtechs, even in the early stages of using I4.0 technologies due to their high cost, are already aware that stakeholder engagement in their circular practices is possible, both in their supply chains and within their organizations. This can lead to greater awareness of the importance of sustainability and CE in Brazilian companies. Furthermore, the use of I4.0 technologies can promote greater social inclusion by increasing resource efficiency, reducing waste and generating more jobs and improved quality of life for local communities.

The limitations of the study primarily include the small number of surveyed companies, which may limit the generalization of results to the foodtech sector. In addition, many of the surveyed companies are still in the early stages of implementing I4.0 technologies, which may result in a limited analysis of the interfaces between CE and I4.0 in these organizations. Another limitation may be researcher bias, which could have influenced the interpretation of results. Moreover, it is important to note that the research was conducted in a Brazilian context, and the conclusions may not be generalizable to other countries or regions with different realities. Finally, the study presents a predominantly qualitative perspective, which may limit the quantitative understanding of the relationships between CE and I4.0.

As suggestions for future studies, a more detailed analysis of how foodtechs are dealing with the implementation of I4.0 technologies in their CSC could be conducted. In addition, a comparison between the surveyed foodtechs and companies from other sectors could be made to determine whether the interfaces between I4.0 technologies and CSC are similar or different in different business contexts. This could contribute to a better understanding of how these interfaces work and what factors influence their success in different types of organizations.

In this way, this study contributes to the understanding of the interfaces between CE and I4.0 in Brazilian foodtechs, identifying key circular practices in supply chains, the adoption of I4.0 technologies by companies and how foodtechs respond to the questions raised by stakeholder theory. Furthermore, practical, managerial and social contributions of this study were presented, as well as its limitations and suggestions for future research.

References

Al-Sheyadi, A., Muyldermans, L., & Kauppi, K. (2019). The complementarity of green supply chain management practices and the impact on environmental performance. *Journal of Environmental Management*, *242*, 186–198, doi: https://doi.org/10.1016/j.jenvm an. 2019._04._078.

Associação Brasileira de Startups (ABSTARTUPS). (2023). Retrieved from www.abstartups.com.br/ (accessed 23 November 2023).

Bag, S., & Pretorius, J. H. C. (2022). Relationships between Industry 4.0, sustainable manufacturing and circular economy: Proposal of a research framework. *International Journal of Organizational Analysis*, *30*(4), 864–898, doi: https://doi.org/10.1108/ijoa-04-2020-2120.

Batista, L., Dora, M., Garza-Reyes, J. A., & Kumar, V. (2021). Improving the sustainability of food supply chains through circular economy practices–A qualitative mapping approach. *Management of*

Environmental Quality: An International Journal, *32*(4), 752–767, doi: https://doi.org/10.1108/MEQ-09-2020-0211.

Beltrami, M., Orzes, G., Sarkis, J., & Sartor, M. (2021). Industry 4.0 and sustainability: Towards conceptualization and theory. *Journal of Cleaner Production*, *312*, 127733, doi: https://doi.org/10.1016/j.jclepro.2021.127733.

Braz, A. C., & de Mello, A. M. (2023). Supply chain management strategies, types and tactics for circular economy transitions. *Management Review Quarterly*, doi: https://doi.org/10.1007/s11301-023-00354-4.

Cagno, E., Negri, M., Neri, A., & Giambone, M. (2023). One framework to rule them all: An integrated, multi-level and scalable performance measurement framework of sustainability, circular economy and industrial symbiosis. *Sustainable Production and Consumption*, *35*, doi: https://doi.org/10.1016/j.spc.2022.10.016.

Castelo-Branco, I., Cruz-Jesus, F., & Oliveira, T. (2019). Assessing Industry 4.0 readiness in manufacturing: Evidence for the European Union. *Computers in Industry*, *107*, 22–32, doi: https://doi.org/10.1016/j.compind.2019.01.007.

Chaudhuri, A., Subramanian, N., & Dora, M. (2022). Circular economy and digital capabilities of SMEs for providing value to customers: Combined resource-based view and ambidexterity perspective. *Journal of Business Research*, *142*, 32–44, doi: https://doi.org/10.1016/j.jbusres.2021.12.039.

Chen, Z., Yildizbasi, A., & Sarkis, J. (2023). How safe is the circular economy? *Resources, Conservation and Recycling*, *188*, 106649, doi: https://doi.org/10.1016/j.resconrec.2022.106649.

Circle Economy. (2023). *The circularity gap report (2023)*, Amsterdam: Circle Economy. Rep., pp. 1–64.

Clarkson, M. B. E. (1995). A stakeholder framework for analyzing and evaluating corporate social performance. *The Academy of Management Review*, *20*(1), 92–117, doi: https://doi.org/10.2307/258888.

Culot, G., Nassimbeni, G., Orzes, G., & Sartor, M. (2020). Behind the definition of Industry 4.0: Analysis and open questions. *International Journal of Production Economics*, *226*, 107617, doi: https://doi.org/10.1016/j.ijpe.2020.107617.

Dantas, T. E. T., de-Souza, E. D., Destro, I. R., Hammes, G., Rodriguez, C. M. T., & Soares, S. R. (2021). How the combination of circular economy and Industry 4.0 can contribute towards achieving the sustainable development goals. *Sustainable Production and Consumption*, *26*, 213–227, doi: https://doi.org/10.1016/j.spc.2020.10.005.

de Sousa Jabbour, A. B. L., Jabbour, C. J. C., Godinho Filho, M., & Roubaud, D. (2018). Industry 4.0 and the circular economy: A proposed research agenda and original roadmap for sustainable operations. *Annals of Operations Research*, *270*(1-2), 273–286, doi: https://doi.org/10.1007/s10479-018-2772-8.

Del Giudice, M., Chierici, R., Mazzucchelli, A., & Fiano, F. (2021). Supply chain management in the era of circular economy: The moderating effect of big data. *The International Journal of Logistics Management*, *32*(2), 337–356, doi: https://doi.org/10.1108/IJLM-03-2020-0119.

Donaldson, T., & Preston, L. E. (1995). The stakeholder theory of the corporation: Concepts, evidence and implications. *The Academy of Management Review*, *20*(1), 65–91, doi: https://doi.org/10.5465/amr.1995.9503271992.

Ejsmont, K., Gladysz, B., & Kluczek, A. (2020). Impact of industry 4.0 on sustainability—Bibliometric literature review. *Sustainability*, *12*(14), 5650, doi: https://doi.org/10.3390/su12145650.

Elkington, J. (1994). Towards the sustainable corporation: Win-win-win business strategies for sustainable development. *California Management Review*, *36*(2), 90–100, doi: https://doi.org/10.2307/41165746.

Ellen MacArthur Foundation. (2015). Towards the circular economy. Retrieved from https://archive.ellenmacarthurfoundation.org (accessed 08 March 2023).

Ellen MacArthur Foundation. (2019). Cities and circular economy for food. Retrieved from https://archive.ellenmacarthurfoundation.org (accessed 10 March 2023).

Ellen MacArthur Foundation. (2021). The big food redesign: Regenerating nature with the circular economy. Retrieved from https://archive.ellenmacarthurfoundation.org (accessed 03 March 2023).

Esposito, B., Sessa, M. R., Sica, D., & Malandrino, O. (2020). Towards circular economy in the agri-food sector. A systematic literature review. *Sustainability*, *12*(18), 7401, doi: https://doi.org/10.3390/su12187401.

Freeman, R. E. (2010). *Strategic management: a stakeholder approach*, Cambridge University Press.

Freeman, R. E., & Reed, D. L. (1983). Stockholders and stakeholders: A new perspective on corporate governance. *California Management Review*, *25*(3), 88–106 doi: https://doi.org/10.2307/41165018.

Freeman, R. E., & Mcvea, J. (2001). A stakeholder approach to strategic management. *SSRN Electronic Journal*, doi: https://doi.org/10.2139/ssrn.263511.

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The circular economy – a new sustainability paradigma? *Journal of Cleaner Production*, *143*, 757–768, doi: https://doi.org/10.1016/j.jclepro.2016.12.048.

Gupta, H., Kumar, A., & Wasan, P. (2021). Industry 4.0, cleaner production and circular economy: An integrative framework for evaluating ethical and sustainable business performance of manufacturing organizations. *Journal of Cleaner Production*, *295*, 126253, doi: https://doi.org/10.1016/j.jclepro.2021.126253.

Khan, S. A. R., Piprani, A. Z., & Yu, Z. (2022). Digital technology and circular economy practices: Future of supply chains. *Operations Management Research*, *15*(3-4), 676–688, doi: https://doi.org/10.1007/s12063-021-00247-3.

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*(12), 221–232, doi: https://doi.org/10.1016/j.resconrec.2017.09.005.

Liga Insights FoodTechs. (2023). Retrieved from https://liga.ventures/insights/relatorios/a-evolucao-das-startups-no-setor-de-food-techs-2021-2022/ (accessed 24 November 2023).

Liu, L., Song, W., & Liu, Y. (2023). Leveraging digital capabilities toward a circular economy: Reinforcing sustainable supply chain management with Industry 4.0 technologies. *Computers & Industrial Engineering*, *178*, doi: https://doi.org/10.1016/j.cie.2023.109113.

Mani, V., Jabbour, C. J. C., & Mani, K. T. (2020). Supply chain social sustainability in small and medium manufacturing enterprises and firms' performance: Empirical evidence from an emerging asian economy. *International Journal of Production Economics*, *227*, 107656, doi: https://doi.org/10.1016/j.ijpe.2020.107656.

Massaro, M., Secinaro, S., Dal Mas, F., Brescia, V., & Calandra, D. (2021). Industry 4.0 and circular economy: An exploratory analysis of academiand practitioners perspectives. *Business Strategy and the Environment*, *30*(2), 1213–1231, doi: https://doi.org/10.1002/bse.2680.

Mitchell, R. K., Agle, B. R., & Wood, D. J. (1997). Toward a theory of stakeholder identification and salience: Defining the principle of who and what really counts. *The Academy of Management Review*, *22*(4), 853–886, doi: https://doi.org/10.2307/259247.

Nascimento, D. L. M., Alencastro, V., Quelhas, O. L. G., Caiado, R. G. G., Garza-Reyes, J. A., Lona, L. R., & Tortorella, G. (2018). Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context. *Journal of Manufacturing Technology Management*, *30*(3), 607–627, doi: https://doi.org/10.1108/JMTM-03-2018-0071.

Parmar, B. L., Freeman, R. E., Harrison, J. S., Wicks, A. C., Purnell, L., & De Colle, S. (2010). Stakeholder theory: The state of the art. *Academy of Management Annals*, *4*(1), 403–445, doi: https://doi.org/10.5465/19416520.2010.495581.

Ranta, V., Aarikka-Stenroos, L., & Väisänen, J. M. (2021). Digital technologies catalyzing business model innovation for circular economy—Multiple case study. *Resources, Conservation and Recycling*, *164*, 105155, doi: https://doi.org/10.1016/j.resconrec.2020.105155.

Rok, B., & Kulik, M. (2021). Circular start-up development: The case of positive impact entrepreneurship in Poland. *Corporate Governance: The International Journal of Business in Society*, *21*(2), 339–358, doi: https://doi.org/10.1108/CG-01-2020-0043.

Rowley, T. J. (1997). Moving beyond dyadic ties: A network theory of stakeholder influences. *The Academy of Management Review*, *22*(4), 887–910, doi: https://doi.org/10.2307/259248.

Schwab, K. (2016). *A quarta revolução industrial*, São Paulo: Edipro. ISBN 978-85-7283-978-5.

Sehnem, S., Provensi, T., da Silva, T. H. H., & Pereira, S. C. F. (2022). Disruptive innovation and circularity in start-ups: A path to sustainable development. *Business Strategy and the Environment*, *31*(4), 1292–1307, doi: https://doi.org/10.1002/bse.2955.

Silva, T. H. H., & Sehnem, S. (2022a). The circular economy and Industry 4.0: Synergies and challenges. *Revista de Gestão*, *29*(3), 300–313, doi: https://doi.org/10.1108/REGE-07-2021-0121.

Silva, T. H. H., & Sehnem, S. (2022b). Industry 4.0 and the circular economy: Integration opportunities generated by startups. *Logistics*, *6*(1), 14, doi: https://doi.org/10.3390/logistics6010014.

Tavera Romero, C. A., Castro, D. F., Ortiz, J. H., Khalaf, O. I., & Vargas, M. A. (2021). Synergy between circular economy and Industry 4.0: A literature review. *Sustainability*, *13*(8), 4331, doi: https://doi.org/10.3390/su13084331.

Urbinati, A., Chiaroni, D., & Chiesa, V. (2017). Towards a new taxonomy of circular economy business models. *Journal of Cleaner Production*, *168*, 487–498, doi: https://doi.org/10.1016/j.jclepro.2017.09.047.

Vegter, D., van Hillegersberg, J., & Olthaar, M. (2020). Supply chains in circular business models: Processes and performance objectives. *Resources, Conservation and Recycling*, *162*, 105046, doi: https://doi.org/10.1016/j.resconrec.2020.105046.

Yin, R. K. (2010). *Estudo de caso: planejamento e métodos*, Porto Alegre: Bookman.

Zhang, A., Zhong, R. Y., Farooque, M., Kang, K., & Venkatesh, V. G. (2020). Blockchain-based life cycle assessment: An implementation framework and system architecture. *Resources, Conservation and Recycling*, *152*, 104512, doi: https://doi.org/10.1016/j.resconrec.2019.1045.

Zhu, Q., Bai, C., & Sarkis, J. (2022). Blockchain technology and supply chains: The paradox of the atheoretical research discourse. *Transportation Research Part E: Logistics and Transportation Review*, *164*, 102824, doi: https://doi.org/10.1016/j.tre.2022.102824.

Author contributions: Tiago Hennemann Hilario da Silva Conceptualization (equal), methodology (equal), investigation (equal), formal analysis (equal), validation (equal), writing – original draft (equal), writing – review & editing (equal). Simone Sehnem conceptualization (equal), methodology (equal), investigation (equal), formal analysis (equal), validation (equal), writing – original draft (equal), writing – review & editing (equal).

Corresponding author
Tiago Hennemann Hilario da Silva can be contacted at: tiago.hennemann.dasilva@gmail.com