THE CIRCULAR ECONOMY IN THE AGE OF THE 4TH INDUSTRIAL REVOLUTION – THE USE OF TECHNOLOGY TOWARDS TRANSITION

A ECONOMIA CIRCULAR NA ERA DA 4ª REVOLUÇÃO INDUSTRIAL – USO DA TECNOLOGIA RUMO À TRANSIÇÃO

LA ECONOMÍA CIRCULAR EN LA ERA DE LA CUARTA REVOLUCIÓN INDUSTRIAL - EL USO DE LA TECNOLOGÍA HACIA LA TRANSICIÓN

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Scientific Editor: José Edson Lara
Organization Scientific Committee
Double Blind Review by SEER/OJS
Received on 18/07/2022
Approved on 14/11/2022

Abstract

Objective: Propose to seek the critical understanding of the quality of evidence of the correlation between "Industry 4.0" and "Circular Economy" for implementing sustainable business processes.

Approach: The method adopted was a systematic review of the literature through a selective search in the CAFe database from CAPES journals, in the search "Subject", which includes all the available search bases.

Relevance: As for sustainability, the "Circular Economy" and "Industry 4.0", although they have different concepts, origins, and fundamentals, they connected to the viability of business models in the face of the socio-environmental, economic, and technological requirements of a current globalised ecosystem.

Main results: There has been a significant increase in the number of publications in the last three years (2019-2021), reflecting the interest in the topic through the development of scientific studies.

Theoretical contribution: The study presents the "Industry 4.0" brings several features that can support the transition to a "Circular Economy" system, rethinking practices of society's economic organization**.**

Contribution to management: The proposed process mainly contributes bringing from the Industry 4.0 several features that can support the transition to a "Circular Economy", given that the latter needs advanced resources for its implementation.

Keywords – Circular Economy; Industry 4.0; Sustainability; Systematic Literature Review; Triple Bottom Line.

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Resumo

Objetivo do Estudo: Propor a busca da compreensão crítica da qualidade das evidências da correlação entre "Indústria 4.0" e "Economia Circular" para a implementação de processos de negócios sustentáveis.

Abordagem: O método adotado foi uma revisão sistemática da literatura por meio de uma busca seletiva no banco de dados de CAFe do periódicos da CAPES, na busca "Assunto", que inclui todas as bases de busca disponíveis.

Relevância: Quanto à sustentabilidade, a "Economia Circular" e a "Indústria 4.0", apesar de possuírem conceitos, origens e fundamentos diferenciados, vincularam-se à viabilidade dos modelos de negócios frente às exigências tecnológicas de um ecossistema globalizado atual.

Principais resultados: Houve um aumento significativo no número de publicações nos últimos três anos (2019-2021), refletindo o interesse pelo tema através do desenvolvimento de estudos científicos.

Contribuição teórica: O estudo apresenta que a "Indústria 4.0" traz diversas características que podem subsidiar a transição para um sistema de "Economia Circular", repensando práticas de organização econômica da sociedade.

Contribuição para a gestão: O processo proposto contribui principalmente trazendo da Indústria 4.0 diversas funcionalidades que podem apoiar a transição para uma "Economia Circular", uma vez que esta necessita de recursos avançados para a sua implementação.

Palavras-chave – Economia Circular; Indústria 4.0; Sustentabilidade; Revisão Sistemática da Literatura; Tripé da Sustentabilidade.

Resumen

Objetivo: Proponer buscar la comprensión crítica de la calidad de la evidencia de la correlación entre la "Industria 4.0" y la "Economía Circular" para implementar procesos de negocio sostenibles.

Enfoque: El método adoptado fue una revisión sistemática de la literatura a través de una búsqueda selectiva en la base de datos CAFe de las revistas CAPES, en la búsqueda "Asunto", que incluye todas las bases de búsqueda disponibles.

Relevancia: En cuanto a la sostenibilidad, la "Economía Circular" y la "Industria 4.0", aunque tienen diferentes conceptos, orígenes y fundamentos, se conectaron a la viabilidad de los modelos de negocio frente a los socioambientales, económicos, y las necesidades tecnológicas de un ecosistema globalizado actual.

Principales resultados: Ha habido un aumento significativo en el número de publicaciones en los últimos tres años (2019-2021), reflejando el interés en el tema a través del desarrollo de estudios científicos.

Contribución teórica: El estudio presenta la "Industria 4.0" trae varias características que pueden apoyar la transición a un sistema de "Economía Circular", repensando las prácticas de la organización económica de la sociedad.

Contribución a la gestión: El proceso propuesto contribuye principalmente a traer de la Industria 4.0 varias características que pueden apoyar la transición a una "Economía Circular", dado que esta última necesita recursos avanzados para su implementación.

Palabras clave – Economía Circular; Industria 4.0; Sostenibilidad; Revisión Sistemática de la Literatura; Triple Balance.

1. INTRODUCTION

The Fourth Industrial Revolution, with "Industry 4.0", brought the convergence of various information technologies to consolidate more effective and efficient industries, thus making them "smart factories". The elevated level of digital informatization and technological development brought by this Fourth Industrial Revolution makes a broad expansion of productive processes possible. However, this generated expansion also points to environmental accounting challenges arising from the impacts on the environment inherited from linear models of economic growth. This linear model of the economy, based on consumption, possession, and easy access to resources, has brought and continues to bring about the depletion of natural resources, the accumulation of waste and toxicity throughout the production chain.

The answer to this dilemma (problem) with "Industry 4.0" is, again, the "Circular Economy". The "Industry 4.0" and the "Circular Economy" are different concepts with different origins and foundations. However, digital, and advanced technologies typical of "Industry 4.0" can enable the implementation of the circular economy. It is interesting to note that digitalization is essential for its own sake as it helps industries keep their market competitiveness. Meanwhile, the circular economy still refers to a paradigm shift in production and business models.

The shift to a "Circular Economy" with "Industry 4.0" technologies constitutes an opportunity for companies, consumers, government, and other actors to understand this model and cooperate to meet an increasingly competitive market with ecological requirements.

The development of this work (Table 1) started with a guiding question: 'Does "Industry 4.0" enable the "Circular Economy" through greater control of the design in the production process and its impacts as a whole?' The hypothesis that is given as an answer to this motivating question is an affirmative, as the convergence between the "Circular Economy" and "Industry 4.0" is essential for the sustainability of processes and services in modern administration. This guiding question deals with these central themes of this study and seeks to evaluate the relationship between them, as enabling forces of one before the other. Thus, the literature review deals with both themes to develop a conceptual and historical knowledge base. In the discussion of results, distinct aspects are presented to deal with the relationships/inter-relationships between the concepts of "Circular Economy" and "Industry 4.0". In conclusion, we offer the final considerations that show where we are in the context of the "Circular Economy" – "Industry 4.0" and where we want to go.

2. THEORETICAL FRAMEWORK

2.1. The Circular Economy -historical context and conceptualization

The first definitions of "Circular Economy" appeared in the 1970s in Switzerland with Walter R. Stahel in the Cycle Thinking or Performance Economics; in the USA with Robert Frosch and Nicholas Gallopoulos in the Industrial Ecology in the USA; the concept of Industrial Symbiosis in Japan; and Jhon T. Lyle's concept of Regenerative Design. In the 1990s, the idea of a "Circular Economy" was addressed by Jhon Elkington's Triple Bottom Line through the economic idea of sustainability and by Janine Benyus's Biomimetics. From 2000 on, the idea of "Circular Economy" was described in Michael Braungart's Cradle to Cradle, written in co-authorship with William McDonough and a popular source for the world's ecological thinking in 2002, and it was finally defined by Ellen MacArthur Foundation's as "Circular Economy" in 2010 (Ellen MacArthur Foundation A, 2021; CIESP, 2020). Figure 1 presents the timeline of the various researchers' contributions to the development of the "Circular Economy".

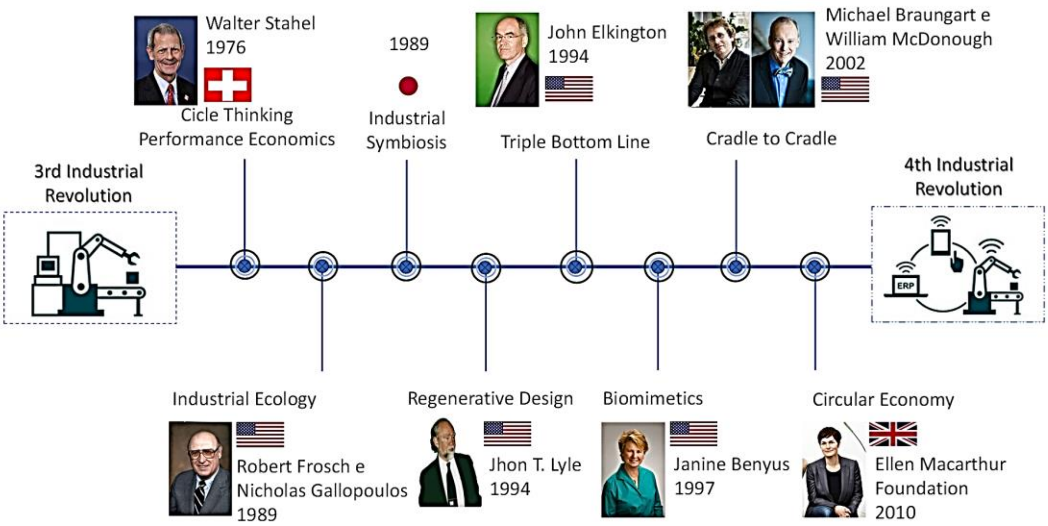

Figure 1. Timeline of the leading worldwide concepts that emerged for the "Circular Economy".
Source: Prepared by the author (2022).

In the late 1970s, Walter Stahel, architect, and economist, outlined in his research report for the European Commission "The potential to replace labor with energy", the vision of a Cycle Economy and its impact on creating employment, economic competitiveness, resource reduction and waste prevention. Stahel thought that if people continued to increase consumption, there would be big problems in the future, so the linear economy was not sustainable due to increased demand for raw materials and the accumulation of waste. Therefore, he suggested closing the material cycles by studying and developing commercial cases in the following years (Ellen MacArthur Foundation A, 2021; Sehnem & Pereira, 2019).

Analogies were created with materials and energy flows in natural ecosystems to argue that the means to generate sustainable development occur via the materials cycle and through the exchange of by-products and waste. In the field of Industrial Ecology, the article "Manufacturing Strategies", by Robert Frosch and Nicholas Gallopoulos, published in 1989 in

Scientific American, was one of the first references for elaborating this concept. The focus of this analysis is the sustainability of the flows of resources between companies since the flows are the possible agents of environmental improvement and have the technological knowledge for executing the environmentally intelligent design of products and processes. This way, economies would no longer be linear and must become circular.

As part of Industrial Ecology, the concept of Industrial Symbiosis placed Japan as one of the pioneer countries in addressing this issue. In the late 1960s, the Japanese government hired an independent consultancy to investigate possibilities of orienting the country's economy towards activities based on information and knowledge, with a lower degree of dependence on the consumption of materials.

An example of Industrial Symbiosis is the eco-industrial park in Kalundborg, Denmark, recognized as a successful case in which companies exchange materials and energy for input, forming a closed production cycle. Since 1972 other companies have joined Symbiosis Kalundborg, and in 1989, the term Industrial Symbiosis was used for the first time to describe a collaboration between companies (NEITEC, 2021).

Industrial Symbiosis involves cooperation, collaboration, sharing and the possibility of synergy between different sectors of the economy (industry), property, geography (facilities), or function (activities and processes) in a collective approach aiming at a mutually beneficial competitive advantage from the point of view of from an economic and environmental point of view. It involves the physical exchange of materials, energy, water, by-products, infrastructure, and the reuse of waste from one company by another, which converts them into resources, even when company boundaries change over time, through mergers, acquisitions, or long-standing Industrial Symbiosis relationships (Sehnem & Pereira, 2019).

Later, in 1994, Jhon T. Lyle inaugurated the Lyle Center for Regenerative Studies and published the book "Regenerative Design for Sustainable Development". Regenerative Design is a process-oriented approach to design that can be applied to all systems. The term regenerative describes processes that restore, renew, or revitalize their sources of energy and materials, creating sustainable systems that integrate the needs of society with the integrity of nature. The goal of the regenerative project is to develop systems with absolute efficiency that allow the co-evolution of the human species, along with other species (Ellen MacArthur Foundation A, 2021).

The Triple Bottom Line (TBL, 3BL or Sustainability Tripod) model, also dating from 1994, is a concept created by British sociologist John Elkington. The Triple Bottom Line is related to sustainable development strategies that combine the promotion of the economy with environmental preservation, conservation, and social participation. This model shows integration in business with a more significant concern with the economic concept of sustainability, so its implementation creates complementary economic, social, and ecological benefits. In this model, these three dimensions must interact holistically for the company to be sustainable (Khan *et al.*, 2021; Venturini & Lopes, 2015).

The concept of Biomimicry emerged with the launch of the book "Biomimetics: Innovation Inspired by Nature", in 1997 in the United States and 2003 in Brazil, by the American biologist Janine Benyus, one of the founders of the Biomimicry Institute in Montana (USA). Biomimicry is based on existing knowledge of nature. It consists of imitating natural models, systems, and elements in searching for effective and efficient sustainability-oriented solutions to complex human problems. Nature is innovative by necessity; clearly apparent it works and its sustainable character. Nature is seen as a model (in simulations), as a measure (in standards) and as a mentor (in learning). Thus, Biomimicry brought, from the knowledge of nature, the development of a sustainable product design concept (Ellen MacArthur Foundation A, 2021; Leitão, 2015).

In 2002, Cradle to Cradle (C2C), which means "from cradle to cradle", was the title of a book manifesto published by the German chemical engineer Michael Braungart and the American architect William McDonough, which became one of the most influential works in world ecological thought (in Brazil published in 2014). C2C involves keeping all materials in continuous cycles, encouraging the use of renewable energy, and celebrating diversity. "Cradle to cradle" thinking arises in opposition to the idea that a product's life should be considered "from the cradle to the grave" – an expression used in life cycle analysis to describe the linear process. For C2C, resources must be managed by a circular logic of creation and reuse, allowing resources to be used indefinitely circularly in safe and healthy flows. C2C design seeks to eliminate the concept of waste, encourage the use of energy from renewable sources and respect local impacts (Ellen MacArthur Foundation A, 2021; Circular Idea D, 2021).

Although the "Circular Economy" theme appeared in the late 1980s, the concept emerged strongly, on a global scale, only in 2012, when the Ellen MacArthur Foundation published the first of a series of reports entitled "Towards a Circular Economy". In Brazil, discussions about its implementation are even more recent (Azevedo, 2015).

The Ellen MacArthur Foundation, a non-profit organization, was created in 2010. Its mission is to accelerate the transition to the "Circular Economy". It supports the idea that the "Circular Economy" must replace the "end-of-life" with restoration. It would evolve towards the use of renewable energy, eliminating the use of toxic chemicals that harm reuse, as it aims to get rid of waste through a superior design of materials, products, systems, and business models (Leitão, 2015).

This movement within the productive sector aims to adopt the "Circular Economy". It is an evolution of the approach of "cleaner production" practices around the 1990s and the eco-design and projection of "environmentally correct products" around the 2000s. It also fostered "innovation in business models with product integration" around 2010, which evolved into the "Circular Economy". In this line of thinking, innovation becomes systemic, with the formation of a circular business ecosystem that involves the entire chain, as it begins to integrate new stakeholders in addition to traditional consumer companies. Moreover, the consumer in this system has multiple options to choose from (CIESP, 2020).

The "Circular Economy" proposes the circulation of resources through integrated production chains. Disposal moves from waste management to a product and system design process. In this way, the "Circular Economy" consists of an intentionally repairing or regenerative industrial system, which seeks to bring operational and strategic benefits, as well as an enormous potential for innovation, job creation and economic growth (Sehnem & Pereira, 2019).

The Butterfly Diagram is well known within the "Circular Economy" concept. It is a powerful tool for understanding how the "Circular Economy" model is applied in practice, Figure 2. The Butterfly Diagram presents a holistic view of the main model assumptions, the proposed changes, and the various solutions that facilitate the transition from the linear to the Circular model. The Butterfly Diagram was inspired by the model used by the authors of the book "Cradle to Cradle" and was developed by the Ellen MacArthur Foundation. This diagram was used in several of this entity's reports, presentations, and activities (BeeCircular, 2021).

The Butterfly Diagram (Figure 2) is divided into two major areas: the biological cycle (on the left) and the technical cycle (on the right), which present the cyclic flows of materials as Nutrients. The first cycle consists of materials that can be reinserted into nature, in addition to being renewable, can decompose (such as wood, paper, cork, or cotton) consumer products that are, to a substantial extent, regenerated in the biological cycle itself. The second cycle presents the materials that need technology/investment to be reinserted in the process. In addition to being finite, these materials do not decompose, which is why their useful life must be extended to the limit of their capacity (such as aluminum, iron, as plastic) (Assunção, 2019; BeeCircular, 2021).

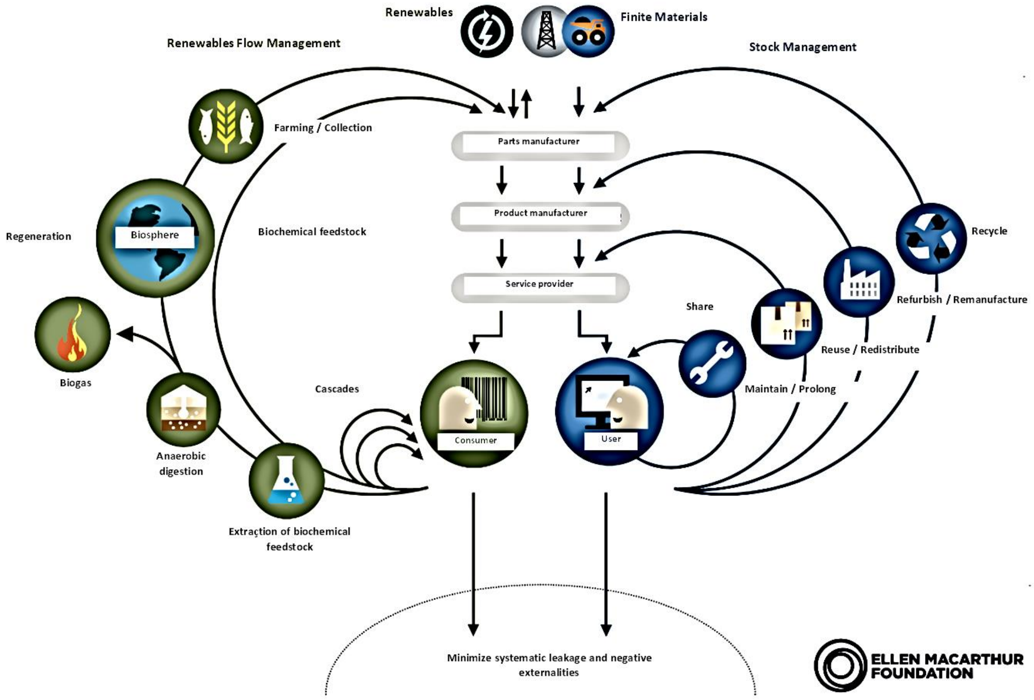

Figure 2. Butterfly diagram, Cradle to Cradle model, to understand the "Circular Economy" model.
Source: Ellen MacArthur Foundation B (2021).

This way, biodegradable materials, or materials obtained from plant matter, become biological nutrients when absorbed by the environment. At the same time, synthetic or mineral materials can be continuously kept in a closed cycle, becoming technical nutrients. When the flow of materials can be constantly maintained in a closed industrial cycle, what has previously been considered waste becomes raw material for another process. In this approach, industrial systems can operate minimally according to the biological cycle of nature, reducing the extraction of raw materials, energy consumption and waste production, and consequently, environmental degradation, thus promoting economic efficiency (Leitão, 2015).

According to the Butterfly Diagram, the "Circular Economy" model has four technical cycles, where materials can be put back into production without losing quality. These four cycles are: a) product maintenance; b) reuse/redistribution – of the used product; c) product upgrade/remanufacture, and d) product recycling. In the minor cycle (product maintenance), the product/material retains the highest value, as it can be applied more times, according to its original purpose. Meanwhile, in the larger cycle (product recycling), the residual value of the product tends to become lower (Sehnem & Pereira, 2019).

The Technical cycle consists of managing finite resources (Technical nutrients). Technical nutrients are recovered and, in most times, restored as they circulate in closed industrial circuits, especially those not produced continuously by the biosphere. So, consumption (as in the biological cycle) is replaced by use. The products incorporated in the technical cycle must be composed of 100% recyclable materials and designed so that their parts can be easily dismantled, and the quality of the materials recovered or improved, ready to be used in the manufacture of new products (Assunção, 2019).

Products and services are designed to circulate efficiently, reducing waste and the need for added resources. Suppose a particular product component cannot be replaced in the production of the company that manufactured it. In that case, it can be transformed by its supplier or an interested third party, thus creating new revenue streams (Azevedo, 2015).

2.2. The Circular economy in Brazil -Transition to the Circular Economy

Today, what is practiced is the Linear Economy, which consists of extracting raw materials from nature, manufacturing goods, distributing, selling, marketing these goods to society, and, when their useful life ends, discarding them (AMB, 2020). In this system, even considering advances in resource efficiency, losses occur along the value chain. In addition, the rapid acceleration of consumption and extractive economies increases negative externalities (Ellen MacArthur Foundation, 2015).

The linear model of the economy, depending on the context in which it operates, is facing increasing challenges, indicating that a more meaningful change in the operating model of the economy is needed. The report "Towards the Circular Economy: The Business Rationale for Accelerating Transition" by the Ellen MacArthur Foundation (2015) points out the following factors that challenge the linear economy: economic losses and structural waste, price risks (volatility), supply risks, degradation of natural systems, regulatory trends (negative externalities), technological advances, acceptance of alternative business models (products as services) and urbanization.

In the linear model, using natural resources does not consider their finitude. Production processes are applied to transform raw materials into products often discarded without considering their proper use. Moreover, there is an increase in waste generation, with detrimental effects on the environment and human health. Conversely, the circular model is based on cyclical processes, in which waste is reinserted into production, either as a source of energy or as by-products. Figure 3 compares linear and circular economy models for the transition of economies, presenting recycling as the first intermediate step between the economies (Assunção, 2019).

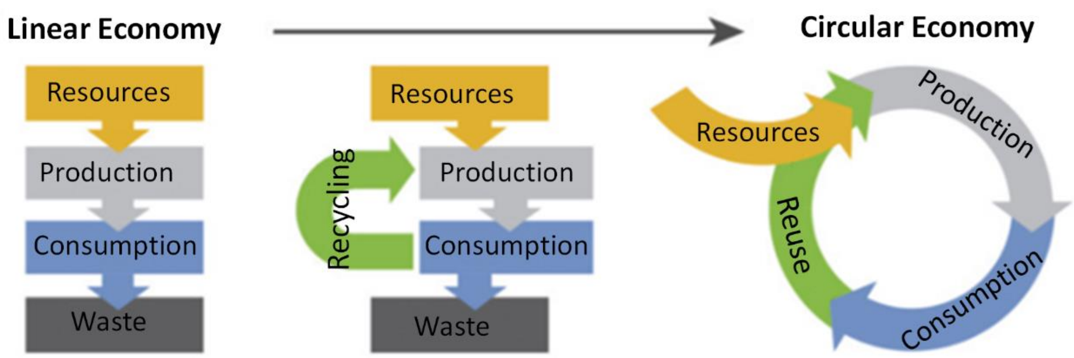

Figure 3. Schematic transition model from the Linear economy to the "Circular Economy".
Source: Assunção (2019).

The "Circular Economy" brings, among other advantages, the reduction of production costs, environmental gains and the fulfilment of requirements established by the countries that import products. For those who export, one of the requirements will be to demonstrate that their company has "Circular Economy" practices (AMB, 2020).

The Circular model aims to manage resources more efficiently throughout the product's life cycle, minimizing or eliminating waste and waste generation and prolonging the product's useful life (Azevedo, 2015).

For the "Circular Economy", there must be a discussion about the product's design to allow its return to manufacturing at the end of its useful life. That way, there will be no discard. This design concept is already in practice by European and some Brazilian industries (AMB, 2020). In this transition context, it is necessary to accelerate the scale of global supply chains without increasing the extraction of (finite) resources while simultaneously promoting their reuse, enabling new business values. So, new business models can be created, incorporating new actors and concepts in the chain, which are the basis of the "Circular Economy" (AMB, 2020).

The "Circular Economy" is not practiced alone, nor is it a matter of marketing. It needs to be genuinely practiced, and the greater the number of parties involved, the greater the chance of advancing with gains for society and the industry. In the long term, this advance will imply social, environmental, cultural, and public policy issues, among others, in a collaborative environment, aiming to benefit all parties involved. (AMB, 2020).

The transition to a "Circular Economy" brings opportunities to all sectors. According to the report "Towards the Circular Economy, the business rationale for accelerating the transition" by the Ellen MacArthur Foundation (2015), these opportunities are: i) economic opportunities: more significant economic growth, substantial net cost reduction, job creation and more innovation; ii) environmental and systemic opportunities: reduction of emissions and consumption of primary materials, preservation and increase of land productivity and reduction of negative externalities; iii) companies opportunities: sets of new and greater profits, greater security of supply and new demand for business services, with the consequent increase in resilience; iv) opportunities for citizens: more usefulness as a result of expanding the range of options, lower prices and lower total property costs.

In a study conducted by the Ellen MacArthur Foundation (2017), entitled "A Circular Economy in Brazil: an initial exploratory approach", preliminary conclusions showed that the transition to the "Circular Economy" in Brazil could generate possibilities for more innovation and value creation. With its unique market, social characteristics, and incomparable natural capital, Brazil is an attractive setting for exploring the opportunities that a "Circular Economy" could bring to developing its economic, social, and natural capital.

It is important to emphasize that macroeconomic research that has already been conducted in other countries indicated that adopting the "Circular Economy" benefits GDP and the level of employment in general. Such opportunities and challenges are common to all economies, such as the importance of leveraging digital technology to take advantage of opportunities in the "Circular Economy" (Ellen MacArthur Foundation, 2017).

2.3. The Fourth Industrial Revolution - The historical context of industrial revolutions

It is interesting to look back at previous industrial revolutions to talk about the Fourth Industrial Revolution (Ideia Circular A, 2021; Teixeira *et al.*, 2020):

- First Industrial Revolution - Industry 1.0 (1760 - 1840). The mechanization of production marked it with the introduction of the steam engine in production processes, productivity gains, formation of large-scale industries.
- Second Industrial Revolution - Industry 2.0 (1850-1945). The use of electrical energy in assembly lines transformed industry and people's lives, as it was used in lighting and industrial engines and machines, changes in production processes with the beginning of series production (mass production) and in the organization of society.
- Third Industrial Revolution - Industry 3.0 (1950 - 2010). Its leading development was the automation of industrial processes by introducing electronics, information technology and computers, while bringing up new business concepts such as lean production.
- Fourth Industrial Revolution - Industry 4.0 (2011 - current). The focus is on digitalization through technological, mechanical, electrical, and electronic enhancements to improve intelligence, bringing greater autonomy in the face of new industry challenges. The convergence of various technologies fosters a fusion between the physical and virtual worlds through the internet.

The importance of industrial revolutions for applying and developing technological solutions, given the industrial paradigms experienced, can be observed over more than 250 years of history. In Figure 4, there is a schematic temporal representation of industrial revolutions and their increasing complexity of demands, technologies, and production processes (Teixeira *et al.*, 2020).

Regarding the Fourth Industrial Revolution, the term "Industry 4.0" emerged in Germany as a strategy for the industry's technological development. It was called "Advanced Manufacturing" by the North Americans and "Industry of the Future" by the French (Sputnik Brasil, 2021).

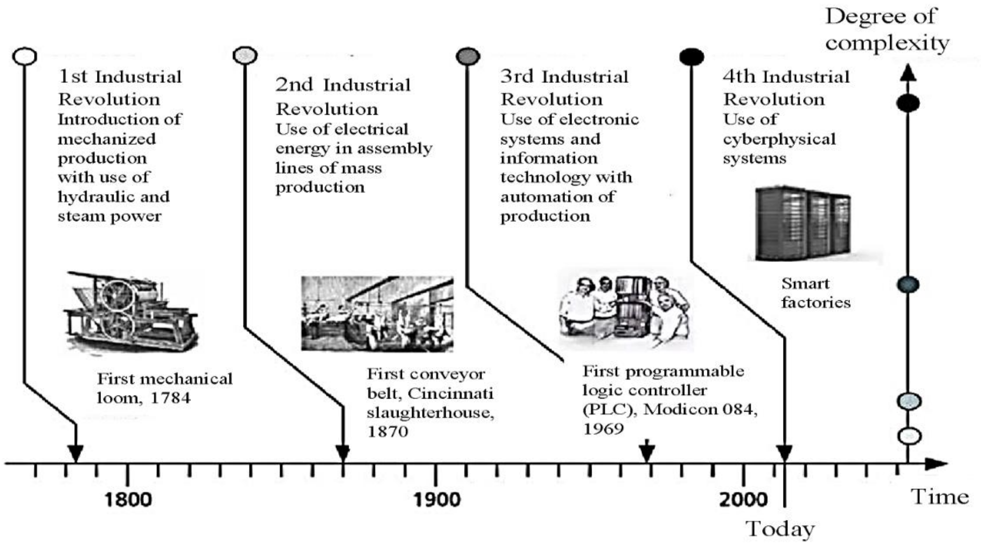

Figure 4. Temporal representation of industrial revolutions versus the degree of complexity of demands, technologies, and processes.
Source: Adapted from Calabrò (2019).

3. METHODOLOGY

The employed research method is classified, in terms of its objectives, as exploratory, seeking in the systematic literature review the foundation for the study topic and the possible construction of a hypothesis. The protocol used was inspired by Davies & Crombie (1998). The authors suggested that the protocol should contain information on the specific issues addressed by the study, the search strategy for identifying relevant studies, and the criteria for inclusion and exclusion of studies in the review.

The research strategy of the systematic review of the literature, therefore, consisted of searching the CAPES Periodicals Portal (Portal CAPES) through the Federated Academic Community (CAFe) network in the "Subject search", which includes all the "databases of research" made available by CAPES. The keywords "Circular Economy" and "Industry 4.0" were used globally or specifically for Brazil. The research was conducted on works published in Portuguese, Spanish and English in the last five years (from 2015 to 2021), as shown in Table 1. From these works, the original articles were selected. The inclusion criteria used were the presence of abstracts (in Portuguese, Spanish and English), the availability of the complete article online, as well as the description of a quantitative approach referring to the analysis of the association between "Circular Economy" and "Industry 4.0", including socio-environmental factors. Articles not reviewed by peers, studies with a qualitative approach, and those of a quantitative nature presented in their abstract had only the description of frequency measures excluded. Book chapters, reviews, case reports and editorials were also excluded.

Table 1
Research strategy of the systematic literature review

Search requirements	
Database	all "Research databases" made available by CAPES
Search type	published articles
Keywords	circular economy and industry 4.0
Languages	Portuguese, English and Spanish
Time course	2015 to 2021

Source: Prepared by the author (2022).

The research conducted presents itself, in terms of nature, as a scientific investigation, as it aims to evaluate the practice of the content addressed. The research approach is qualitative, seeking to deepen the critical understanding of the quality of evidence of the correlation between "Industry 4.0" and "Circular Economy" for implementing sustainable business processes.

4. PRESENTATION AND DISCUSSION OF RESULTS

Based on the proposed methodological procedures presented in item 3 (search criteria, inclusion, and exclusion criteria), the search results for articles in the literature are shown in Figure 5. In step 1, with the search criteria, a total of 360 papers (357 in English and 3 in Portuguese/Spanish). However, when applying the inclusion and exclusion criteria in steps 2 and 3, 41 articles were obtained (39 in English and 2 in Portuguese/Spanish). Therefore, 41 articles were selected that met the selection criteria of the 360 articles presented by CAFe. It could be seen at first, through the number of articles selected, that the research topic is very recent and underdeveloped, making this research theme relevant.

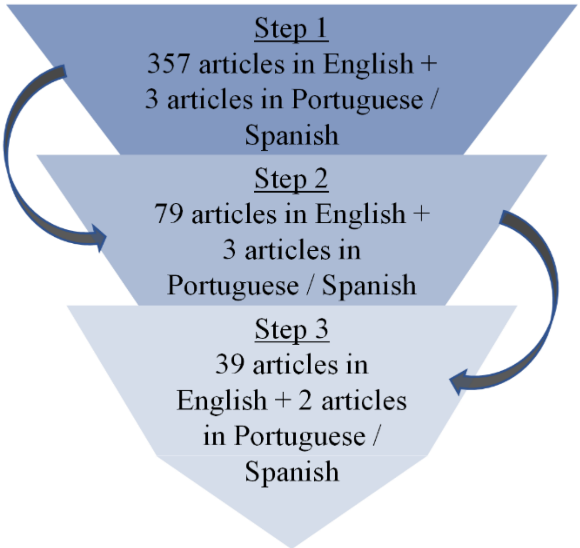

Figure 5. Detailed scheme of the steps of the systematic research review.
Source: Prepared by the author (2022).

Regarding the articles selected for the development of this work, Figure 6 graphically presents the Number of Publications per Year of Publication that met the selection criteria. There has been a significant increase in the number of publications in the last three years (2019-2021), and for the year 2021, only publications related to the first half of the current year were raised. In this way, the number of publications in 2021 (which could be selected) should be higher than that of the previous year, reflecting the interest in the topic through the development of scientific studies.

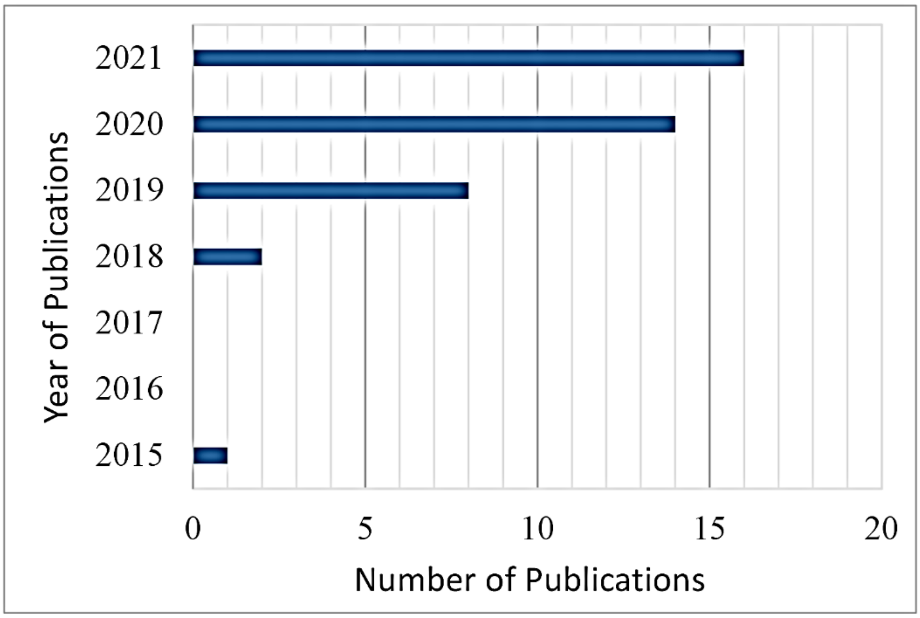

Figure 6. Graphic presentation of the selection of articles in Year of Publications by Number of Publications.
Source: Prepared by the author (2022).

4.1 The Use of Technology Towards Transition

The Fourth Industrial Revolution brought the convergence of several technologies to consolidate more effective and efficient industries, turning them into "Smart Factories". "Industry 4.0" and "Circular Economy" are different concepts and have different origins and premises. However, "Industry 4.0" can be considered an enabling factor for the "Circular Economy", and vice versa. It is interesting to note that the digitization promoted by "Industry 4.0" is targeted by the industries, while the "Circular Economy" is still considered a change in basic assumptions for many.

The "Circular Economy" concept can lead organizations and societies toward sustainable development within a new entrepreneurial mindset. In the study by Kahn *et al.* (2021) it is shown that most of the literature consulted applied the well-known 3Rs principles of sustainability (reduce, reuse, recycle) and the 6Rs (reduce, reuse, recycle, recovery, remanufacture and redesign) in approaches related to "Industry 4.0". Meanwhile, a small part adopted the ReSOLVE model (regenerate, share, optimize, loop, virtualize, exchange) developed by the Ellen MacArthur Foundation, which shows how the six dimensions of the "Circular Economy" are conceptualized in the actions of businesses and how they can affect them. This finding allows the conclusion that manufacturing is changing along with the current industrial revolution,

"Industry 4.0" technologies can also provide digital solutions for manufacturing automation. This context was evaluated in the study by Bag *et al.* (2021), using models based on the "Circular Economy" in which resources remain in the system while experiencing one of the 10Rs principles (refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, recover). These processes (10Rs) require the development of advanced manufacturing capabilities and pose several challenges that can be effectively overcome through "Industry 4.0" technology applications. Although the literature indicates the use of various "Industry 4.0" technologies, little information is available on the opinions of companies on the intensity of the levels of application of "Industry 4.0" in advanced manufacturing,

In other studies, conducted by Mastos *et al.* (2021) and by Rizvi *et al.* (2021), evidence was shown of how "Industry 4.0" technologies tend to redesign traditional supply chains into circular supply chains. In the study by Mastos *et al.* (2021), the ReSOLVE model (regenerate, share, optimize, loop, virtualize, exchange) was used.

In the ReSOLVE model, the term regenerate relates to the transition to renewable energies and materials and the preservation and enhancement of natural ecosystems. The term "share" refers to the "sharing economy", with the product life cycle extension and waste reduction. The term "optimize" refers to the minimization of activities that give no added value to the company and the supply chain, using advanced technologies and tools to improve resource efficiency and performance of products and services. The circularity loop is related to closed-loop activities, where products follow a circular path rather than a linear one. The term "virtualize" denotes the delivery of virtual utilities and the visualization of materials and processes so that the availability and exchange of information, which replace or postpone the actual physical consumption of goods, are also included in this dimension. The last term, "exchange" refers to replacing old materials with advanced, non-renewable products and services and implementing innovative technologies (Mastos *et al.*, 2021).

In discussing how "Industry 4.0" can contribute to sustainable development, Birkel & Muller (2021) claimed that many articles investigate "Industry 4.0" from the point of view of technologies. However, studies containing holistic assessments of the effects of technologies in the economic, environmental, and social dimensions remain scarce. Implementing "Industry 4.0" in companies requires deep transformations, which can generate several conflicts, requiring further studies on these issues and how technologies can operate in a facilitating way.

"Industry 4.0" technologies are required for the "Circular Economy" (Kahn *et al.*,2021; Mastos *et al.*, 2021; Shayganmehr *et al.*, 2021). For example, the application of the IoT facilitates traceability, production, and logistics. Thus, tracking a material throughout its life means following its production, from its use to its destination, and then starting a new life cycle (Ideia Circular A, 2021).

The IoT has been used in several areas, such as agriculture, energy, manufacturing, transport, logistics, health services, and aviation, among others, with intelligent devices operating as part of systems or in systems that make up the value chain of companies. (Inoue *et al.*, 2019).

However, the use of innovative technologies can present, in addition to opportunities, barriers that need to be considered so that they can be overcome. Such is the case of the adoption of IoT in the "Circular Economy" in an industrial environment in which, according to Cui *et al.* (2021) identified in their research 22 main barriers in this regard, namely: infrastructure standardization, automation system virtualization, data quality, adaptability, customer preferences, sensor technology, smart device development, upgradeability, semantic interoperability, financial risk, compatibility, government support, investment cost, process eco-efficiency, cyber-physical systems, customer behavior, process digitization, network architecture, coordination and collaboration, systems interface, 3D printing is another tool that can work by decentralizing production and reducing waste generation. This technology allows the production of prototypes that minimize material waste and promotes small-scale production and the manufacture of materials that can be recycled (Ideia Circular A, 2021).

Blockchain is another tool that, through the traceability process, provides detailed information about products, from their origin to their destination, with the monitoring of their useful life. It is a handy tool for the idea of circularity, considering the potential initial costs involved in implementing the technology, although its benefits exceed its challenges (Ideia Circular A, 2021; Upadhyay *et al.*, 2021).

According to a study conducted by Cezarino *et al.* (2019), "Industry 4.0" will bring the possibility of designing new digital business models and with greater access to services by customers and can be seen as a facilitator of the "Circular Economy" due to its visibility and intelligence in the construction of products and assets.

The development of "Industry 4.0" responds to the technological challenges related to resources for companies/industries. "Industry 4.0" generates growth and new job opportunities and can reduce the negative environmental impacts through balancing economic, social, and environmental values, to bring about the transition to the "Circular Economy".

Technological advances, guided by the "Circular Economy" paradigm, can create better opportunities for society. Information technology and technologies used in industries with online access and deployed on a large scale make it possible to create new businesses for the "Circular Economy" that were not possible before. Such advances add efficiency to collaboration and sharing, enable more accurate tracking of materials, improve logistics and reverse logistics setups, and increase the use of renewable energy (Ellen MacArthur Foundation, 2015).

Digital transformation could redefine the core of our materials-dependent industrial economy, making it less dependent on the extraction of finite resources. The "Circular Economy" helps decouple economic value creation from resource consumption. In this perspective of systemic change, the internet of things becomes the new virtualized infrastructure that governs the use of assets and moves the value chain. Digital tools, such as exchange platforms, which enable many lifetimes and product-integrated information – become essential physical tools for determining and directing asset flows. The value created can go beyond direct business benefits and generate significantly amplified societal benefits (Ellen MacArthur Foundation, 2015).

Many companies are already exploring the interactions between the "Circular Economy" framework and smart assets, eliminating structural barriers between production and consumption or use established over time. This generates considerable opportunities for various sectors such as the manufacturing industry, the energy sector and public utilities, civil construction (including infrastructure), logistics and waste management, agriculture, and fisheries (Ellen MacArthur Foundation, 2015).

4.3. New Business Models

Given the current social, economic, political, and environmental context, the transition of manufacturing processes, technological discoveries, climate change, its impacts and the demands imposed to guarantee the quality of life, the evolution of thinking about the ecosystem until we arrived at the concept of the "Circular Economy". After the technological advances brought us to this new digital world, we are experiencing unique business ecosystems.

Incorporating the "Circular Economy" into existing businesses has implications that must be evaluated. In the study by Salvador *et al.* (2021), the strategies of the "Circular Economy" were identified with their more significant influence on the management of the blocks of the Canvas business model (customer segment, value proposition, channels, key resources, main partnerships, revenue sources, cost structures, activity, and customer relationships.) in circular businesses. These are the blocks most affected by the "Circular Economy" strategies.

The "Circular Economy" strategies raised by the study were: 1) the development of strategic partnerships for circularity and involving stakeholders along the value chain; 2) design for roundness; 3) projecting waste; 4) industrial symbiosis; 5) reuse; 6) recycling; 7) reconditioning; 8) practices oriented towards the use of ecological materials; 9) prolonging the life of the product; 10) return systems; 11) product-as-a-service systems; 12) remodeling; 13) remanufacturing; 14) repair and maintenance; 15) dematerialization and 16) digital technologies to enable circularity (Salvador *et al.*, 2021).

The Canvas blocks most influenced by the "Circular Economy" strategies were customer segments, customer relationships and key partnerships. Thus, the analysis made during this research indicated where companies should focus their efforts in managing their businesses when implementing/managing different strategies of the "Circular Economy" (Salvador *et al.*, 2021).

In general, business models need to be updated, given the environmental and technological requirements of the globalized and digital ecosystem, to promote business sustainability. Thus, the business strategies that can be presented in three groups concerning the consumer, as they occur before consumer use, during use and after use, are as follows:

1st group – business strategies that precede the use of the product by the consumer:

- To encourage/give preference to local production, which favors the local economy, brings benefits, and strengthens the region.
- To support cooperatives, as they seek the common benefit around a specific activity, in addition to generating jobs and wealth for cooperative members and society.
- To give preference to the use of circular raw materials as renewable, recyclable inputs with low embodied energy, non-polluting.
- To invest in R&D with innovations in product design, development of metrics and indicators of circularity, a partnership between academia and the private sector.
- To maximize the efficiency of processes (in production), for example, by industrial symbiosis, custom manufacturing, and eco-efficiency, among others.
- To seek the integration of the value chain to generate competitive advantage.
- To use the virtualization of systems and equipment for monitoring, tracking and simulation. Virtualization offers the advantages of reducing energy consumption and costs, improving processes, increasing productivity, optimizing management, physical space, hardware integration, variety of platforms and security.
- To invest in developing durable products so that they can be rented or shared in a product-as-a-service system.
- To invest in circular product design, which consists of adopting a design for the use of the product, such as design for repair, updating, remanufacturing, and recycling.

2nd group– business strategies for the consumer use phase of the product:

- To extend the product's useful life, offering products with more outstanding durability, with extended warranties and (or) services.
- To make available the sale of consumables, spare parts and accessories that favor the longevity of the products.
- To offer product-oriented services to meet product needs, such as maintenance contracts, return agreements, consulting, and upgrades.

- To offer usage-oriented services, the supplier remains the owner of the product but offers services, such as rent, leasing (rental financed with an option to purchase), sharing (multiple independent users) and pooling (simultaneous use by several users).
- To offer result-oriented services (servitization or system-product-service), which consists of a combination of products and services to meet user needs. In a more extreme format, companies sell the function of the product rather than the product itself. Some examples are the sale of servers leased by the hour from IBM; the Pay-per-copy model - pay per print from Xerox; the Rolls-Royce power-by-the-hour service package where maintenance, repair and overhaul services are billed per flight hour; Atlas Copco's Air Contract service, where air compressors are sold per m^3 of compressed air generated; Philips' pay-per-lux model for selling lighting fixtures, where customers pay for the promised level of lighting in a building;

3rd group– business strategies for the post-use phase of the product by the consumer:

- To seek the integration of the reverse chain, which consists of reverse channels of exchange, warranty return, purchase cancellation, return of packaging, return of waste for processing or final disposal, return of post-consumer materials for reuse.
- To sell second-hand products (reuse), with the creation of a market for used products.
- To remanufacture, in which the used product is re-industrialized (disassembled, cleaned, reconditioned, and reassembled) by the product manufacturer himself and has its worn components replaced by new or recovered ones, returning its original performance and with a guarantee equal to or better than the new product.
- To remodel and to promote the aesthetic improvement of a product.
- To update and to introduce functional improvements.
- To recover or recycle when recovery or transformation of waste into other materials or products occurs.
- To reuse the product for another purpose.

5. FINAL CONSIDERATIONS

The global economy advances, adapting to needs and requirements, based on an essentially linear model but marked by efforts toward a "Circular Economy". This transition process, even motivated by demands imposed by the current conditions of environmental problems, can and should be seen as an opportunity. It can give rise to efficient and environmentally sustainable production processes irrespective of regulatory issues. Meanwhile, "Industry 4.0" brings several features that can support the transition to a "Circular Economy", given that the latter needs advanced resources for its implementation.

The "Circular Economy" system rethinks the practices of society's economic organization. It substitutes the linear economy mindset by adopting intentionally restorative and regenerative industrial systems, the flow of renewable (biological nutrients), finite (technical nutrients), circular design of products and processes, and reducing systemic losses and negative externalities.

On the other hand, "Industry 4.0", through a process of extensive technological modernization, brought the digitization of functions, the intelligence of systems with "smart factories", the autonomy of machines, the convergence of technologies for digital transformation and the fusion of the physical and the virtual for breaking paradigms, and thus facing the technological challenges of the current dynamic system.

Conflict of interest

The authors declare no conflict of interest.

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