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ON THE INTEGRATION OF IMPACT ASSESSMENT AND CIRCULAR ECONOMY: A LITERATURE REVIEW

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Dissertação (Mestrado) - Programa de Pós Graduação em Ciências da Engenharia Ambiental - Área de concentração: Ciências da Engenharia Ambiental

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SÃO CARLOS SCHOOL OF ENGINEERING

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DEDICATION

This study would not be possible without the orientation from my research advisor, my wife, and my work colleagues who became friends and part of my family. To people who work in the same building as I do (in a variety of positions), our conversations during coffee breaks made my day. Everyone gave contributions, as well as intellectual, material, and emotional support, which made this research's process and result possible. To people who always took care of me and loved me, frequently giving up to care for themselves and their own, my profound gratitude. Without you, I would not be. I hope to leave the doors from where I came wide open so that many can go through. To my family thank you for material and emotional support. Thank you for always seeing me. For the respect. For the humanity.

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ABSTRACT

PEREIRA, M. M. **On the integration of Impact Assessment and Circular Economy: a literature review**. 2023. Thesis (Master) in Science - São Carlos School of Engineering, University of São Paulo, São Carlos, 2023.

Achieving sustainability requires overcoming a series of challenges, among which are rapid population growth, increased climate temperature, and environmental degradation. One of the ways to deal with these challenges is the transition from the linear economy, based on "extract, produce and discard, to a Circular Economy (CE), a scenario in which the flow of materials and energy is as closed as possible of an image of a circle. However, not all Circular Economy strategies achieve a sustainable result. Therefore, it is necessary to assess the impact of these circularity strategies to ensure that they achieve the expected results. In this context, the Impact Assessment (IA), is a process used as a tool to influence the decision-making process towards decisions that promote Sustainability, to help in the transition to a more circular mode of production. Thus, the objective of this work is to understand the perspectives of the integration of Impact Assessment and the Circular Economy from the perspective of a critical review of the literature. To this end, a Bibliometric Analysis was initially carried out to map the areas of integration between the two disciplines. A critical Content Analysis of the results proved the need for further investigation. Thus, based on the patterns that emerged from the Bibliometric Analysis, keywords were chosen to start a Systematic Literature Review (SLR). The SLR aims to point out how the themes of Circular Economy and IA interact and interconnect, analyzing the aspects and possibilities of this integration indicated by the relevant literature. In this way, it will be possible to identify how Circular Economy principles relate to Impact Assessment through the identification, in the literature, of the different types of relationship that may exist between Impact Assessment and Circular Economy (for example: Impact Assessment is seen as a tool/process that assesses the impact of circular strategies/actions or as a tool/process that incorporates circular strategies?). The results of this work should contribute to the Impact Assessment area by filling gaps such as the assessment of alternatives, cumulative impacts, analysis of biodiversity, climate change, and several other IA challenges that can find a theoretical and practical solution in the Circular Economy. In addition, we intend to demonstrate, through the literature, that the ability to promote a Circular Economy is one of the many potentialities of Impact Assessment, being crucial for the implementation of circular actions and strategies to guarantee that they reach a truly sustainable result.

Keywords: Impact Assessment, Circular Economy, Sustainability, Bibliometric Analysis.

RESUMO

PEREIRA, M. M. **Sobre a Integração da Avaliação de Impacto com a Economia Circular: uma Revisão da Literatura**. Dissertação (Mestrado) – Escola de Engenharia de São Carlos, Universidade de São Paulo, São Carlos, 2023.

Alcançar a Sustentabilidade exige superar uma série de desafios, entre os quais o rápido crescimento populacional, o agravamento da crise climática e a degradação ambiental. Uma das formas de lidar com estes desafios é a transição da economia linear, baseada em “extrair, produzir e descartar”, para uma Economia Circular (EC), cenário em que o fluxo de materiais e energia é o mais fechado possível se aproximando da imagem de um círculo. No entanto, nem todas as estratégias de Economia Circular alcançam um resultado sustentável. Portanto, é necessário avaliar o impacto destas estratégias de circularidade para garantir que alcançam os resultados esperados. Neste contexto, a Avaliação de Impacto (AI) , é um processo utilizado como ferramenta para influenciar o processo de tomada de decisão em direção a decisões que promovam a Sustentabilidade, de modo a ajudar na transição para um modo de produção mais circular. Assim, o objetivo deste trabalho é compreender as perspectivas da integração de Avaliação de Impacto e Economia Circular através de uma revisão crítica da literatura. Para tanto, foi realizada inicialmente uma Análise Bibliométrica para mapear as áreas de integração entre as duas disciplinas. A Análise Crítica do conteúdo dos resultados comprovou a necessidade de investigações mais aprofundadas. Assim, com base nos padrões que emergiram da Análise Bibliométrica, foram escolhidas palavras-chave para iniciar uma Revisão Sistemática da Literatura (RSL). A RSL visa apontar como os temas da Economia Circular e da Avaliaçãi de Impacto interagem e se interligam, analisando os aspectos e possibilidades dessa integração indicados pela literatura pertinente. Desta forma, será possível identificar como os princípios da Economia Circular se relacionam com a Avaliação de Impacto através da identificação, na literatura, dos diferentes tipos de relação que podem existir entre Avaliação de Impacto e Economia Circular (por exemplo: a Avaliação de Impacto é vista como uma ferramenta/processo que avalia o impacto de estratégias/ações circulares ou como uma ferramenta/processo que incorpora estratégias circulares?). Os resultados deste trabalho deverão contribuir para a área de Avaliação de Impacto, preenchendo lacunas como a avaliação de alternativas, impactos cumulativos, análise da biodiversidade, alterações climáticas, e vários outros desafios de AI que podem encontrar solução teórica e prática na Economia Circular. Além disso, pretendemos demonstrar, através da literatura, que a capacidade de promover uma Economia Circular é uma das muitas potencialidades da Avaliação de Impacto, sendo crucial para a implementação de ações e estratégias circulares para garantir que estas alcancem um resultado verdadeiramente sustentável.

Palavras-chave: Avaliação de Impacto, Economia Circular, Sustentabilidade, Análise Bibliométrica

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CHAPTER 1 – INTRODUCTION

The Circular Economy (CE) can be defined as an umbrella concept that addresses how humankind produces and consumes products and services, with the primary goal of adjusting the production-consumption system to meet environmental sustainability needs (Suárez-Eiroa et al., 2019). Many countries have taken policy actions for a successful ecological transition and the change from a linear economy to a circular economy (K. Zhou et al., 2014). The topic's growing importance on the political agenda is one of the signs of the increased attention it has been receiving. In China, the Circular Economy Promotion Law, which went into effect in 2009, intends to have an impact on three levels: micro/firm, meso/eco-industrial-park, and macro/eco-city (Geng et al., 2012). Six years later, in 2015, the European Union approved an action plan for the circular economy, which included, among other things, long-term goals to decrease landfilling and boost the preparation of major waste streams, like municipal trash and packaging waste, for reuse and recycling (EC, 2015b). However, even though a circular economy has the potential to reduce the need for primary raw resources by, for instance, recycling them, circular systems are not always sustainable (Schaubroeck, 2020). Therefore, assessing the environmental impacts of the outcomes and goals targeted by Circular Economy policy initiatives is essential for their successful implementation (Haupt & Hellweg, 2019; Millar et al., 2019).

Impact Assessment (IA) is a tool, that, as an output produces information regarding a development's potential effects to enable decision-makers to consider their options (Morrison-Saunders et al., 2014), including decisions regarding CE policy implementations (EC, 2015b). Such as the Circular Economy, 'Impact assessment' (IA) is also an umbrella term (A. Bond & Dusík, 2020; Morgan, 2012). The term here refers to the evaluation of proposed actions (ranging from policies to projects) (Morgan, 2012) regarding all levels of decision-making, involving quite a few related decision-support instruments (Morrison-Saunders et al., 2014). Despite the various types of IA, the impact assessment community shares the pursuit of sustainability (Morrison-Saunders et al., 2014). The growing acceptance of different types of impact assessments and IA's broad inclusion in laws and international agreements are both considered strengths of Impact Assessment (Pope et al., 2013). In this regard, the European New Circular Economy Action Plan states that several of the suggested circular policies need to be evaluated in advance to ensure they will result in "genuine environmental benefits" (EC, 2020b). However, areas of inefficiency still exist in Impact Assessment, such as evaluating alternatives and evaluating and managing cumulative effects (Pope et al., 2013). Additionally, global emergent themes related to resource consumption, biodiversity, and climate change operate at magnitudes that make it challenging to capture them at even strategic levels of IA (A. Bond & Dusík, 2020).

Circular Economy practices can contribute to IA practice and make it more effective (Yijun et al., 2011). The implementation of circular strategies not only could help mitigate climate change and promote low-carbon infrastructure (Bellezoni et al., 2022; Yang et al., 2023), but also in recent years has enabled the assessment of cumulative impacts on a global scale (Maiurova et al., 2022). The circular economy undoubtedly has significant sustainability potential. Circular practices play an important role in environmental sustainability by reducing emissions (Hailemariam & Erdiaw-Kwasie, 2022) and resource scarcity while creating financial benefits (Lieder & Rashid, 2016). Some argue that the circular economy delivers a compelling economic approach that enables the decoupling of sustained economic growth from environmental costs (Rosa et al., 2020). However, an increase in the material footprint and associated environmental impacts have been associated with increases in the global gross domestic product (GDP) (Hickel & Kallis, 2020). Because of that many CE definitions presume that, due to the second law of thermodynamics and the inevitable entropy, it is impossible to separate economic expansion from the use of natural resources, therefore admitting the spatial limitations of the economic system (Korhonen et al., 2018). Hence, if secondary production genuinely minimizes primary production activities, the environmental benefits of the circular economy can be realized (Zink & Geyer, 2017). In that case, stabilizing global demand in terms of product volume and composition would enable achieving a circular economy (Allwood, 2014).

The previously exposed ideas are closely linked with, and determined by, the idea of sustainability. Sustainability is a concept that can be understood as a value that, when adopted in a policy, seeks to add elements to the current status quo (R. Dovers, 2007). Given that the concept has many approaches to it, environmental sustainability aims to maintain the natural resources that constitute the world's life support systems (Goodland, 1995). Within the framework of Environmental Sustainability, there are four degrees (weak, intermediate, strong, and absurdly strong) of Sustainability (Goodland & Daly, 1996; Khalili, 2011). On the one hand, many definitions of the circular economy are based on the Weak Sustainability concept, which suggests that despite scarce resources, nature has an essentially limitless capacity to produce materials and assimilate environmental pollutants (Ruggerio, 2021). In this sense, Ruggerio (2021) states that the Circular Economy is a conceptual proposal that emerged from a Weak Sustainability approach, which is reinforced by other authors who point Circular Economy's limitation in questioning economic growth (D'Amato et al., 2017) and the need to connect CE with strong sustainability (Nikolaou et al., 2021). Since CE both in research and practice is not only focused on impact prevention but also system reconfiguration (moving away from the linear economy), the Strong Sustainability concept is better than Weak Sustainability to create a theoretical basis on which CE can contribute to sustainability transitions (Z. Liu et al., 2023). Here, it is important to note that even though Sustainable Development is the consequence of actions resulting from a sustainability policy (Khalili, 2011; Oliveira et al., 2009), many use both terms Sustainability and Sustainable Development interchangeably (Ruggerio, 2021), while others understand that development is not compatible with sustainability (S. R. Dovers & Handmer, 1993). In this last case, joining both words - "Sustainable Development" - would be an oxymoron since sustained economic growth would not be compatible with true Sustainability.

Because the definition of Sustainability is not settled, the relationship between Circular Economy and Sustainability also varies. Some propose Circular Economy is viewed as a condition for sustainability, others as it CE being beneficial to achieving Sustainability and some understand that there is a trade-off between the concepts (Geissdoerfer et al., 2017). This last group of authors understands that CE can have beneficial environmental outcomes or not depending on how it is approached (Schaubroeck, 2020), in other words: a circular strategy may not always be sustainable (Navare et al., 2021). Therefore, addressing Sustainability issues, and even the different approaches to the concept, is one of Circular Economy's limitations. Additionally, Korhonen et al., (2018) state that circular economy activities (recycling, reuse, remanufacturing, and refurbishment processes) do not ensure a sustainable outcome because entropy, if not checked, will eventually lead to unsustainable levels of resource depletion, pollution, and waste generation. As a result, technological development may result in increased energy consumption – rebound effect (Zerbino, 2022) - or increased material throughput since increased resource efficiency leads to increased use of that resource rather than decreased utilization - Jevon's paradox (Mayumi et al., 1998). This suggests that circular strategies should be assessed by their global environmental sustainability impacts' contribution (Korhonen et al., 2018). This would additionally result in avoiding nature conservation policies which cause exported environmental damage to boomerang (reverberate) into nations with high environmental standards – boomerang effect (Mayer et al., 2005).

Because of the difficulties CE has in measuring and assessing the entire impacts of circular economy projects due to the previously mentioned factors (Calisto Friant et al., 2020), Impact Assessment is the tool that can assist the Circular Economy initiatives in becoming truly sustainable. This is because IA has a consistent approach across jurisdictions and outcomes, is a technical and political process that provides precise information and guarantees that environmental factors are considered as early as possible, and finally Impact Assessment is legitimized mainly by public participation (A. Bond et al., 2014). Impact evaluation of circular economy initiatives is crucial to their implementation, particularly in the context of public service (Klein et al., 2020), but CE environmental impact evaluations have primarily focused on waste, greenhouse gas emissions, and the use of virgin raw materials, with few or no consideration given to biodiversity loss (Ruokamo et al., 2023). In this sense, at the same time CE strategies can improve IA practice by making it more effective (Henry et al., 2021), Impact Assessment helps the transition to a CE to be truly Sustainable, by assessing the impacts of circular initiatives and trying to guarantee there is no overexploitation of natural resources and no further degradation of ecosystems.

Taking the previously mentioned aspects into account, the literature on Impact Assessment and Circular Economy demonstrates the contributions that both research and practice fields may provide each other. However, to the best of the author's knowledge, no research has been conducted on the relationship between the Circular Economy and Impact Assessment. This drives and motivates the current study. The purpose of this research is to investigate the relationship between Impact Assessment and the Circular Economy and the main characteristics of this relationship. Therefore, the following research question guides this work: What is the relationship between Impact Assessment and Circular Economy? To answer this question, this work developed a methodology divided into two stages consisting of performing a Bibliometric Study (1) followed by a Systematic Literature Review (2). The first stage further develops the main research question into secondary research questions, they are: (RQ1) What are the main themes of the intersection between IA and CE? (RQ2) What connections do the themes of interaction have between them? (RQ3) What are the yearly publication patterns within the intersection between IA and CE? (RQ4) Who are the most prolific authors and their affiliated institutions and countries or territories intersection between IA and CE? Also, within the second stage, the main research question is used as a guide to design a secondary RQ to be answered by the SLR, it is: (RQ5) What are the types of relationship that can be observed between IA and CE?

The first part of this dissertation is a Bibliometric Study that uses two main techniques: (1) science mapping and (2) performance analysis. Science mapping is chosen to analyze all the data retrieved, which consists of 69,081 documents gathered from Scopus and Web of Science containing the terms “impact assessment” or “circular economy” within their titles, author keywords, or abstracts. Science mapping techniques chosen to answer the research questions previously presented are co-word analysis and co-citation analysis. These techniques are used for detecting themes where IA and CE share notable connections. To understand the connection between these themes and to study specifically this area of connection the following performance analysis technique was chosen: the annual number of articles (Total Publications –TP) and citations (Total Citations – TC), and frequency distribution of Journals (Source). The results of the Bibliometric Analysis allowed us to map the main areas where Circular Economy and Impact Assessment intersect. Then, these thematic areas comprised the *a priori* coding framework that guided the second part of this work: the Systematic Literature Review. The thematic areas indicated the terms to be searched in the fields of author keywords, abstract, and title. The results of the SLR are presented as follows: (i) descriptive analysis and (ii) thematic analysis.

The main results of the Bibliometric Study and the SLR show that 1) Even though both Impact Assessment and Circular Economy aim for Sustainability and are environmentally centered, they both struggle to deal with Climate Change's environmental impacts, and the practice of Impact Assessment is more directed to Strong Sustainability than current Circular Economy policy measures; 2) Even though Life Cycle Assessment is the most used Impact Assessment tool to evaluate the environmental impacts of Circular Economy measures, an integrated Impact Assessment process that incorporates other techniques is needed; 3) Impact Assessment relationship to Impact Circular Economy lies in the environmental impacts appraisal of Circular Economy activities. Additionally, although there are benefits from CE strategies being incorporated into the IA process, not many articles discussed this result. Therefore, the importance of this work lies in the creation of a relationship framework to situate the literature on Impact Assessment and Circular Economy as a starting point to guide future works. We hope that the potential that

Impact Assessment has of helping Circular Economy strategies to achieve more sustainable outcomes identified in this work meets T. Fisher's (Fischer, 2023) encouragement and gives evidence of how IA approaches contribute to achieving sustainable results, "providing proof for the usefulness of IA.”. The goal of this study is not to end the debates, but rather to enrich the conversation about the relationship between the two concepts, as well as to improve the two research and practice fields.

This dissertation is structured as follows: The first chapter contemplates a theoretical basis that guides the work. It comprehends the competing definitions of the main terms used for the discussions of this research, which are: Sustainability, Impact Assessment, and Circular Economy. The second chapter consists of the methodology used to develop this work and it was divided into two steps to best achieve the goal of this study. The first step (a Bibliometric Analysis) aims to look at the relationship in a broader way, analyzing first a large volume of documents to find patterns. Those patterns are then applied to analyze a smaller and more focused number of papers through content analysis. The first step showed the need for an even more focused and systematic approach. The second step of the methodology (Systematic Literature Review) aims to look at the CE and IA relationship in a narrower way than the first by adding the ‘Sustainability’ variable to the analysis. The third chapter discusses the results in the same way the methodology is presented: first the Bibliometric Analysis results and then the SLR results. Finally, in the fourth and last chapter, we make our final remarks. Because this work is mainly based on literature contributions, the last chapter consists of policy contributions, and critics of the literature, especially what hasn't been pointed out.

CHAPTER 2 – THEORETICAL BASIS

This chapter explores the main theoretical foundations to develop this dissertation and further discusses and explores the results that might emerge from this research, aiming at the various definitions from the many perspectives the concepts may have depending on the lens of analysis. We try to navigate these different opposing views that aim to define and interpret the fundamental ideas that are central to the discussions aimed at this work. At the center of the work lies the Sustainability concept, which is a transactional field with many definitions, serving different political actors. The Sustainability definition is then used by the following two concepts discussed. Impact Assessment is a policy concept that aims to achieve Sustainability, so as the concept of Sustainability changes, Impact Assessment can become more or less effective. Finally, the last concept defined in this chapter is the concept of the Circular Economy, which is a proposition of an economic model that aims for Sustainability, and therefore is also a concept in dispute.

2.1. Sustainability

The concept of Sustainability is one in dispute. Defining it is of extreme importance since how one defines it can influence the outcome of public policies. Throughout the history of humanity, many civilizations promoted what we nowadays consider sustainable practices to preserve the earth's "everlasting youth" in response to environmental challenges (Du Pisani, 2006). Sustainability is a notion that can be traced to the 17th and 18th centuries and linked to the idea of sustainable yield by forestry specialists (Caradonna, 2022; Warde, 2011), and that was just one of the signs of a developing understanding of the importance of respecting the ecological limits as well as the need to prevent resource overconsumption (Caradonna, 2022). This idea of sustained yield, in the 19^{th} and early 20^{th}, was one of the main goals of resource conservationists, which differs from the idea advocated by wilderness preservationists who believe in the idea of preservation of nature because of its intrinsic value (Callicott & Mumfordf, 2017; Purvis et al., 2019). However, it wasn't until the latter half of the 20th century that the modern notion of sustainability appeared.

The Brundtland report was the first document to adopt the concept of sustainability and attribute to it a policy meaning through the notion of Sustainable Development (Kuhlman & Farrington, 2010; WCED, 1987). This was the culmination of a debate that began with "The Limits to Growth" and other significant writings that questioned whether continuing growth in the economy was desirable or even feasible (Du Pisani, 2006; Meadows et al., 1972; Purvis et al., 2019). The discussion so far has been split into two main focal points: the proponents of growth were on one side of the argument – or optimists, and on the other were the ones who believed that an expanding economy could not last on a finite earth – or pessimists. The first group acknowledged their current situation's reality as well as potential issues with population pressure, the availability of food and energy, and the existing threats to the environment (Rostow, 1978). Although the environmental harm and wealth disparity were acknowledged, continued scientific and technical advancement was considered as the solution. The "pessimists," on the other hand, expressed concern over the "ecocide" (the deterioration of ecosystems) that was occurring (Du Pisani, 2006). This was described in "The Limits to Growth" as the basic claim that for a sustainable, global equilibrium to be achieved, global population and capital stock were required to remain constant (Meadows et al., 1972).

In the period following the end of the post-Second World War economic boom, which promised 'progress' based on economic growth but did not materialize, calling for a better consideration of social problems, and a 'basic needs' approach (Hicks & Streeten, 1979). In this period there was an increase in the discourse criticizing militarism economic growth, state monopoly capitalism, competition, and consumption as the primary causes of environmental problems (Van Der Heijden, 1999). The 1972 United Nations Conference on the Human Environment in Stockholm was the first to explore the effects of humanity on the natural environment, as well as the first significant attempt to reconcile economic progress and environmental integrity, which were widely seen as irreconcilable (Caldwell, 1984). The Stockholm Conference resulted in a transition from a two-dimensional notion of socio-economics to a three-dimensional eco-socioeconomics, compared to going from plane and linear geometry to space mathematical concept (Sachs, 2012). From the middle of the 1960s to the beginning of the 1970s, the idea was to give some ground to environmentalists on certain issues, like environmental impact assessment and pollution control, while making sure that some activities remained profitable (O'Riordan, 1985). This period in environmentalism is characterized by an increasing division between the opposing optimist and pessimist views, leading to the environmental belief system shown in Table 1, adapted from (Oliveira et al., 2009). The many environmentalist perspectives express distinct degrees of sustainability and ideological structure (Oliveira et al., 2009; O'Riordan, 1985).

Technocentrism is based on a man-centered perspective of the world, with the goal of environmental protection, which is believed to be achievable by replacing natural capital with wealth generated by technology (Oliveira et al., 2009; O'Riordan, 1985). Within this extreme, there is also the idea that the market has unlimited capacity to regulate all negative environmental externalities (Oliveira et al., 2009). On the other extreme side, ecocentrism is defined as an ideological direction that believes in the strict observance of environmental limits for economic growth (Oliveira et al., 2009; O'Riordan, 1985). Between the two, two further categories can be mentioned: accommodation and communalist. First, without any substantial change in the distribution of political power, accommodation is a form of technocentrism that believes waste reduction and economically uncomfortable pollution can be achieved by adapting and shaping regulation (this includes regulation regarding environmental impact assessment) as well making changes in managerial and commercial practices (O'Riordan, 1985). O'Riordan (1985) states that the communalists, one of the subdivisions of ecocentrism, believe in people's cooperation capacities to organize their economies if given the correct incentives and freedom. It's noteworthy to note that the approach and framework of reference adopted for sustainability establish the potential scope for the environmental variable and, subsequently, how the environmental policy will be carried out within each country.

Table 1. The environmental belief system of environmentalism and sustainability

Technocentrism		**Ecocentrism**		
Optimism/ Cornucopia	Accommodation	Communalism	Gaianism/ Profound Ecologism	
Natural resource exploitation is driven by economic growth	Conservationist perspective on natural resources and management	preservationist perspective of natural resources	Extreme preservationist perspective of natural resources	**Environmental Level**
Very Weak Sustainability	Weak Sustainability	Strong Sustainability	Very Strong Sustainability	**Sustainability Level**

Source: Authors (2023)

Besides the Stockholm Conference, another turning point in the evolution of the Sustainability concept was the emergence of the term "eco-development". In this context, Ignacy Sachs defined 'eco-development' as a development approach aimed at reconciling social and economic goals with ecologically sound management, without jeopardizing the basic needs of the communities involved and while attempting to reconcile solidarity with both our contemporaries and future generations (Sachs, 1978). This idea of environmentally and socially responsible growth was being rejected by many governments, especially in developing countries (Purvis et al., 2019). Along with the international the dominance of neoliberal narrative, the environmental discourse has undergone a transition from radical social change to ecological modernization since the 1980s, culminating in a massive surrender to ecological modernization (Van Der Heijden, 1999). From the middle of the 1980s on, ecological modernization was the predominant narrative, an idea endorsed by the Brundtland report in 1987 (Du Pisani, 2006; Van Der Heijden, 1999). The World Commission on Environment and Development (WCED), also known as the Brundtland Commission, concluded in their final report, among other things, that economic growth was crucial, especially for developing nations (Du Pisani, 2006; WCED, 1987). The publication of 'Our Common Future' - the Brundtland Report - called for a "new era of economic growth" that is "socially and environmentally sustainable". By appropriating the eco-development notion of economic growth a new 'win-win' possibility emerged by viewing the former economic growth through a "socially and environmentally sustainable" lens (Purvis et al., 2019). Economic expansion stopped being the problem and started being the solution.

Sustainable development was a term made popular within the Brundtland Report, which defined the development that meets "the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Since there have been two main changes in the notion of sustainability: the first is the change in interpretation from two (relationship human-nature) to three dimensions (social-economic-environmental) and the second is the contrast between "strong and "weak" sustainability (Kuhlman & Farrington, 2010). Despite acknowledging the tension between economic growth and environmental protection, the Report expressed the belief that social equity, economic growth, and environmental preservation can co-exist in harmony (Du Pisani, 2006). These three perspectives in which Sustainability is applied and interpreted have changed in the way it is represented, ranging from the Venn diagram (Barbier & Burgess, 2017) - illustrating the convergence of the goals associated with the environmental, economic, and social contexts – to assuming a form a "three pillar" approach (Purvis et al., 2019) and a form of a triangle (Campbell, 1996). The primary concerns about sustainable development were that it was supporting neo-liberal interests by failing to effectively challenge the consumer culture and the idea of economic growth (Du Pisani, 2006). In this context, when development is seen as economic growth, the terms "sustainable" and "development" when combined convey a sense of contradiction that creates an oxymoron (S. R. Dovers & Handmer, 1993; Goodland, 1995).

These critiques of the idea of Sustainable Development led to the second transformation that can be observed since this period when Sustainable Development was made popular, which was the contrast between ‘strong’ and ‘weak’ sustainability (Kuhlman & Farrington, 2010), as well as the concept of Environmental Sustainability as the only approach possible (Goodland, 1995). Environmental Sustainability in public policies can be defined as the approach that prioritizes the environmental factor in the decision-making, while the opposing idea - Integrated Sustainability - was defined by Oliveira (2009) as being an imbalance in the weighting of the Sustainable Development pillars, putting more weight in the Economic variable. This idea is aligned with Milne (1996) who states that Sustainability demands the replacement of traditional economic principles with social and ecological values. Additionally, many authors defined Sustainability according to the idea of carrying capacity, a term used to define the maximum population size that the environment can support regularly (Brown et al., 1987; Goodland, 1995). In this sense, Environmental Sustainability emerges as a possible solution because it aims to continuously sustain planetary life-support systems (especially those that support human existence) (Goodland, 1995). In this context, sustainable development is viewed as the “development without throughout growth beyond environmental carrying capacity and which is socially sustainable” (Goodland, 1998). In this context, Sustainable Development would be a development within the planetary boundaries. The planetary boundaries are the Earth's limits for biophysical systems and processes that control the stability and ability to maintain life, and these limits also specify a region that is safe for people to live and develop (Sureth et al., 2023).

Regarding Environmental Sustainability, Goodland (1995) divides it into three degrees: weak, strong, and absurdly strong. A very weak level of sustainability can also be mentioned, and it is defined as a principle within which there are no boundaries to development because natural capital can be replaced by human (technological) capital (Beckerman, 1994; Gibbs et al., 1998; Van-Bellen, 2002). Secondly, weak sustainability is a scenario in which only critical natural capital is not replaced but every other environmental resource can be substituted by human-manufactured capital of similar value (Beckerman, 1994; Gibbs et al., 1998). Even though weak sustainability would be a first step to achieving sustainability (Goodland, 1995), by definition, it merely substitutes for resources consumed and tries to provide typical economic welfare maximization (Beckerman, 1994). Going further, strong sustainability is a concept that revolves around the idea that natural and human-made capital, instead of being perfect substitutes, are complementary in most cases (Beckerman, 1994). Goodland (1995) adds the Absurdly Strong level, understood as a scenario in which there would be no depletion of natural resources.

As seen, the concept of Sustainability is constantly in dispute since it can guide public policy, limit resource consumption, and provide human development. The main difference between Sustainability and Sustainable Development lies in how "development" is understood. If we are being literal, Sustainability means sustaining human life on Earth and, consequently, the means to do so. For Goodland & Daly (1996) the environmental source function that provides humans with the resources needed and waste absorption by environmental sink services are the two important environmental services that must be preserved during the time determined for Sustainability. Sustainable Development, in this case, would be the development that can sustain human life on Earth, that does not go beyond environmental carrying capacity (Goodland & Daly, 1996). The first is a value, and the second is an outcome of the measures implemented according to a sustainability policy (Oliveira et al., 2009). The problem is that in the current capitalist system usually development is a synonym of "economic growth", leading "Sustainability" to be more suitable to social and environmental interactions than "Sustainable Development" which suggests elitism, a policy direction, and a preference of economic expansion above other social aims (Sneddon, 2000). When that is the case, Sustainability, and Sustainable Development become a contradiction.

For some authors, the only way to truly achieve Sustainability would be to shift the production and consumption mode because the main characteristic of capitalist accumulation is the exploitation of natural resources and human labor (Lane & O'Connor, 1995). In this context, to achieve Sustainability, there is the need for a change that is systematic, this includes emancipation and democratization, not only in socio-technical systems but also in the capitalism and marketization processes that have been the primary forces of transformation during the past 200 years (Feola et al., 2021). Circular Economy emerges as one of these systematic changes proposed to achieve Sustainability being defined essentially as "a means for reducing the use of natural resources" (Ministry of the Environment, 2023). Increasing circularity can help achieve Sustainability (Nesterova &

Robra, 2022), but for Circular Economy (CE) to achieve Environmental Sustainability there is a need to assess the impacts of CE policies to guarantee a Sustainable outcome (Schaubroeck, 2020; Zink & Geyer, 2017). Impact Assessment is an essential tool to achieve not only a Circular Economy but also Sustainability.

2.2. Impact Assessment

Impact Assessment (IA) is a decision-making process for project implementation that may have significant impacts on the environment (A. J. Bond et al., 2010). The origin of this IA can be found in the United States National Environmental Policy Act (NEPA) of 1969 (Morgan, 2012). Its emergence can be explained by a result of the public's apprehension and worry caused by unprecedented population growth, technological advances, and economic development following the Second World War by the start of the 1960s (Caldwell, 1988). Impact Assessment (IA) answered these concerns when NEPA was approved by the United States Congress at a time when substantial environmental degradation, triggered by a variety of human activities, was becoming inescapable, as well as the object of growing public concern and political activism (Jay et al., 2007). IA is a process sometimes defined as a tool that also answers the need at the time for operational tools that could assist planning and decision-making with an effect on environmental quality and people's health and safety (Caldwell, 1988). Caldwell (1988) adds that this new legislation required a drastic rupture from usual agency practice, needing an integrated interdisciplinary use of the scientific information from environmental and social fields in agency planning and decision-making.

Impact Assessment is an umbrella term that can be defined as a process that assesses proposed actions regarding the impacts these actions can have on all facets of the environment. IA within the National Environmental Policy Act of 1969 referred to the mandatory requirement of an Environmental Impact Assessment (EIA) imposed on agencies following the other NEPA's norms, and confirmed through an Environmental Impact Statement (EIS) subject to review in federal courts (Caldwell, 1988; NEPA, 1969). From that period on, the field has grown and there is now a growing variety of diverse and specialized varieties of practice (Pope et al., 2013), IA is mostly popularly defined as a "**planning tool**" since assessments are performed to anticipate and analyze the implications of a proposed action (project, program or policy) and its alternatives (Ortolano & Shepherd, 1995).

Impact Assessment in the literature is mostly defined by its main characteristics and objectives. IA can be first defined as a **process that systematically processes information**. In this sense, IA is essentially a technique for creating, managing, and communicating information generated by a rational process as well as through participatory and collaborative processes (Bartlett & Kurian, 1999; Pope et al., 2013). The information produced through this process aids the environmental conception of development proposals and the conception of decisions on consent for development actions and, if approved, the terms to develop (Pope et al., 2013). Being a tool that processes information, through more technical analysis or public participation, this data needs to be taken into account in the decision-making process, leading to the second premise on which IA is defined: IA can also be defined as a **policy tool**. Through this lens, IA is considered a successful policy innovation to approach development that includes numerous analytic approaches in a process known as comprehensive impact analysis (Caldwell, 1988; Sadler, 1996). Being a process for environmental policy, IA is frequently defined as a decision-making tool for environmental planning (A. J. Bond et al., 2010). The policy impact of IA is attributed to the level of participation, involvement, and influence that IA has on the public and organized groups (Bartlett & Kurian, 1999). This influence is mainly because Impact Assessment is formalized in at least 140 nations worldwide (Glasson & Therivel, 2019), and nearly all member nations of the UN have agreed to employ EIA in a variety of policy scenarios (Morgan, 2012).

So far, IA has been defined as a process that manages information to be used in policymaking, through aiding the decision-making process. In this context, IA can also be defined as being a process for gathering information and a system of monitoring environmental impacts that, not only aids in achieving Sustainability but is essential to the **development of sustainable approaches** to environmental management (Doelle & Sinclair, 2006; Dunster, 1992). Sustainability is a principle that has been present in IA since its “birth”. NEPA in 1969 attributes to both public and private organizations the responsibility of fostering and promoting the general welfare, creating and maintaining conditions that allow the productive coexistence of man and nature while meeting present and future generation needs (NEPA, 1969). Impact Assessment seeks to enhance Sustainability by making sure that significant environmental impacts are analyzed during the decision-making process (Fonseca, 2022a). IA’s ability to improve Sustainability is explained by it being a process based on developing knowledge, validating it, and incorporating it into the decision-making process (A. J. Bond et al., 2010). Therefore, IA is a tool for Sustainable Development, being the Sustainability perspective intrinsic to Impact Assessment (Lawrence, 1997; Nooteboom, 2007). Because of this strong relationship between IA and Sustainability, how Sustainability is defined and approached influences the environmental policy development designed and influenced by IA. The different approaches to Sustainability appear in IA practice because they incorporate, structure, and refine sustainability objectives and assessment criteria within IA objectives and evaluation criteria (Lawrence, 1997). In other words, the approach to Sustainability affects the approach to IA. Even though IA can impulse Sustainability and Sustainability parameters can be inserted into the IA process (Duffy, 1992), if an Integrative Sustainability approach is adopted, then IA is going to be less effective.

So far, we have defined IA as a process used as a policy tool to manage information that is essential to the development of sustainable approaches to environmental planning. The information generated needs to have an impact on decision-making for IA to be effective, and because of that, the information needs to be gathered before any action is taken. Therefore, IA must apply the "precautionary principle" to guarantee the sustainability of development operations and to ensure that preventative measures are taken, environmental damage is repaired at the source, and the polluter pays pay (Glasson et al., 2005; Sadler, 1996). This principle can be described as protecting the environment based on caution even in situations when there is no clear proof of harm or risk from an activity (Jalava et al., 2013). Requiring the use of the precautionary principle in decision-making is associated with the enhancement of IA's efficiency (Jay et al., 2007), which makes IA an environmental policy instrument that embodies the **precautionary principle** since it tries to detect and decrease the uncertainties as well as negative repercussions associated with development (de Sadeleer, 2002). In other words, IA creates information about development actions so decision-makers can think before acting (Morrison-Saunders et al., 2014). However, the Impact Assessment process is better comprehended if it is understood within the policy and institutional framework it is inserted (Sadler, 1996).

In this context, (Sadler, 1996) defines the "**effectiveness**" of IA as the evaluation of performance regarding the purposes set by policy and institutional functions the process is inserted. In other words, IA is effective if it "works as intended" (Sadler, 1996). Therefore, IA's effectiveness depends on the aim, and the goal depends on the policy and institutional context. As values and views shift, so do the purpose and use of IA, and these varying viewpoints also mean that IA must deal with the different perspectives of weak and strong sustainability (Glasson & Therivel, 2019). However, the purpose of IA is in dispute (Rozema et al., 2012). This diversity of effectiveness can be viewed as a strength, and (Fonseca, 2022a) associates it with IA's potential to promote a democratic debate.

Impact Assessment can be used as an umbrella term that encompasses many forms of practice and, in this dissertation, this is the IA we focus on. The IAIA (Impact Assessment International Association) uses the generic term Impact Assessment (IA) while other authors, such as Sadler (1996), consider Environmental Assessment (EA) as the generic process that comprises EIAs of a particular form of Impact Assessment. Impact Assessment is then, for this work, an umbrella term defined as a process used as a policy tool that processes information systematically, which is essential to the development of sustainable approaches to environmental planning, as well as to ensure the evaluation of the environmental impacts of proposed actions (project, program, plan, or policy) and its alternatives, and to make sure the results are properly presented to and considered by the public and decision-makers.

The IAIA Principles of Environmental Impact Assessment Best Practice establish that impact assessment should be purposive, rigorous, practical, relevant, cost-effective, efficient, focused, adaptive, participative, interdisciplinary, credible, integrated, transparent, and systematic (IAIA & EIA, 1999). These principles are integrated into one another as a rigorous and systematic impact assessment process is consequently more credible (Morrison-Saunders et al., 2014). These purposes and principles are shared by all the types of Impact Assessment and more than 40 types can be identified, ranging from Strategic Environmental Assessment (SEA) to Life Cycle Assessment (LCA) (Morrison-Saunders et al., 2014). The main types of IA are found within the four main levels: project Environmental Impact Assessment (EIA), program EIA, plan EIA, and policy Strategic Environmental Impact Assessment (SEA) (João et al., 2011; Noble, 2002). Other important IA types are social impact assessment (SIA), health impact assessment (HIA) (João et al., 2011), and Life Cycle Impact Assessment (LCIA) (Kim & Wolf, 2014). LCIA or LCA is understood by some, such as (Kim & Wolf, 2014), as a type of assessment per se, while others, such as (Manuilova et al., 2009; Tukker, 2000), understand LCA as a tool to be used in IA process.

All the types of IA also share the same operating principles. The process should provide for screening, scoping, preparation of environmental impact statement (EIS) or report, examination of alternatives, impact analysis, mitigation, and impact management, evaluation of significance, review of the EIS, decision making and follow-up (IAIA & EIA, 1999). These operating principles prove that even though IA structure might seem linear, there is room for feedback between activities, which makes IA a cyclical activity, with interaction and feedback between the steps, making impact assessment more aggressive (Glasson & Therivel, 2019; Petts, 1999; Pope et al., 2013; Sadler, 1996). These characteristics make IA a very important tool for the shift to Sustainability (Gibson et al., 2013). Some themes in IA have been highlighted not only as research trends so far but as important topics for future research and practice, such as IA as a governance tool, legitimacy in IA, and IA's ability to promote transformative change (Fonseca, 2022a). First, IA is a governance tool because it can affect decision-making. IA's governance is directly related to public participation since participation in an IA process can improve people's say in decision-making, making it more democratic (Glasson & Therivel, 2019). Second, legitimacy in IA is related to the 'consistency and fairness' of IA (A. Bond et al., 2014), which can be achieved by aiming at the good and negative impacts, as well as suggesting ways to improve the beneficial effects of the development actions (João et al., 2011). Also, legitimacy is considered one of the positive influences of IA (Ortolano & Shepherd, 1995) because the IA process is only efficient – and influences decision-making - if proponents accept the process as legitimate (Bartlett & Kurian, 1999; Gibson et al., 2013; Jay et al., 2007). Lastly, IA's ability to promote change is rooted in its origins when the US federal agencies were first required to prepare environmental 'statements'. Then, NEPA intended to alter the nature of the proposal development process such that environmental issues were routinely included alongside the regular economic and technical considerations (Gibson et al., 2013).

These topics are also related to the four main strengths of IA summed up by (Garner & O'Riordan, 1982) fundamental IA benefits, and viewed as the underlying purposes for IA practice, which are: 'consistency and fairness', 'early warning', 'environment and development', and 'public involvement' (A. Bond et al., 2014). "Consistency" is related to the approach of consistency across jurisdictions and outcomes, providing justice to all parties (A. Bond et al., 2014). "Fairness" is one of the best practice principles advocated by the International Association of Impact Assessment (IAIA & EIA, 1999), and "early warning" is an IA characteristic that guarantees that environmental factors are considered as early as possible in the decision-making process (Glasson & Therivel, 2019). As previously stated, the approach to IA depends on the context it is inserted and the same happens with IA being beneficial to 'environment and development', not to be mistaken for ‘Sustainable Development’. This is because this last term is understood as a discourse that can enable economic development interests to advance their agendas (A. J. Bond & Morrison-Saunders, 2009). ‘Environment’ is the center of IA decision-making because the positive outcomes are going to be perceived by the communities and by the biophysical environment (João et al., 2011). Finally, ‘public involvement’ is directly related to one of the basic principles of Impact Assessment, which states that IA should be participative (IAIA & EIA, 1999). Public participation is an important factor for the articulation and legitimation of IA, and consequently for achieving its goals (Rozema et al., 2012).

However, despite IA’s strengths, IA has some important challenges ahead. A. Bond & Dusík (2020) highlighted as key challenges the global megatrends associated with climate change, biodiversity, and resource use, as well as with the fourth industrial revolution and neoliberal politics (or economic stress). In this sense, the Impact Assessment of Circular Economy actions has proven that CE can lessen the extraction of virgin raw materials and relieve land use demands, consequently decreasing biodiversity burdens (Ruokamo et al., 2023). Also, the Circular Economy is viewed as a possible solution to the socio-economic and environmental problems that are brought about by the technological transformations of Industry 4.0 (Upadhyay et al., 2023). Therefore Impact Assessment might benefit from CE strategies and mindset to deal with the impacts of this new industrial revolution, impacts such as a potentially higher overall footprint as a result of a lower impact per unit produced, as well as potential significant impacts resulting from the emergence of new livelihoods to replace jobs lost in traditional occupations (A. Bond & Dusík, 2020). Finally, because Impact Assessment is in its essence and unavoidably political (Cashmore et al., 2010), and the timeframe throughout which it has been the most common decision-support tool corresponds to neoliberal governance (A. Bond & Dusík, 2020), IA has to deal the unsustainable set of practices intrinsic to capitalism (Sneddon, 2000). In this sense, although the current framing of most Circular Economy discourses is far from providing Sustainability (Hobson & Lynch, 2016), CE contains and enables different types of material combinations (Hobson, 2016) thus having the potential for significant governance changes. Studies of IA will need to include criteria to encompass criteria that can assess CE policies (Wu et al., 2022) to meet the European New Circular Economy Action Plan’s (EC, 2020a) proposition to evaluate Circular Economy strategies.

2.3. Circular Economy

Circular Economy (CE), as the previous terms defined, is a concept in dispute, and as Sustainability and Impact Assessment, how CE is viewed changes. The origin of the term is often attributed to Kenneth Boulding's publication "The Economics of the Coming Spaceship Earth" who stated that Earth was a "closed system" as opposed to an "open system" (Boulding, 1996). So an "open economy" would be how economists viewed the economy in the past with unlimited input resources and output sink abilities, and in a "closed economy," resource and sink nature services should be the primary concern of the economy. Previously, the physiocrats understood that agriculture was the base of economic progress, and the concept of a circular flow of income was defined by Francois Quesnay in 1758 as the money that circulated through the economy as blood flowed around the body (Charles, 2018). Industrialists developed the concept of industrial symbiosis and industrial ecology in the late nineteenth and early twentieth centuries through the notion of industrial metabolism, in which an industry instead of operating through a series of separate inputs and outputs, is understood as an 'organism', where "waste-is-food" (Fischer-Kowalski & Haberl, 1998). Both ideas would be later part of the Circular Economy thinking (Murray et al., 2017).

Only then do we arrive at the concept most authors understand as the roots of the Circular Economy definition. The concept of a Spaceship Earth was presented by (Boulding, 1996) who defines the Earth as one spaceship with scarce resources for extraction and space for pollution, and in which humans must find their place in the environmental cycle that can continuous reproduction of material, for which the best fit is the "spaceman economy". This idea of a closed-loop economy was later developed by Stahel and Reday-Mulvey, influencing German and Japanese policy-making in the 1980s and 1990s (Moriguchi, 2007; Triebswetter & Hitchens, 2005). This inspired China to apply the Circular Economy as the major environmental framework for policy decision-making. Murray et al. (2017) state that, at least in the Chinese context, the Circular Economy and most of the sustainable schools of thought emerged from legislation, which makes it, just as Sustainability and Impact Assessment a politicized concept. Circular Economy, within Chinese legislation, has been framed very similarly to Industrial Ecology, with three levels of initiatives: enterprises (micro), eco-industrial parks (meso), and regions (macro) (Navare et al., 2021; Prieto-Sandoval et al., 2018; Suárez-Eiroa et al., 2019). Since its first use in legislation, the term has had many meanings and associations by various authors, usually with the common idea of a cyclical closed-loop system (Murray et al., 2017).

Just as Impact Assessment, Circular Economy can also be understood as an umbrella concept since it can encompass and account for a set of diverse phenomena (Blomsma & Brennan, 2017), and thus it is also a politicized concept and a notion in dispute. Circular Economy is here explained by the different Sustainability foundations it can have. (Johansson & Henriksson, 2020) identify two types of interpretation given to circularity based on policy reports analysis: Weak and Strong circularity. The first one is defined as a cycle that has a closed outflow to nature but an open input from nature (Johansson & Henriksson, 2020). In other words, secondary resources (such as recycled materials) will only be used to be added to the extraction of natural resources. Because natural resources are viewed as limitless, so is resource extraction, making the size of the circle bigger since there is continuous material input and consequently an increase of material circling within the economy. This ideal is aligned with the concept of Weak Sustainability. Neglecting what causes waste generation, such as rising consumption, might explain the current success of a Weak Circularity (Johansson & Henriksson, 2020) given that this weak conceptualization has been largely adopted in policy, particularly regarding waste policy (Johansson & Corvellec, 2018). This is a similarity regarding Impact Assessment policy: both need to be more legally binding to be truly effective (Johansson & Corvellec, 2018; Therivel, 2020). Regions of the world that have implemented Circular Economy policies are China, the United States, the European Union, and Columbia (Kirchherr et al., 2023; van Hoof & Saer, 2022).

The European Union Circular Economy Action Plan (EC, 2020a), which simply aims for increased circulation, does not target the decrease in usage and extraction of primary materials, thus being more aligned with a Weak Circularity approach. Also aligned with a Weak Circular Economy is the definition of the Ellen MacArthur Foundation, for which a Circular Economy is a restorative and regenerative industrial system based on the 'zero waste principle' (Ellen MacArthur Foundation, 2014), which means waste is a resource, but there is no diminishing of primary resource extraction. The idea of a 'zero waste' aligned with continued economic growth is the new dominant discourse of Sustainability and the danger of de-politicizing the discourse in practice is that waste not only is added to the continuously growing extraction of natural resources but the cause of waste generation is not addressed and it is seen as merely a commodity (Kalina, 2020;

Valenzuela & Böhm, 2022). Furthermore, in a Weak Circular Economy, people and business owners are the ones held accountable for circularity rather than the government, which in this case just works and serves as a facilitator of economic growth. (Johansson & Henriksson, 2020). From this weak perspective, the consumers are made responsible for correctly separating, reducing, and disposing of waste, and the companies build their projects based on resource efficiency, with technical innovation and waste valorization at the center of efforts. (Savini, 2023). A key part of this 'weak' approach is the scale of change focused on the individual and the household. This type of change is understood to be limited regarding its ability to effectively decrease environmental impacts (Hobson, 2020). This process of individualization entails not only the change of responsibility for social change from the estate to the private capital but also from the citizen who starts to be seen as a consumer (Hobson & Lynch, 2016; Johansson & Henriksson, 2020).

On the other hand, Strong Circularity aims for Strong Sustainability, being defined as a closed loop, with minimized input and output (Johansson & Henriksson, 2020). In this case, it is important to note one of the main Circular Economy challenges: entropy. Materials cannot be circulated endlessly within an economy since they decrease in quantity and quality with each cycle or use (Korhonen et al., 2018; Reuter et al., 2019). Because of that, in a Strong Circular Economy, there is the need for inputs to be from recovered or renewed resources, as well as for a general reduction in material demand and a decrease in the economic throughput (Korhonen et al., 2018). This idea of circularity goes back to the suggestions of (Boulding, 1996) who proposed a stabilized (or diminished) production and consumption, limiting the flow of materials, and consequently limiting the size of the circle. The state has overall responsibility for the transition in this powerful model of circulation, while producers have the responsibility of taking back their products to promote circulation (Johansson & Henriksson, 2020). Within Strong Circularity, individual consumers start to be seen as socio-political subjects with collective responsibilities (Savini, 2023). Strong Circular Economy is the ideal form of Circular Economy and it would increase opportunities for social participation, social justice, equality, integration, and solidarity (Z. Liu et al., 2023). Therefore, planetary boundaries are viewed as a limit for material circulation, and the scarcity of resources is a reality, even for minerals that exist in vast global deposits (Johansson & Henriksson, 2020).

Circular Economy and Impact Assessment, not only share a common goal of achieving Sustainability but are also linked through the interdependence created by the fact that one of the most important things to achieve Circular Economy is assessing its impacts previously (Boldoczki et al., 2021; Haupt & Hellweg, 2019; Korhonen et al., 2018; Luthin et al., 2023; Navare et al., 2021; Roos Lindgreen et al., 2022; Velenturf & Purnell, 2021a). The need for assessment comes from weak circular economy practices, which do not always lead to more sustainability (Boldoczki et al., 2021; Helander et al., 2019; Millar et al., 2019; Schaubroeck, 2020; Velenturf & Purnell, 2021a). This is usually explained by the rebound effect (technological development resulting in increased energy consumption) (Zerbino, 2022) and by Jevon's paradox (resource efficiency leading to increased use of that resource rather than by its decreased utilization) (Mayumi et al., 1998). At a company level, many Weak Circular practices lead to unsustainable results given the lack of challenging the capitalist system we are inserted in, which leads to practices that can draw our attention away from the planned obsolescence embedded into some practices the manufacturing and advertising that promote wasteful logics (Valenzuela & Böhm, 2022). Another reason to assess the impacts of Circular Economy actions is to evaluate the impact of using biotic resources, since they are believed to be naturally circular and sustainable (Haas et al., 2020). The need for Impact Assessment here lies in the importance of assessing the attempts to shift to biomass and their impact on the ecosystem, so they do not result in forest resource overexploitation, shifts in land use, damage to biodiversity, and rising competition for territory (Navare et al., 2021). Therefore, to truly achieve a Strong Circular Economy as a new perception of the economic system (Andersen, 2007), projects should be assessed by their global environmental sustainability impacts' contribution (Korhonen et al., 2018). Given that the Sustainability aimed by the Circular Economy also has a social aspect, achieving the changes aimed by CE policy measures may implicate the well-being of people (Pitkänen et al., 2023). These social impacts should be assessed in particular because the distribution of CE's positive and negative effects are not always equal for different socio-groups of people and geographical regions, being the negative effects (like an increase in job losses) are more likely to happen in low - to upper-middle-income nations (Repp et al., 2021). Thus, assessing CE would also avoid nature conservation policies which cause exported environmental damage to boomerang (reverberate) into nations with high environmental standards – boomerang effect (Mayer et al., 2005).

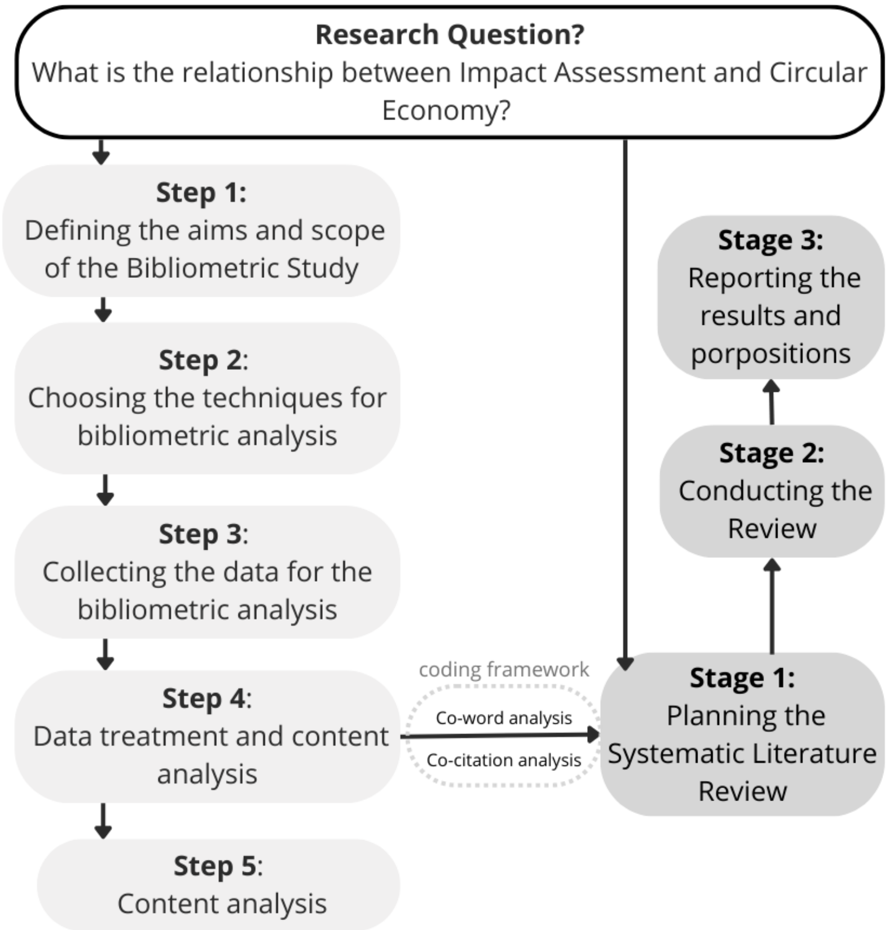
To assess the sustainability of circularity (usually circularity means 'CE-related practices') (Schaubroeck et al., 2021), the most assessment methodologies are material flow analysis (MFA) as well as life cycle assessment (LCA), while (Sassanelli et al., 2019) found that LCA is the most used method for assessing Circular Economy ability in decreasing the environmental impacts. Life Cycle Impact Assessment or Life Cycle Assessment is an Impact Assessment tool used to assess the environmental impact of a product, service, or process, as well as determine potential impacts throughout the product's life cycle (Manuilova et al., 2009). LCA is an important tool in Impact Assessment processes (Manuilova et al., 2009; Morero et al., 2015; Tukker, 2000) given that IA is an umbrella concept that encompasses a vast range of tools and techniques, including LCA (Glasson & Therivel, 2019; Manuilova et al., 2009). Although LCA is the most used technique for assessing the impacts of Circular Economy strategies on the environment, many aspects of the evaluation are lacking (Navare et al., 2021) and Impact Assessment still has much do to if it aims to help CE strategies already being implemented to be truly effective. It is important to note that many LCA studies do not properly incorporate environmental implications related to land use and natural degradation of resources (Navare et al., 2021), and integrated impact assessment methods aiming for sustainability (such as those that incorporate technical, economic, and socioeconomic evaluations) can produce more dependable and precise outcomes (Bellezoni et al., 2022). Therefore, this idea reinforces the idea that LCA is a tool that can be applied to the IA process to improve it (Manuilova et al., 2009), while IA keeps on being a process able to support decision-making regarding a broad range of activities while being integrative regarding the use of tools and methods.

To achieve a Circular Economy, (Suárez-Eiroa et al., 2019) developed operational principles of circular economy taking into account the different levels of Sustainability. Each of the seven operational principles encompasses important CE strategies derived from a literature review. First are the *Target Operational Principles,* which emerge from CE's theoretical goals and serve as routes between theory and some real execution strategies. Those principles are: (1) adjusting inputs to the system to regeneration rates and (2) adjusting outputs from the system to absorption rates. Second, are the *Core Operational Principles* which did not directly emerge from theory but are essential for achieving CE and indirectly can adjust resource input and waste output. They are: (3) closing the system, (4) maintaining resource value within the system and (5) reducing the system's size. Finally, *Transversal Operational Principles* are required to ensure the effectiveness of all the other principles. These are: (6) designing for a circular economy and (7) educating for a circular economy.

CHAPTER 3 – METHODOLOGY

This chapter contemplates the strategies used to achieve the objectives presented in the Introduction chapter of this study. In this chapter, the authors justify and reference the methodological decisions made by detailing the procedures utilized to collect, analyze, and interpret data. A Bibliometric Study and a Systematic Literature Review are the two main methodological approaches, as will be seen, and therefore the chapter is divided into two topics. The first step of this methodology (the Bibliometric Analysis) aims to be a broader analysis, evaluating first a large volume of documents to find patterns. Those patterns are then applied to analyze a smaller and more focused number of papers through content analysis. The first step showed the need for an even more focused and systematic approach. The second step of the methodology (Systematic Literature Review) aims to be a narrower and more focused assessment than the first by adding one more variable to the analysis.

Figure 1. Methodology Stages and Steps



Source: Authors (2023)

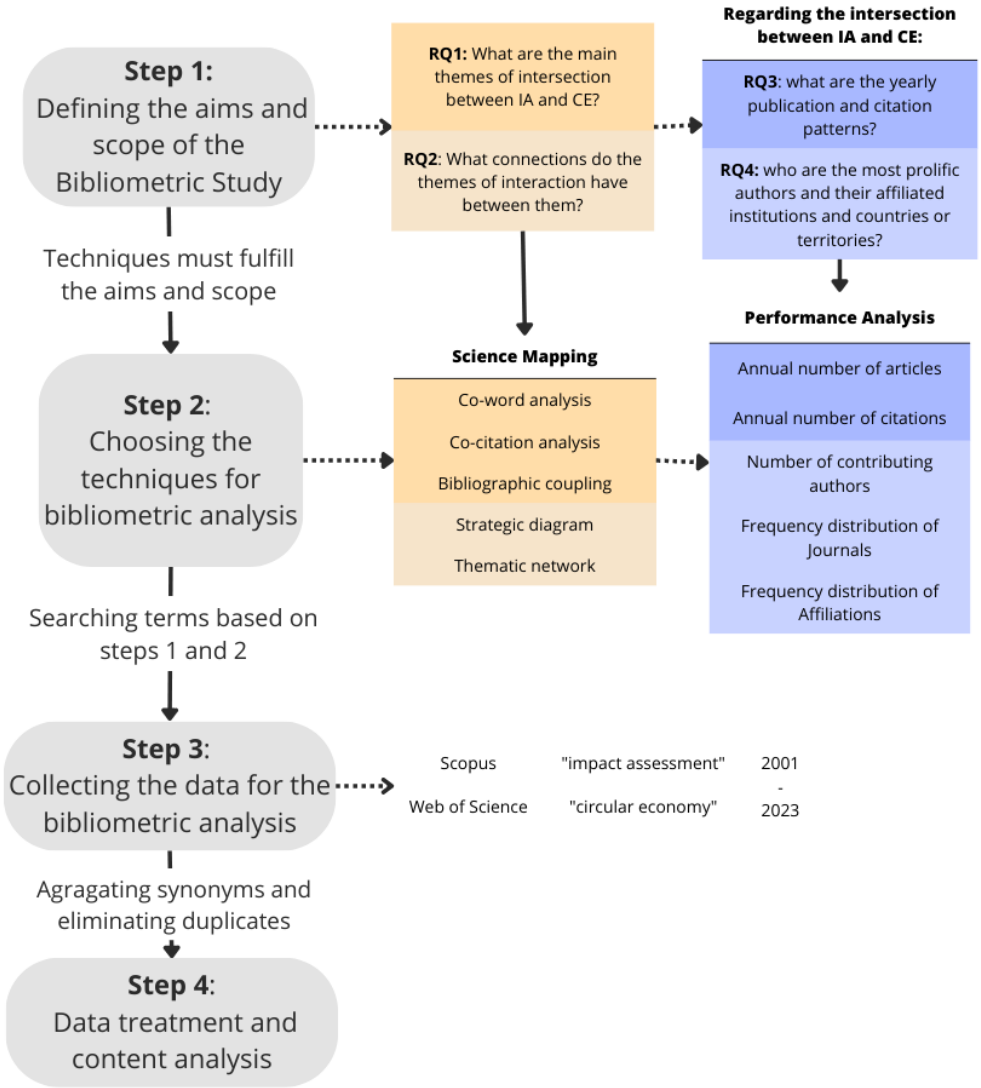
2.1. Bibliometric Study

The bibliometric methodology was chosen because of its ability to examine documents quantitatively and qualitatively. A bibliometric analysis organizes information in a particular subject area by analyzing bibliographical material from an objective standpoint (Albort-Morant & Ribeiro-Soriano, 2016). Therefore, the first part of this study aims to comprehensively explore the conceptual links between Circular Economy (CE) and Impact Assessment (IA). Accordingly, the research question addressed in this Chapter is: What are the links between the concepts of CE and IA in the literature?

Because the study is usually built to handle big volumes of bibliometric data, *a priori* search in Scopus and the Web of Science database was carried out to guarantee there is a large enough dataset to warrant it (Donthu et al., 2021). For this study, the number of papers is large enough for a Bibliometric analysis, as will be seen in further steps. Furthermore, interpretations of bibliometric analysis frequently rely on both objective (e.g., performance analysis) and subjective (e.g., thematic analysis) evaluations developed by informed approaches and procedures (Donthu et al., 2021). In other words, even though bibliometric techniques are quantitative by nature, they are employed to make assumptions about qualitative characteristics (Wallin, 2005), allowing for the discovery of knowledge gaps, the generation of new research questions, and the positioning of the authors' intended contributions to the fields.

The main goal of this section of the study is to identify the areas where IA and CE connect. To achieve this, we examined the literature on Impact Assessment and Circular Economy separately as well as the area of intersection. Since they contain the most significant papers in these study fields, we selected the Scopus and Web of Science databases. Additionally, those databases offer the largest global collections of publications and papers and have been consulted for numerous other systematic literature assessments. Therefore, to achieve the mentioned goal, this dissertation employed the method for bibliometric analysis proposed by Donthu et al. (Donthu et al., 2021), who divided the Bibliometric Study into 4 steps presented in Figure 2.

Figure 1. Bibliometric Analysis Steps



Source: Authors (2023)

<u>Step 1: Defining the aims and scope of the Bibliometric Study</u>

To uncover the links between the concepts of CE and IA in the literature, a bibliometric analysis is carried out. To this end, five research questions derived from this study's main research question are designed to fit the goal of the first part of this study, which is to identify the areas where IA and CE connect and aid in the achievement of this dissertation's main goal. The Research Questions for this Bibliometric Study are as follows:

- RQ1: What are the main themes of the intersection between IA and CE?
- RQ2: What connections do the themes of interaction have between them?
- Regarding the intersection between IA and CE:
    - RQ3: What are the yearly publication patterns?

- RQ4: Who are the most prolific authors and what are their countries or territories?

In the context of this research, bibliometric analysis attempts to examine bibliographical content with information from the thematic fields of Circular Economy and Impact Assessment from an objective, quantitative perspective. Reoccurring patterns in the data retrieved from the materials being examined may indicate researchable issues or relationships worthy of further investigation.

It is important to note that the bibliometric analysis is a step before a content analysis. Both analyses will be combined for this work. Therefore, the bibliometric analysis has an aim in itself but also aims to inform and guide the content analysis. This is done because, despite its ability to identify the more important works, analyze the connections between them, and recognize changes in the intellectual framework of the research disciplines (Donthu et al., 2021), bibliometric analysis does not replace in-depth reading and fine-grained content analysis (Ramos-Rodríguez & Ruíz-Navarro, 2004).

Step 2: Choosing the techniques for bibliometric analysis

Following are the two bibliometric techniques that have been selected to fulfill the aims and scope specified in the first step: (1) science mapping and (2) performance analysis. The first one focuses on the relationships between research topics while the second analyses the contributions made by the works being analyzed (Donthu et al., 2021). Both techniques are combined for a more complete analysis. Because science mapping examines the connections between the components of research and the intellectual organization of a discipline (Baker et al., 2021), it was the chosen technique to answer the first Research Question (RQ1).

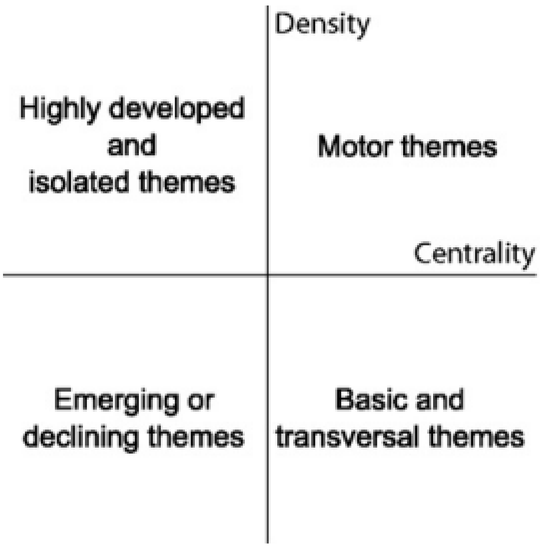
Science mapping techniques chosen to answer RQ1 are co-word analysis and co-citation analysis. The first recognizes that words that frequently occur together have a thematic relationship (Donthu et al., 2021). The approach used in this study's **co-word analysis** measures the frequency of keywords to look for evidence of conceptual connections between CE and IA. This method is thought to be effective since keywords are reliable indications for conceptual and discipline-related links generated by writers themselves to concisely describe their study (de Jong et al., 2015). Conclusions about the strength of association for each author's keyword can be made by counting the instances of each keyword that appear in CE articles only, IA articles only, and articles that address both fields of research at the same time. In other words, keyword occurrences in articles that contained both terms were taken into account (direct linkages), as well as keywords that commonly appeared in the different literature bodies (indirect links/co-occurrences). For this work, themes that were pertinent to both fields were indicated by co-occurring words. Following Henry et al (2021), co-occurring terms were only considered significant if they were presented in at least 15% of the collected articles for each field. However, it can be said that there are certain drawbacks to using keywords for this research. For example, certain keywords can be quite wide, making it difficult to place them in a specific thematic cluster (Donthu et al., 2021). Therefore, the three aforementioned methodologies - **most cited keywords**, **co-appearance** in the fields, and **most significant keywords** within the fields - are combined with the creation of a **co-word network** and a **keyword thematic map** to complete the science mapping component of this method since each bibliometric analysis technique demonstrates distinct advantages. For the first three techniques mentioned, data handling is done manually (using Bibliometrix and Excel software), and Bibliometrix is used to help with the network and theme map development.

The second technique mentioned, **co-citation analysis**, similar to co-word analysis, implies that works that are frequently mentioned together share a common theme (Donthu et al., 2021). A co-citation relationship exists between two documents when a third document cites both of them (Chang et al., 2015). That means that the co-citation strength of two papers increases with the number of documents that cite them. The co-citation performed in this study helps answer RQ1 because this technique enables not only the identification of the most significant articles from their samples but also the identification of the most important areas of study (Y. Liu et al., 2019). For this work, it is also created a "**co-citation matrix**" for the retrieved articles, which contains data about the works that those articles cite, to determine the intellectual hierarchy of the field. Similar to the co-word analysis, the **most cited references**, **co-citation across the fields,** and **most significant references** within the fields are analyzed. The co-citation matrix is further examined to find groups of articles that point to underlying research areas, thus, creating thematic clusters. However, this technique only focuses on the most “influential” articles (Y. Liu et al., 2019) and excludes more current or niche publications from its theme clusters, making this method more appropriate for dealing with knowledge foundations than with emerging topics (Donthu et al., 2021). Due to their weaknesses, the previously mentioned co-word and co-citation analysis methods will be followed by a thematic coupling.

Additionally, it is important to note that the main terms from the preliminary keyword and co-citation analyses performed for answering RQ1 served as the basis for the coding framework to guide the second part of this dissertation, which is based solely on a Systematic Literature Review (SLR) of the intersection area between the field of IA and CE. This method is here referred to as "a priori coding" (Crabtree & Miller, 2023; Thomé et al., 2016) because the collection of codes – or set of parameters - is developed through a bibliometric analysis rather than emerging from a theoretical basis or full text reads. In other words, the techniques performed so far will guide the choice of words for database search during the SRL phase of this research process.

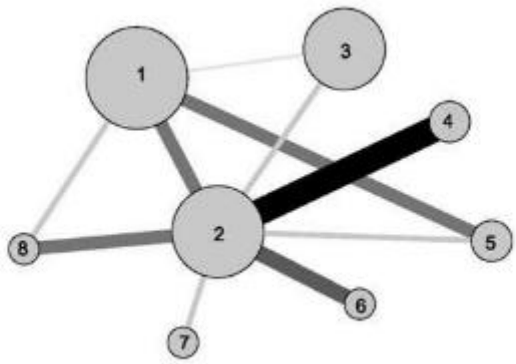
The RQ2 is related to the detected themes where IA and CE share notable connections. This question is answered by using two science mapping techniques that are applied to the data retrieved from the databases. They are **a Strategic Diagram** and a **Thematic Network**. To understand the first one it is important to note that the keyword clusters that result from co-word analysis are treated as themes (Cobo et al., 2011). The themes can be then classified into median and mean values for both density and centrality (Cahlik, 2000). Thus, a Strategic Diagram is created by plotting the themes in a two-dimensional graphic based on their centrality and density rank values (median) or values (mean) (Cobo et al., 2011). An example of a Strategic Diagram is presented in Figure 3, where “motor themes” are highly developed and crucial for a study field's organization. The positioning of these clusters in this quadrant suggests that they have external connections to ideas that apply to other, conceptually similar subjects. Themes in the upper-left quadrant are extremely specialized and peripheral, making them of just minor value for the connection here researched. Emerging or declining themes are both underdeveloped and marginal, but transversal and universal, fundamental themes are critical for this connection between IA and CE investigation. Furthermore, the links between the themes form a network graph known as a thematic network. Each thematic group is labeled with the name of the most significant keyword in the related cluster created, which is characterized here by the theme's most central keyword (2011). Here, for the labeling of the themes, the terms that do not appear in both fields of study at the same time are eliminated. Additionally, the period analyzed is divided into subperiods to understand the Thematic Evolution of the area of integration. For every subperiod analyzed, a set of discovered themes is obtained as a result of the co-word analysis. Several visualization techniques can be applied to provide a visual representation of the results and Cobo et al. (2011) suggest to use of theme areas to display the thematic evolution and strategic diagrams to showcase the results, which is performed with the aid of Bibliometrix. Figure 4 shows an example of a Thematic Network in which the volume of the spheres is proportional to the number of documents corresponding to the keywords within the subject and the thickness of the link between two spheres is proportional to the intensity of the relationship between themes.

Figure 2. Strategic Diagram model



Source: (Cobo et al., 2011)

Figure 3. Thematic Network Model



Source: (Cobo et al., 2011)

It is necessary to identify these themes (clusters/communities) from the networks built to identify the key areas of intersection between IA and CE. For that, network metrics are used to enhance the evaluation of bibliometric analysis, as the community detection algorithm determines how many communities or clusters are found (Budel & Van Mieghem, 2021). Here, the clustering approach is used to identify node clusters that have strong links inside them but weak connections between them (Mkhitaryan et al., 2019). Similarity or proximity between nodes is frequently described in the context of complex networks by the number of links or the weights of the links in weighted networks (Budel & Van Mieghem, 2021). In this context, a module is distinguished by a higher density of "inside" links compared to "outside" links (Fortunato & Castellano, 2012). As a result, modularity serves as a metric for comparing the effectiveness of various community recognition techniques as well as an objective function for determining how best to divide the graph's vertices into communities (Blondel et al., 2008). Modularity is a widely used metric to analyze how well a network is divided into communities (Mkhitaryan et al., 2019), and in graph theory, the modularity of a graph serves as an indicator of the effectiveness of a particular network division based on the number of links between nodes in the same cluster (Budel & Van Mieghem, 2021). Thus, the network modularity clustering metrics used are the Louvain Algorithm, Leading Eigenvector Algorithm, and Fast Greedy Algorithm.

For the **Louvain** algorithm to function, each network node is first given a unique community, with an equal number of communities as there are nodes. Then, for each node i, the approach takes into account its neighbors j, and the gain in modularity for removing i from its community and putting it in the community of j is assessed (Blondel et al., 2008). In other words, this method first discovers small communities by optimizing modularity locally and then combines nodes belonging to the same community to form a network (Mkhitaryan et al., 2019). This method is repeated until maximum modularity is achieved and a community hierarchy is established. Additionally, the **Leading Eigenvector** is the second clustering measure employed. This approach is based on the assumption that modularity may be represented succinctly in terms of a network's eigenvalues and eigenvectors (Newman, 2006). Eigenvector is a network centrality measure. Eigenvector centrality increases for nodes connected to other highly connected nodes, where each node represents a study element (Donthu et al., 2021). A higher value of eigenvector centrality, in particular, reflects the importance of the node in the network responsible for transferring information to other highly linked nodes. The third and last method for creating clusters used in this work is the **Fast Greedy** algorithm. This method is an upgraded version of the greedy algorithm (Clauset et al., 2004) that works by linking vertices to maximize modularity. After a repeated procedure in which modularity is no longer maximized, the network is partitioned into communities (Mkhitaryan et al., 2019). For this work, the three algorithms were run to analyze which resulted in the most appropriate clusters for this work.

The questions RQ3, RQ4, and RQ5 are related only to the intersection area between Impact Assessment and Circular Economy. That means that the methods are only applied to articles that contain both terms (IA and CE) within the same research paper. A performance analysis was the approach adopted for these articles. Performance analysis of certain themes or entire thematic areas can analyze quantitatively and qualitatively the contributions of groups of papers to the overall study field, identifying the most influential, fruitful, and prolific subfields (Cobo et al., 2011). In order answer to RQ3, we use the most widely used performance analysis criteria, which is the **annual number of articles** (Total Publications –TP or Publications per Year) (Donthu et al., 2021). To address RQ4, the measurement parameter was the Most Relevant Authors and the **frequency distribution of Countries** (Source - Countries' scientific production).

Step 3: Collecting the data for the bibliometric analysis.

The third step includes setting up search terms based on the research areas covered by the first step's study scope and gathering the data needed for the second step's chosen bibliometric analysis techniques. Additionally, in this phase, search terms must be defined in a way that will produce a sufficient number of results for bibliometric analysis (Donthu et al., 2021). Therefore, the databases chosen to retrieve data are the Web of Science and Scopus databases, from which research was conducted within the following research categories: title, abstract, and author keywords. The search string that is chosen to contemplate the Circular Economy research field is “circular economy”, while for the field of Impact Assessment, the search string used is “impact assessment”. Because this Bibliometric Analysis contemplates a Content Analysis, to guarantee the quality of the documents retrieved, the types of documents excluded from the analysis are revision articles, editorial material, book chapters, letters, abstract reports, reports, data papers, conference reviews, book, short survey, note, and review. Additionally, another criterion for the inclusion of articles was the language of the document. Only documents in English and Portuguese are included and the documents published before 2001 were excluded from the analysis. The period studied (from 2001 and 2023) was chosen because it is the period of publications available for the Circular Economy research area in the Scopus database.

<u>Step 4: Data treatment and content analysis</u>

For Science Mapping and following Performance Analysis, the data was cleaned and duplicate entries were deleted. The first analysis executed was the co-word analysis. So, right after data collection, the following synonyms are considered for keyword data treatment:

- Life cycle assessment (lca), life cycle analysis (lca), life cycle impact(s) assessment (lcia), life cycle impact analysis (lcia), life cycle environmental analysis, life cycle environmental assessment, environmental life cycle assessment, environmental life cycle analysis, life cycle environmental impact(s), life cycle environmental impact assessment
- environment(al) impact(s) assessment (eia), environment impact(s) assessment
- environmental impact(s) analysis, environment impact(s) analysis, environment(al) impact evaluations)
- Environment assessment, environmental assessment
- environment analysis, environmental analysis
- environmental impact(s), environment impact(s)
- Health impact(s) assessment, health-related impact assessment, environmental health impact assessment
- strategic environment(al) impact assessment(s) (seia), strategic environmental assessment (sea), strategic environment assessment, strategic impact assessment
- case study, case analysis, case research, case report, case study analysis, case study research, case-based learning, case-study research strategy, cross-case analysis, multiple-case study, case-crossover study/analysis

The bibliometric and intellectual structure were summarized after the chosen science mapping methodologies outlined in the second stage were applied to the retrieved data. A performance analysis was conducted to examine the intersection of the research fields of IA and CE, and the research components of the data that encompass the intersection area between the two fields were summarized. For performing the techniques previously selected, the Bibliometrix package in R and Excel were chosen tools to aid the analysis.

Step 5: Content Analysis

After data collection and data treatment, a personal database with articles related to Impact Assessment and Circular Economy is created. After applying the science mapping techniques selected it is possible to determine key areas key of intersection between IA and CE, represented by keywords. Within the fields of titles, abstracts, and author keywords as well as any combination of those three criteria, the collected article library allowed for filtering and keyword searches. Full articles were examined to see whether they could support cluster formation and other bibliometric tendencies, which would further the content analysis. Understanding each cluster's content and the significance of the publications in that cluster is crucial for comprehending the results of the bibliometric analysis (Donthu et al., 2021). The causes of these patterns were then qualitatively evaluated to see if they were due to common conceptual frameworks. For the data extraction, the criteria for article selection is based on the aim of this study: this bibliometric analysis tries to understand the approximation and reciprocal need between the research areas, as well as trying to explain the reason why this approximation is happening in specific areas. To deepen the content analysis, a Systematic Literature Review is proposed to analyze solely the intersection area between the research topics of Impact Assessment and Circular Economy.

2.2. Systematic Literature Review

After identifying and exploring the conceptual links between Impact Assessment and Circular Economy through a Bibliometric Study, the second part of this dissertation aims to summarize and evaluate the existing literature on CE and IA to understand the relationship between the fields analytically and systematically (Hart, 1998). To achieve this purpose, the Systematic Literature Review is the approach employed in the second part of this dissertation, which can assess what has already been done, as well as indicate the gaps in existing research (Knopf, 2006). The procedure identifies, assesses, and synthesizes the relevant literature related to a specific research question while reducing systemic error or bias (Thomé et al., 2016). Furthermore, among the benefits of SLR are its ability to ease the generalizability of findings by regrouping similar results from different populations or interventions, to allow a systematic assessment of relationships among variables, and to systematically report procedures and methods, improving accuracy or at least allowing verification (Mulrow, 1994). Because of the different views that exist within the fields explored in this dissertation, it is expected that, in completing this research, this SLR can contribute to the creation of knowledge in the IA and CE areas in a critical manner.

In this context, Systematic Literature Reviews are different from traditional ones because they use a more rigorous and well-defined review procedure, with methods that include thorough searches for all potentially relevant research (Thomé et al., 2016). This SLR searched for relevant documents using *a priori* coding generated by the Bibliometric Study conducted in the first part of this work. The coding framework was applied to the articles that are located within the CE and IA intersection to investigate the relationship between Impact Assessment and Circular Economy, specifically identifying the types of relationships that exist between the concepts. The SLR was then conducted employing Tranfield *et al*.'s (2003) methodology for a Systematic Literature Review. In this sense, systematic reviews may at first seem less ideal for the social sciences because they are typically used in fields and disciplines that prioritize a positivist and quantitative tradition, such as medicine (Tranfield et al., 2003). Thus, the chosen technique applies SLR to social science to increase the scientific rigor of the reviewing process while making the method viable for domains involving disputed ideas.

This Systematic Literature followed Tranfield *et al*.'s (2003) steps but also acquired some characteristics of an Integrative Literature Review to ensure the completeness of the analysis. To this aim, the extracted information identifies and collects data from studies within both researched fields to avoid bias and include an objective portrayal of opinions from each field (Cronin & George, 2023). Furthermore, this SLR proposes not only summarizing and assessing documents but also critically analyzing them and contributing to the literature and practice of the fields of knowledge of Circular Economy and Impact Assessment. Therefore, this review is divided into three stages and seven steps, as shown in Figure 5.

Figure 4. Stages and Steps of the Systematic Literature Review

Stage I – Planning the review
Step 1 - Identification for the need for a review
Step 2 - Preparation of a proposal for a review
Step 3 - Development of a review protocol
Stage II – Conducting the review
Step 4 - Applying search strings in the databases
Step 5 - Reading of document's abstracts and application of inclusion and exclusion criteria
Step 6 - Study quality assessment
Step 7 - Data extraction and synthesis
Stage III – Reporting and Propositions
Step 8 - Descriptive, thematic and critical analysis

Source: Authors (2023)

Stage I: Planning the review

This first stage is crucial to the SLR since it leads to other components of the process. The document that results from this stage is the Research Protocol (see Appendix A). This stage comprises three steps: 1) identification of the need for the review; 2) Preparation of a proposal for a review and 3) development of a review protocol. Regarding **Step 1**, the conceptual framework of the research fields and the identification of the problem's importance established in the earlier sections of this dissertation serve as the foundation for the need for a review. A circular strategy might not always be sustainable, and by analyzing the effects of circular activities, impact assessment may assist in making the transition to a CE effectively sustainable. In this sense, the significance of this work can be defined by the need for understanding the relationship between Impact Assessment and the Circular Economy. Additionally, for **Step 2**, Tranfield *et al.* (2003) suggest conducting scoping studies to determine the amount and importance of the literature as well as to focus on a particular topic or theme. For this work, this Step consists of the Bibliometric Study, which creates the *a priori* coding framework. For this work, this coding includes the preliminary keyword and co-citation analyses.

Finally, for **Step 3**, to generate the Research Protocol, a research question specifically for the SLR was developed: (RQ6) What are the types of relationships between

Circular Economy and Impact Assessment? The review only includes peer-reviewed articles from the Social Science Citation Index (Web of Science) and Scopus databases, considering the amount of data they cover (Echchakoui, 2020). Additionally, it is important to use two or more databases to ensure greater research diversity (Thomé et al., 2016). To answer this question, and based on the Bibliometric Study results, this study used the search strings “circular economy”, “impact assessment” and “sustainability” aiming to allow for critical analysis and replication by others, as well as informed acceptance, improvement, or disagreement with the original claim (Valentine & Cooper, 2008). Additionally, since the oldest CE-related document within the bases is from 2001, the articles retrieved range from 2001 and 2023. Finally, we add that only documents in English and Portuguese are considered.

Stage II: Conducting the review

The second stage of the Systematic Literature Review starts with using the pre-defined search strings in the databases chosen (**Step 4**). Therefore, the terms selected through *a priori* coding, which in turn are based on key areas of intersection between IA and CE, are searched in the fields of author keywords, abstract, and title. This results in the data being researched. The subsequent step (**Step 5**) of the SLR consists of the review of the document’s abstracts and the application of inclusion and exclusion criteria (Table 1), which are: (i) Only scientific articles are considered for this SLR. This means that all gray literature, such as newsletters, reports, working papers, and theses were excluded from the review. Although risking causing research bias, this choice of excluding gray literature is based on the difficulty in finding this type of document in typical bibliographic databases or indexes (Thomé et al., 2016). (ii) Only articles that adhere to the research question are included, meaning that they must relate to Impact Assessment and Circular Economy at the same time. (iii) The period of publication considered for the inclusion of articles ranges from 2003 to 2023. This period is based on the date of the first publication retrieved with the use of the “circular economy” search string. Because this dissertation aims to understand the integration that exists between the fields, articles published before 2001 would not aid in achieving this goal since they were only Impact Assessment related. (iv) Only articles available through the CAPES Journal Portal are considered for analysis. Brazilian researchers linked to Brazilian universities and research institutes have access to a large number of article databases through the referred Journal Portal. (v) Studies written in English are considered since it is the language in which the most important scientific publications can be found. Studies in Portuguese were not found with the use of the chosen search strings. (vi) Documents with less than three pages were not included to ensure the retrieval of scientific articles only.

Table 2. Inclusion and Exclusion criteria

Criteria	Inclusion	Exclusion	Aim
Academic articles	Academic articles	revision articles, editorials, books, letters, abstracts, reports, data papers, literature review surveys, notes	Ensure that only scientific articles - peer-reviewed information – are retrieved
Adherence to the research question	Adequacy to the research question regarding both fields	Inadequacy to the research question for both fields	Ensure the articles remain within the scope of the study
Period of publication	Published between 2003 and 2023	Published before 2001	Ensure that publications from both fields are considered for all the years studied
Access availability	Availability through CAPES Journal Portal	Unavailability by accessing the CAPES Journal Portal	Limitation of access to databases by Brazilian researchers
Language of publication	Articles in English	Articles in Other languages other than English	Accessibility and replicability
Number of pages	Articles with more than 3 pages	Articles with less than 3 pages	Ensure that surveys, extended reports, and abstracts are not included

Source: Authors (2023)

For **Step 6**, a quality assessment during the full-text review of selected papers is carried out. Because a quality evaluation needs to be transparent to enable other scientists to decide if the conclusions are valid (Valentine & Cooper, 2008), this work adopted the following quality criteria: (i) Overall coherence. The analysis of the correspondence between theory, methods, and results is one of the primary approaches to ensuring the quality of a study (Levy & Ellis, 2006). (ii) Technical appraisal. Even though limiting the search to indexed articles helps the inclusion of quality documents, assessing the quality through full-text reads helps that only studies with good methodological consistency are considered. (iii) Theoretical appraisal. Studies included in the review need to be based on the pertinent literature. The authors here recognize that even though the SLR is a method that offers a more trustworthy result, the peer-review process is a way to elevate the quality and fix errors during the review process (Levy & Ellis, 2006) and the full-text reading in this SLR was executed by one author only, elevating in this work the chance of bias.

Table 3. Quality Assessment Criteria

No.	Quality Assessment Question
QA1	Are the paper's objectives clearly stated and defined concerning the theoretical framework and methods?
QA2	Does the paper have a clear methodological framework?
QA3	Are the conclusions, recommendations, and consequences for practice and future studies appropriate for the target audience? Are the propositions supported by the relevant literature?

Source: Authors (2023)

The **seventh step** consists of defining the information to be retrieved from the full-text reading of the papers, and how is it going to be approached and further synthesized. To this end, the first information to be extracted is the **relationship types** that can be observed between Impact Assessment and Circular Economy. A semantic relation extraction method was applied to the texts to acquire a more systematic and reliable result. In this sense, based on the definitions provided by Gharagozlou *et al*. (2023), the method used for this portion of data extraction is categorized. The initial characteristic of the relation extraction (RE) for this work is that it is a Global RE. This indicates that the full-text reads generate a list as its output from a large amount of text as input. This analysis should produce a list of entity pairings that have a specific semantic relationship (Gharagozlou et al., 2023). For this work, important sentences that could indicate the relationship type are retrieved from the documents to be submitted for semantic analysis. The problem with the sentence-level approach is that it neglects relationships that demand a careful examination of all the sentences across a document. Additionally, for some documents, the RE was only possible through a document-level analysis, which made important use of both levels of assessment to extract information.

The second important characteristic of the Relation Extraction method chosen is that it is a Nested RE. This means that while (arg1, relation, arg2) is the coding for the more frequent binary relation extraction, some nested relation extraction (NRE) can have the format of (arg1, relation, relation2, arg3) or (arg1, relation, (arg2, relation2, arg3)). The technique chosen RE is pattern-based because of its ability to compare the textual patterns manually delimited. Pattern-based techniques, although unable to identify every pattern, can extract both taxonomic and non-taxonomic relationships between pieces of information (Gharagozlou et al., 2023). Finally, a semi-supervised technique is used in this study to extract semantic relations from the manually labeled samples. At least one sample is extracted from each article. The extracted sentences – in which these patterns can be observed - are then used to extract patterns from other sentences.

For this project, the relationship type is not clearly expressed in the majority of the documents, and frequently within the papers one of the topics under study is only briefly discussed, requiring the need to locate its existence. To aid in this process of data extraction and synthesis (**Step 7**), further information needs to be uncovered during full-text reads, which leads to the second information to be extracted being the **Circular Economy strategies** addressed by the texts. The extraction of strategies and following classification within Circular Economy principles followed Suárez-Eiroa *et al*.'s (2019) classification, which is based on the primary objective of each practical approach of implementation. Figure 6 below shows the CE principles extracted from the text based on the CE strategies they presented. Also, the output of this step is a data extraction form (Appendix B and C), which contains all the data extracted during this step, with the aid of Office Excel Software.

Figure 6. Circular Economy principles for data extraction and synthesis

	Strategies
Target operational principles	**Principle 1: Adjusting inputs to the system to regeneration rates**
	Substituting non-renewable by renewable inputs (e.g., bio-based materials, renewable energy)
	Substituting renewable materials with low regeneration rates for other with faster regeneration rates
	Adjusting taxes and subsidies of technology, products and materials based on their resource regeneration rates
	Saving energy and materials (i.e. improving energy efficiency, resource productivity, virtualizing products, etc.)
	Fostering renewable mobility (i.e. walking, bicycle, renewable fuels, etc.)
	Principle 2: Adjusting outputs from the system to absorption rates
	Substituting materials and processes which produce technical outputs by those which produce biological outputs
	Substituting processes for those with lower waste generation rates (i.e. more eco-efficiency processes)
	Adjusting taxes and subsidies of technology, products and materials based on their waste generation rates
Core operational principles	**Principle 3: Closing the system Separating biological and technical wastes properly**
	Remanufacting products and components
	Promoting and improving downcycling, recycling and upcycling of wastes (i.e. logistics, take-back systems, technology, etc.)
	Promoting energy recovery by converting waste into heat, electricity or fuel
	Promoting Extended Producer Responsibility
	Principle 4: Maintaining resource value within the system
	Interconnecting stages (i.e. redistributing second-hand goods)
	Promoting industrial symbiosis (i.e. establishing standards, cascading, by-products, etc.)
	Increasing durability (i.e. practical guides for reparability, preventive and corrective maintenance, repurposing, etc.)
	Reducing obsolescence (i.e. updating software)
	Principle 5: Reducing the system's size Informing consumers properly (i.e. eco-labelling, product labelling, product declarations, etc.)
	Expanding the Extended Consumer Responsibility
	Promoting functional service economy and sharing economy (i.e. collective mobility)
	Promoting green procurement (i.e. local products, season products, etc.)
	Adjusting selling doses to consumer doses
Transversal operational principles	**Principle 6: Designing for circular economy**
	Eco-design (i.e. optimizing packaging, improving durability, etc.)
	Designing transparent, reproducible and scalable products to build the same products in other places based on local resources
	Thinking about practical utilities and consumer preferences (customization/made to order)
	Designing new business models and strategies
	Designing new business models and strategies
	Designing new methodologies to guarantee a continual improvement
	Designing projects to promote sustainable development and circular economy
	Principle 7: Educating for circular economy
	Adjusting educational curricula to the current challenges
	Promoting knowledge, skills, capabilities and values that ensure the proper performance of circular economy
	Promoting habits and individual actions in favor of circular economy

Source: Authors (2023) – adapted from (Suárez-Eiroa *et al*., 2019)

Stage III: Reporting and propositions

This stage comprehends the reporting of the exported and synthesized data. The reporting process can be divided into two steps: (i) **descriptive analysi**s and (ii) **thematic analysis**. Following (Tranfield et al., 2003) suggestions, the first intends to provide a broad descriptive overview of the field, with particular examples and a verification record (Data

Extraction Form) to support the conclusions. To achieve this aim, the following questions are formulated: What are the main themes this SRL studies? How do these themes interact? What are the yearly publication and citation patterns? Who are the most prolific authors and their affiliated institutions and countries or territories? These questions can be answered by the use of the following science mapping and performance analysis techniques, in order: the **annual number of articles** (Total Publications –TP), and **citations** (Total Citations – TC) (Donthu et al., 2021), the **frequency distribution of Journals** (Source). Additionally, the second step of this stage comprehends a thematic analysis, which aims to discuss the results' main contributions to the fields studied. Differing from the descriptive analysis, the thematic analysis aims to be a more aggregative and interpretative approach. To achieve this goal, this dissertation provides a throughout the discussion of **types of relationship** between Circular Economy and Impact Assessment, as well as the main **CE principles** discussed within the papers. This thematic analysis also aims to provide a critical review of the articles read, with the intent of making propositions for theory and practice.

CHAPTER 4 – RESULTS AND DISCUSSIONS

This chapter summarizes the Bibliometric Analysis findings, analyzes the findings' content, and conducts a Systematic Literature Review. The Bibliometric Analysis performs a qualitative study to evaluate a large number of documents and find patterns that will guide Content Analysis of a smaller number of articles. The Content Analysis and the previous patterns that emerged guided a focused and systematic review of articles that discussed Impact Assessment and Circular Economy, aiming for Sustainability.

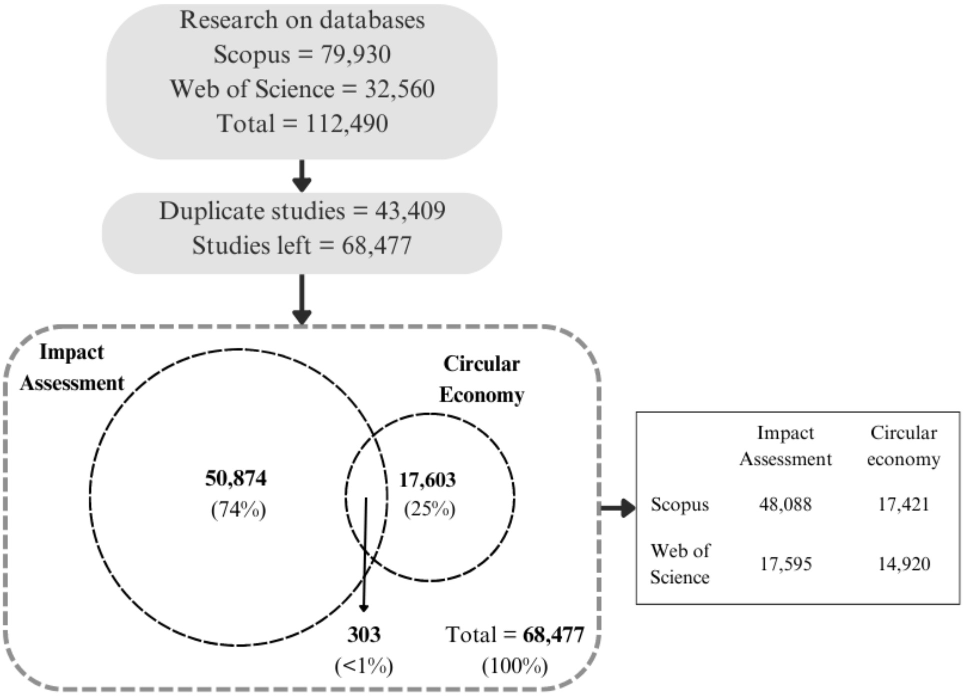
4.1. Bibliometric Analysis

1) Data Collection:

The data collection used the search strings “circular economy” and “impact assessment” given that this dissertation aims to understand the relationship between Impact Assessment and Circular Economy. The 68,477 documents retrieved are divided into different bodies of knowledge involving CE, IA, and their overlap. The Venn diagram in Fig.7 shows that the body of IA literature is nearly three times the size of the body of IA literature for the period analyzed. This is most likely because Impact Assessment is present in most of the legislations around the world, while even though indirectly Circular Economy principles are already seen in public policy, there are still few countries to adopt CE-specific policies, if compared to countries to adopt IA.

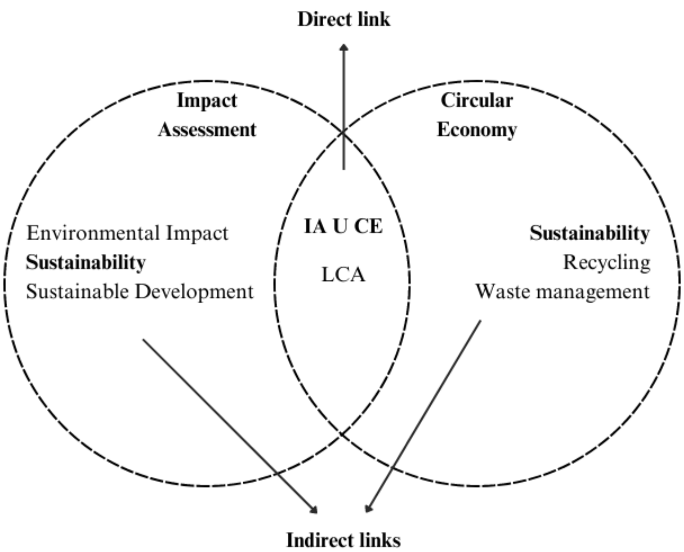
The direct scientific overlap (AND-operator in Scopus and Web of Science search query) accounted for less than 1% of the dataset, as previously stated. Most of these 303 documents were recently published. Only one of the 303 overlap articles contained specific information regarding the relationship between CE and IA, which proves the lack of studies dedicated to analyzing this relation. Additionally, this also explains the search for direct and indirect links (see figure 8) as well the second part of this dissertation, which is focused solely on the Systematic Literature Review of overlap articles. Furthermore, the idea that Impact Assessment and Circular Economy have been rarely discussed emerges when examining dominant keywords and citations (see Table 4).

Figure 5. Bibliometric Analysis results



Source: Authors (2023)

Figure 8. Examples of direct and indirect links



Source: Authors (2023)

<u>2) Science Mapping</u>

If we look at the 20 **most cited keywords** (see Henry et al. (2021)),19 out of the 20, appear at the same time in both bodies of literature, showing the first signs of association between the two concepts. "Health impact assessment" was the only keyword to appear only related to one of the research areas. Health Impact Assessment (HIA) is one of the main forms of Impact Assessment (João et al., 2011), probably being the reason why it appeared as an important keyword associated with that body of knowledge. Not being associated with Circular Economy may indicate a gap to be filled by Circular Economy research and practice. Regarding keywords that seem to have shown the most important link are "impact assessment" and "industrial ecology", given the higher percentage in IA∩CE within balanced and unbalanced appearances (see Table 5).

"Life Cycle Assessment", "sustainability" and "climate change" are the terms that most appear with balanced appearances (>15 %) across CE and IA literature fields. Life Cycle Assessment is a clear connection between Impact Assessment and Circular Economy that was anticipated within the "theoretical basis" chapter of this dissertation. This connection is because the LCA is the most common Impact Assessment technique for assessing Circular Economy strategies. 'Sustainability' indicates a connection between the themes since it is the main goal for both study fields (A. Bond & Dusík, 2020; Z. Liu et al., 2023). IA and CE being connected by 'climate change' (indirect link), is also supported by theory in both areas separately. For Impact Assessment, 'climate change' in 2015 was identified as an important research trend IA, especially for developed countries (Li & Zhao, 2015), and this importance is mostly attributed to climate change's ability to affect the environmental effects being predicted by IA predictive models for forecasting effects (Ohsawa & Duinker, 2014). For Circular Economy, because the concept may be adopted in a variety of sectors (such as industry, waste, energy, buildings, and transportation) and because it improves resource efficiency, it can efficiently address the problem of climate change (Yang et al., 2023).

This dissertation contemplates a "content analysis" section where these keywords will be further explored, individually and as groups ('Impact Assessment', 'Circular Economy', and 'Sustainability').

Table 4. The most common keywords in both CE and IA literature

Rank	Keywords	Keyword count in the domain:			
		IA ∪ CE	**CE**	**IA**	**IA ∩ CE**
1	circular economy	10821	10701 (98,89%)	120 (1,11%)	178 (1,64%)
2	life cycle assessment	3902	869 (22,27%)	3033 (77,73%)	107 (2,74%)
3	impact assessment	2908	15 (0,52%)	2893 (99,48%)	14 (0,48%)
4	environmental impact assessment	2814	20 (0,71%)	2794 (99,29%)	19 (0,68%)

Rank	Keywords	Keyword count in the domain:			
		IA ∪ CE	CE	IA	IA ∩ CE
5	sustainability	2460	1873 (76,14%)	587 (23,86%)	34 (1,38%)
6	recycling	1292	1189 (92,03%)	103 (7,97%)	19 (1,47%)
7	climate change	1162	175 (15,06%)	987 (84,94%)	5 (0,43%)
8	environmental impact	1040	159 (15,29%)	881 (84,71%)	15 (1,44%)
9	sustainable development	1006	667 (66,3%)	339 (33,7%)	13 (1,29%)
10	health impact assessment	917	0 (0%)	917 (100%)	0 (0%)
11	waste management	773	680 (87,97%)	93 (12,03%)	17 (2,2%)
12	environment	450	147 (32,67%)	303 (67,33%)	4 (0,89%)
13	industrial ecology	386	279 (72,28%)	107 (27,72%)	12 (3,11%)
14	waste	369	329 (89,16%)	40 (10,84%)	3 (0,81%)
15	renewable energy	365	164 (44,93%)	201 (55,07%)	1 (0,27%)
16	social impact assessment	343	2 (0,58%)	341 (99,42%)	2 (0,58%)
17	air pollution	323	13 (4,02%)	310 (95,98%)	1 (0,31%)
18	Reuse	315	296 (93,97%)	19 (6,03%)	6 (1,9%)
	China*	303	140 (46,2%)	163 (53,8%)	2 (0,66%)
19	industry 4 0	302	289 (95,7%)	13 (4,3%)	3 (0,99%)
20	risk assessment	266	19 (7,14%)	247 (92,86%)	1 (0,38%)

Source: Authors (2023)

Table 5. Top 10 author keywords with balanced (>15 %) appearances across CE and IA literature

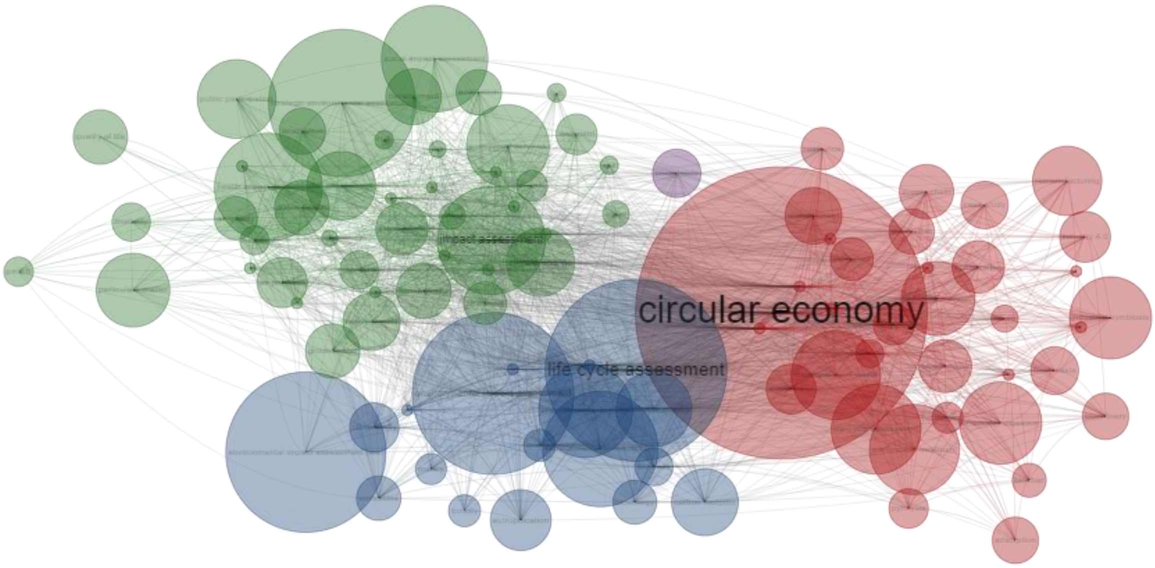
Rank	Keywords	Keyword count in the domain:				
		IA ∪ CE	CE	IA	IA ∩ CE	Cluster
1	circular economy	10821	837 (22,46%)	2889 (77,54%)	104 (2,79%)	Sustainability
2	life cycle assessment	3902	175 (15,06%)	987 (84,94%)	5 (0,43%)	LCA
3	sustainability	2460	667 (66,3%)	339 (33,7%)	13 (1,29%)	Sustainability
4	climate change	1162	117 (70,91%)	48 (29,09%)	1 (0,61%)	Environment
5	environmental impact	1040	147 (32,67%)	303 (67,33%)	4 (0,89%)	LCA
6	sustainable development	1006	279 (72,28%)	107 (27,72%)	12 (3,11%)	Sustainability
7	environment	450	164 (44,93%)	201 (55,07%)	1 (0,27%)	Environment
8	industrial ecology	386	99 (43,81%)	127 (56,19%)	3 (1,33%)	Sustainability
9	renewable energy	365	140 (46,2%)	163 (53,8%)	2 (0,66%)	LCA
	china*	303	171 (77,03%)	51 (22,97%)	1 (0,45%)	Environment
10	agriculture	247	76 (30,77%)	171 (69,23%)	0 (0%)	LCA

Source: Authors (2023)

* The content analysis evinced that the author-keyword ‘China’ emerged with a high frequency of appearance in CE and SE literature due to its locational character. Not only China was the first to put the Circular Economy concept into practice, but also many of the articles found in this literature review are Chinese.

For thematic analysis, keyword theme clusters using author keywords were generated. Different clustering algorithms (Louvain, Leading Eigenvalues, and Fast Greedy) were used and the results were compared. Figure 9 shows the result of the keyword network generated using the Leading Eigenvalues algorithm. The results generated by the clustering algorithms were very similar. The results show the clear emergence of three clusters: one around the terms “Sustainability”, “Sustainable Development” and “industrial ecology”; the second around the terms “climate change” and “environment”, and the third made mainly of the terms “life cycle assessment”, “environmental impact”, “renewable energy” and “agriculture”. Because “Impact Assessment and “Circular Economy” were search strings used to achieve the results being analyzed, it explains their appearance among the most cited words so they will not be considered for keyword analysis. Thematic analysis, as well as the analysis of the word frequency across literature fields, helps to answer **Research Question number 01**, meaning that the thematic areas where IA and CE are connected seem to be clearer when analyzing keyword frequency.

Figure 6. Keyword network generated by Leading Eigenvalues algorithm.



Source: Authors (2023).

Among the top ten cited publications, only one of them is equally relevant (>5%) to both CE and IA fields (Table 4): Directive 2008/98/EC of The European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (UE, 2008). This may point to an existing connection between IA and CE that is emergent and potential within public policy. Additionally, only half of the top-cited publications are also cited in articles that overlap the literature fields (IA ∩ CE). It is worth noting that among the 50 most cited documents, only 12 are equally relevant to both fields. Within these 12, it is worth noting that 3 of them are European Union Directives, one of them is ISO 14040 (the LCA normative) and only one of them included both terms IA and CE (AND operator). The top ten references, along with these 12 articles, will be considered for the content analysis, since they may help to further understand the thematic pattern identified previously.

Table 6. Top 10 references, with balanced appearances in both CE and IA literature (with a minimum of one occurrence in the IA ∩ CE domain)

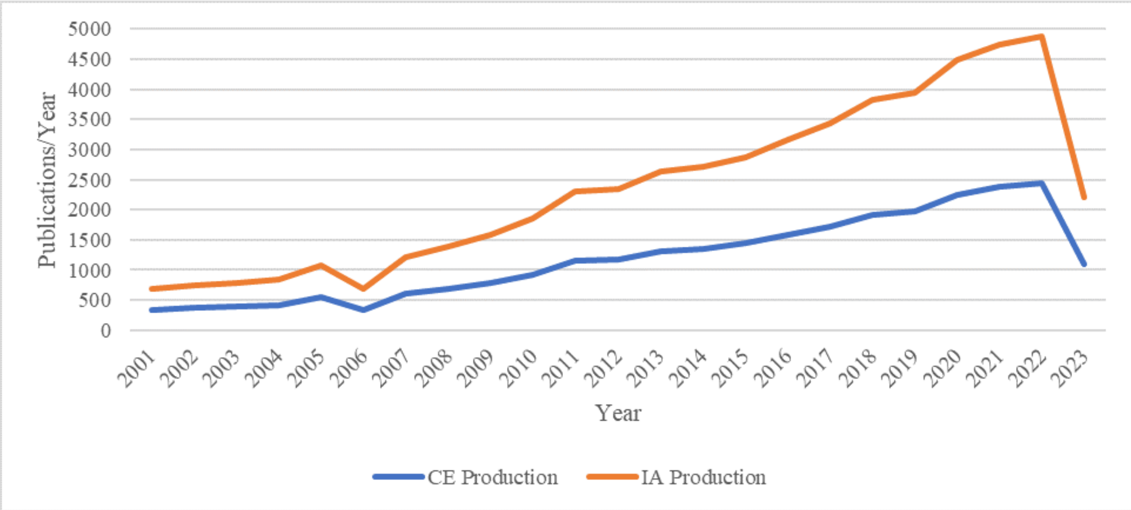
Reference	IA ∪ CE	CE	IA	IA ∩ CE
(Kirchherr et al., 2017). Conceptualizing the circular economy: An analysis of 114 definitions	204	200 (98,04%)	4 (1,96%)	3 (1,47%)
(Geissdoerfer et al., 2017). The Circular Economy – A New Sustainability Paradigm?	195	190 (97,44%)	5 (2,56%)	0 (0%)
(Ghisellini et al., 2016). A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems	179	177 (98,88%)	2 (1,12%)	2 (1,12%)
(Haas et al., 2015). How Circular is the Global Economy?	227	224 (98,68%)	3 (1,32%)	0 (0%)
(Korhonen et al., 2018). Circular Economy: The Concept and its Limitations	104	103 (99,04%)	1 (0,96%)	1 (0,96%)
(Murray et al., 2017). The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context	97	96 (98,97%)	1 (1,03%)	1 (1,03%)
(Lieder & Rashid, 2016). Towards circular economy implementation: a comprehensive review in the context of manufacturing industry	91	91 (100%)	0 (0%)	0 (0%)
(Bocken et al., 2016). Product design and business model strategies for a circular economy	84	83 (98,81%)	1 (1,19%)	1 (1,19%)
(Stahel, 2016). The circular economy	78	78 (100%)	0 (0%)	0 (0%)
(UE, 2008). Directive 2008/98/EC of The European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives	77	72 (93,51%)	5 (6,49%)	0 (0%)

Source: Authors (2023)

Even though Impact Assessment and Circular Economy aim for Sustainability, IA is a process, used as a policy tool to achieve this aim, and it challenges the status quo by inserting in the decision-making process the environmental variable. On the other hand, the Circular Economy is a broader concept, being a “new” economic system that opposes itself to the current one (Kirchherr et al., 2017), trying to offer solutions to the unsustainable linear mode of consumption, production, and life. CE is understood by some as a ”new” type of economy that has the potential to replace the prevailing system of mass production and corporate practices with more resource-efficient alternatives (Easterling, 2018; Todeschini et al., 2017). Thus, Circular Economy may fundamentally shift the way we live creating a Sustainable society, while Impact Assessment seems to be one the most important tools to aid in that transition.

The concepts of IA and CE have both received increased attention since 2008 (see Figures 10 and 11). CE seems to have gained momentum after the 2008 financial crisis (Henry et al., 2021), emerging as a viable idea to transform the capitalist-dominated economic system that had produced the crisis (Henry et al., 2021). Additionally, after “Circular Economy Promotion Law of the People's Republic of China” was approved in 2009, there has been a lot of focus on implementing a circular economy at the corporate, inter-firm, and social levels (Geng & Doberstein, 2008; Lieder & Rashid, 2016). Most recently, while China was the first to put the Circular Economy concept into practice, the Ellen MacArthur Foundation emerged in 2012, 2013, and 2014 as a proponent of the concept in the UK (Ellen MacArthur Foundation, 2012, 2013, 2014; Murray et al., 2017). On the other hand, IA production growth, especially around 2012, seems to coincide with important IA policies, for example, the European EIA Directive (EEC, 1985)’s revisions (2003 and 2009) and consolidation in 2011 (Jha-Thakur & Fischer, 2016), as well as the Chinese Law on Environmental Impact Assessment of 2003 (Law of the People’s Republic of China on Evaluation of Environmental Effects, 2003) and Plan Environmental Impact Assessment Regulation of 2009 (Jia et al., 2011).

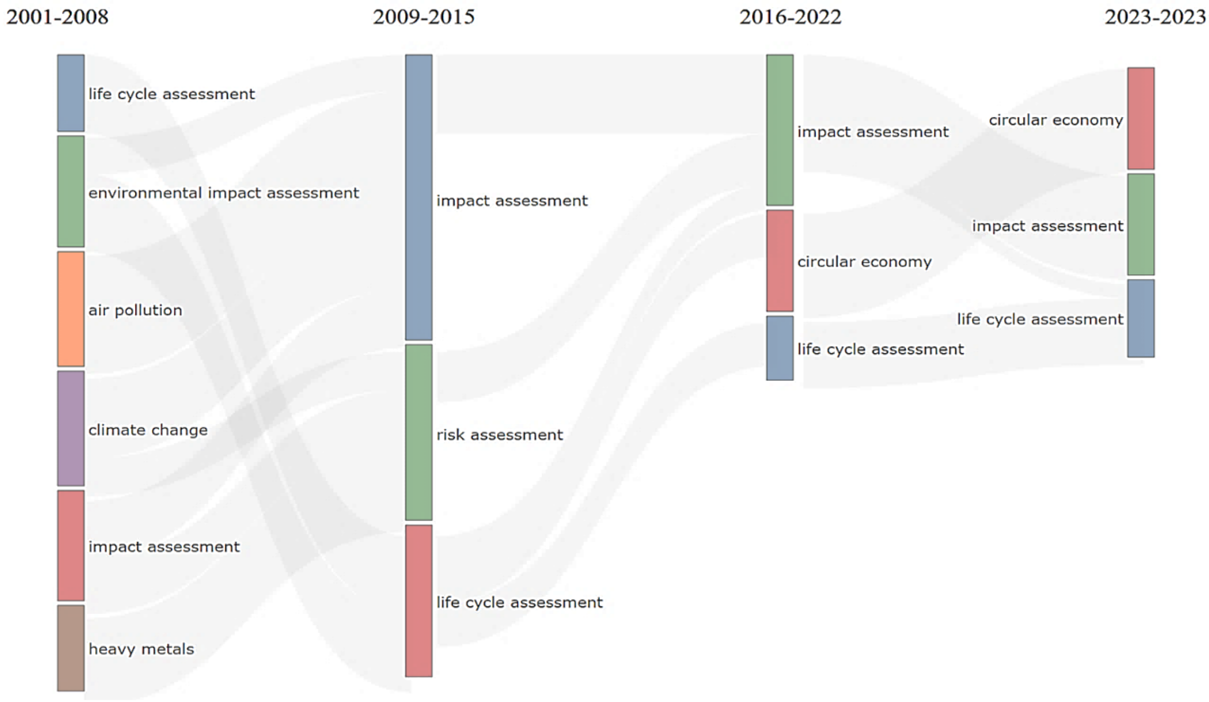
Figure 7. Publications per year



Source: Authors (2023)

‘Sustainability’, ‘sustainable development’, industry 4.0’, and ‘industrial ecology’ are among the 10 ten most cited keywords within the CE field, which supports CE’s more conceptual scope. On the other hand, Impact Assessment most cited keyword, even though they also encompass Sustainability and Sustainable Development themes, this literature field is mostly focused on types of IA practice, climate change, and air pollution, supporting the idea of IA being more focused to practice than theory if compared to CE. Additionally, it is important to note that from 2009 on, there is a clear emergence of three main thematic areas when IA and CE literature fields are analyzed together (Figure 10). In 2009, the Circular Economy Chinese Law was approved and there was a need to assess the unknown risks of implementing circular measures (Circular Economy Promotion Law of the People’s Republic of China, 2008). Life Cycle Assessment was already used for assessing the impact of products and services on the environment, but it appears its potential to assess CE measures has been further developed from 2009 on. It seems that from 2015 on, the three main thematic areas of ‘circular economy’ ‘impact assessment’, and ‘life cycle assessment’ are already evident. It is noteworthy that for Content Analysis, the thematic areas ‘Circular Economy’ and ‘Impact Assessment’ become that order ‘Sustainability’ and ‘Environment’, since ‘circular economy’ and ‘impact assessment’ are the most important themes since they were the search strings that generated this results.

Figure 8. Thematic evolution

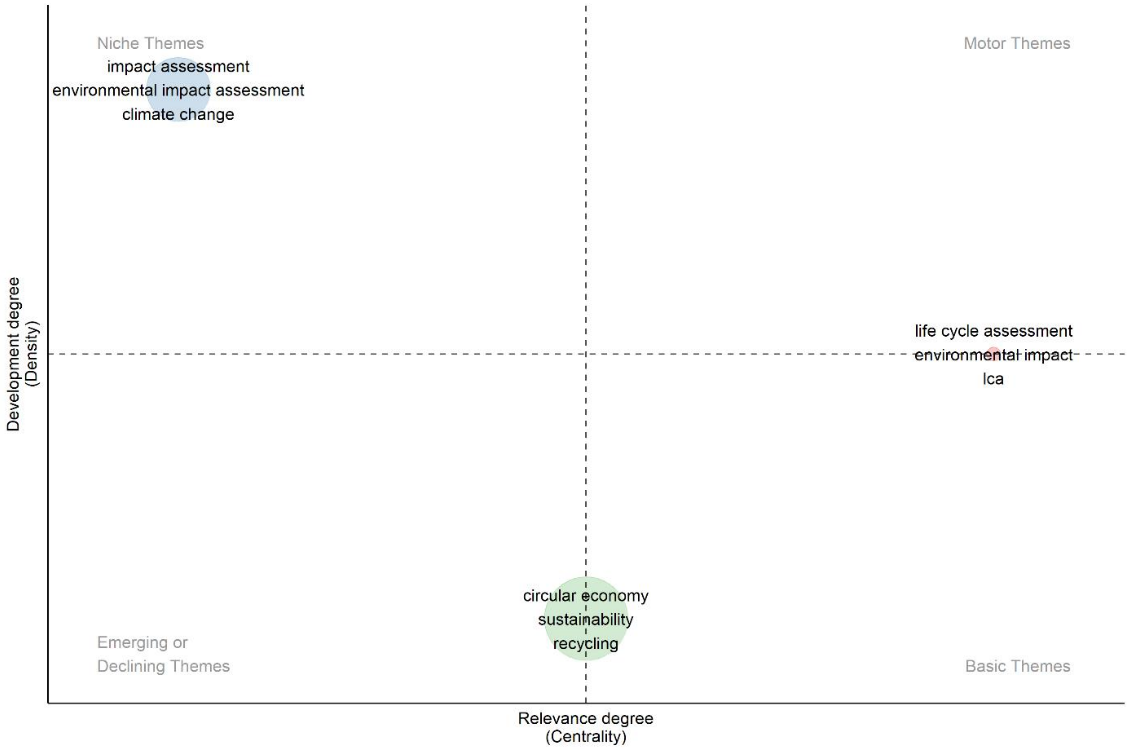


Source: Authors (2023)

The results of the Strategic Diagram and a Thematic Network can be seen in Figures 11 and 12. Just as, the keyword co-occurrence network, different clustering algorithms (Louvain, Leading Eigenvalues, and Fast Greedy) were used and the results were compared. Figures 11 and 12 show the result of the Strategic Diagram and Thematic Network generated using the Leading Eigenvalues algorithm. The results generated by the clustering algorithms were very similar. Similar to the co-occurrence network, here we can observe and confirm the interaction between Impact Assessment and Circular Economy in three thematic areas: Sustainability, Environment, and Life Cycle Assessment, which will be further explored within the content analysis.

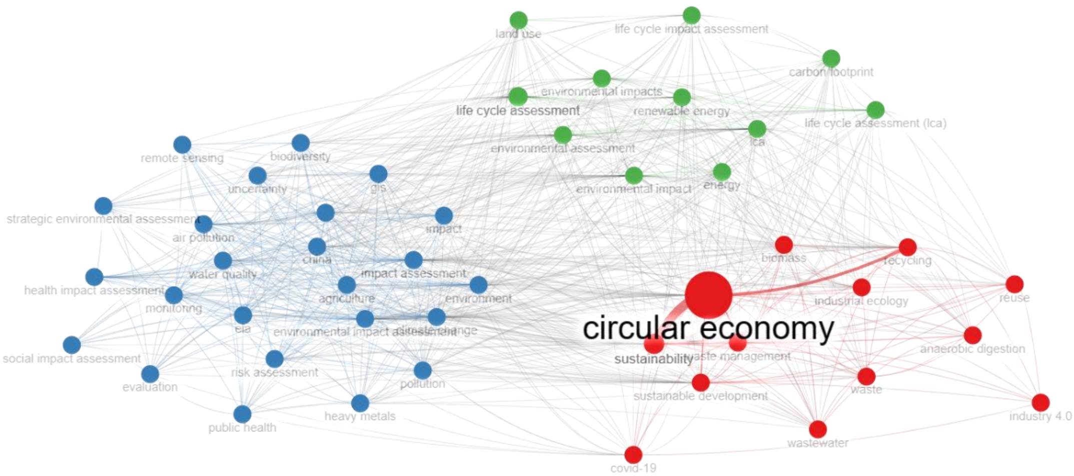
The Thematic Network (Fig 12) and the thematic evolution (Fig 10) aid in answering **Research Question number 2**. The stronger connection between the themes is observed within the Sustainability Cluster, where the stronger link is between Circular Economy and Sustainability, and between Circular Economy and recycling. The Strategic Diagram shows that LCA is a highly developed theme (motor theme) as well as a critical theme for investigating the connection between IA and CE (basic/transversal/universal theme). Additionally, the positioning of LCA in the "motor theme" quadrant suggests an external connection to ideas that apply to other, conceptually similar subjects. Impact assessment, Environmental Impact Assessment, and climate change appeared as extremely specialized and peripheral, usually making them of just minor value for the connection here researched. If we analyze balanced keyword appearances across IA and CE, this is only true for Environment Impact Assessment. For climate change, its relatively balanced appearance across IA and CE (see Table 5) indicates the importance of this theme for the understanding of this connection.

Figure 9. Strategic Diagram generated using Leading Eigenvalues



Source: Authors (2023)

Figure 10. Thematic network generated by Leading Eigenvalues algorithm.

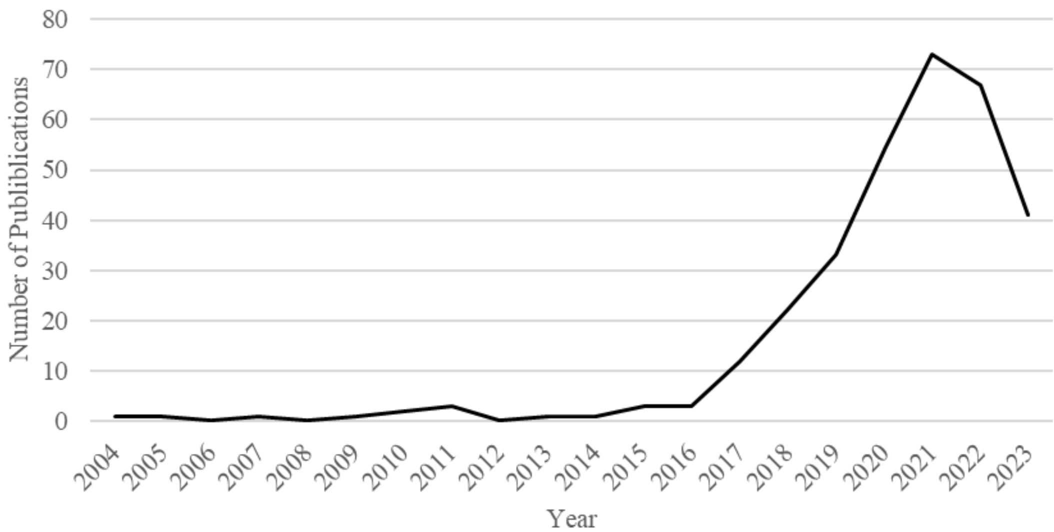


Source: Authors (2023)

<u>3) Performance Analysis of the intersection between themes</u>

The performance analysis was only applied to articles that contain both terms (IA and CE) within the same research paper to answer **Research Questions 3 and 4**. This was with the aim of quantitatively and qualitatively assessing the contributions of this intersection to the overall study field, identifying the most influential, fruitful, and prolific authors, references, and themes deemed useful for further Content Analysis. This analysis may help us divide the field that studies CE and IA into epochs in terms of the volume of documents or themes studied. Thus, annual scientific production (Figure 12) shows the emergence of the joint discussion of IA and CE in 2016, which can be attributed to the European Union's 2015 approval of the Circular Economy package (EC, 2015a), which included the need for assessing Circular Economy policy measures.

Figure 11. Annual scientific production (IA ∩ CE)



Source: Authors (2023)

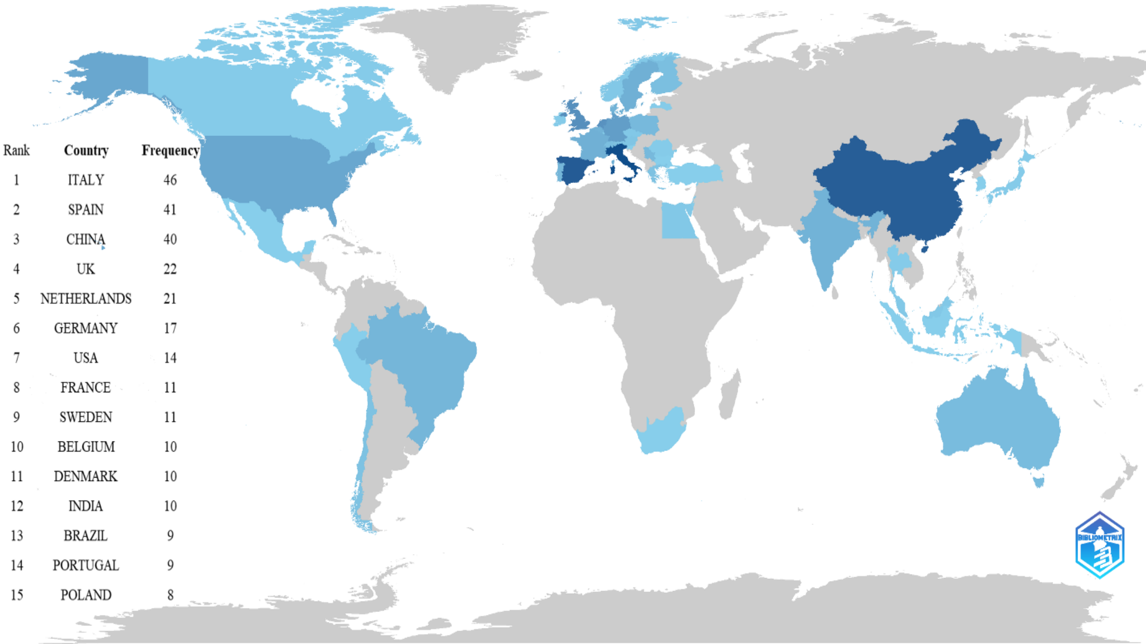
The author with the greatest number of publications that address both Impact Assessment and Circular Economy literature fields is Adisa Azapagic (see Figure 14). All of these publications are LCA-related and none of them has A. Azapagic as its first author. Among these 5 publications, the most cited one is entitled “Life cycle environmental impacts of chemical recycling via pyrolysis of mixed plastic waste in comparison with mechanical recycling and energy recovery”, where the sustainability of a waste management circular measure is assessed using LCA methodology, including the CE measure contribution to climate change.

Figure 12. Most relevant authors (IA ∩ CE)

Source: Authors (2023)

A noteworthy result is that both CE and IA research are focused on Chinese topics (Table 4, Table 5, and Figure 15), with China having a high number of publications associated with the country, accounting for 12.54% of the overlap between IA and CE research articles. However, Italy is still the country with the most publications regarding this intersection of IA-CE. Italy and Spain together represent 30% of the publications of this joint research field. In this sense, it is vital to note that China's publication record looks to be the outcome of China's CE strategy, which entered into effect in January 2009, while in Europe the high number of publications can be attributed to the EU CE Policy of 2015. Finally, there hasn't been much overlapping CE and IA research that has looked toward Latin America, East Asia, and African nations.

Figure 13. Countries' scientific production (IA ∩ CE)



Source: Authors (2023)

4) Content Analysis

For the Content Analysis, the most cited articles and the most recent articles from each of the IA and CE literature were fully read. The first thematic pattern that emerged from the keyword and citation analysis is 'Sustainability' and Sustainability related themes. Impact Assessment researchers use the term 'Sustainability' disproportionally more than CE scholars (see Table 4), while CE uses the term 'Sustainable Development' more. While some authors believe that the Circular Economy can contribute to Sustainable Development, this idea is contested by those who perceive Sustainable Development as a set of initiatives that were implemented within linear thinking, with CE being only possible if Sustainability was approached from a broader perspective (Sauvé et al., 2016). One of the most cited articles not only discusses the different approaches but the authors also map the different relationship types existing between the Circular Economy and Sustainability (Ghisellini et al., 2016). One of the main concerns is that, as the Circular Economy is growing as a business idea, corporations continue with the "business as usual. This fear can be explained by the fact that while some organizations have made an effort to embrace the Sustainability initiative and redefine the terminology to give the impression that it is not hard to manage and deliver, others have questioned the concept's applicability (Murray et al., 2017). This shows that, even though this discussion is present in the theory of CE literature, most of the authors understand Sustainable Development and the Circular Economy as related and interdependent areas (Suárez-Eiroa et al., 2019), and CE policy measures are still oriented to Weak Sustainability practices (Johansson & Corvellec, 2018).

The idea that the practice of CE is oriented to weak practice and, therefore, those practices need to be assessed, is a clear idea within the most cited references. In this regard, most of the referenced authors emphasize the importance of assessing Circular Economy policy measures (Bocken et al., 2016; Ghisellini et al., 2016; Haas et al., 2015; Korhonen et al., 2018; Stahel, 2016), but there is a lack of specific definitions and standards for assessing actions that can increase the circularity of the economy (Haas et al., 2015). In this sense, it is still difficult to assess the actual environmental effects of biofuels, biomaterials, and other eco-efficiency projects since they are mostly approached by Life Cycle Assessments (LCA), which is not always ideal for these scenarios (Korhonen et al., 2018). The need for Impact Assessment is also mentioned as a solution to the unsustainable outcomes that may accompany the recycling processes and development of new materials (Ghisellini, 2016). On the other hand, the Impact Assessment adapts according to the view that one has regarding the issues addressed by Sustainability (Glasson & Therivel, 2019). Additionally, the practice of Impact Assessment understands that it needs to achieve Strong Sustainability to be effective (Loomis et al., 2022; Morrison-Saunders & Retief, 2012), The evidence found in the bibliometric analysis supports this statement: the imbalance in the occurrences of the keyword 'Sustainability' (which appears more in articles related to IA) and the keyword 'Sustainable Development' (which appears more in articles related to EC). **Thus the Impact Assessment can contribute to the practice of the Circular Economy, assessing the impacts of circular activities and ensuring that they truly achieve Strong Sustainability.**

‘Industrial ecology’ was the first academic and sustainable economics movement to bring together previous ideas and analyze the potential circulation of resources (Henry et al., 2021; Murray et al., 2017). This idea is closely related to the ‘recycling’ of products within the economy. Resource cycling is needed for a Circular Economy because it slows down cycles of usage to delay resource output (Murray et al., 2017). However, the practice of Circular Economy has mostly addressed ‘waste management’, narrowing the CE perspective (Ghisellini et al., 2016). In this context, ‘recycling’ and ‘waste management’, along with ‘sustainability’ are among the most researched themes within the CE literature body, which may indicate weak circular practices. Moving from fossil to renewable energy sources, converting efficiency gains into a decrease in total resource extraction, alongside recycling and reuse is crucial (Haas et al., 2015). Most organizations view recycling as the main and sole path to Circular Economy, but that is not what circularity is or should be (Kirchherr et al., 2017). The analysis of keywords from Impact Assessment-related articles indicates that this body of literature mostly approaches themes related to the practice of IA (eg.: LCA) as well as environmental-centered topics (eg.: climate change and air pollution).

Within the Sustainability thematic group, it is worth calling attention to the term 'industry 4.0'. The term *a priori* does not seem to indicate a theme of integration between the concepts of IA and CE, considering that 96% of its appearance is concentrated in the CE literature. However, Impact Assessment plays a crucial role in the face of the 4th Industrial Revolution due to the significant threats associated with inadequate environmental and social management of the future growth in the utilization of these emerging technologies (A. Bond & Dusík, 2020). The Impact Assessment will need to be able to deal with increasing inequality, resource use, greenhouse gas emissions, and ecosystem degradation. In addition, Industry 4.0 can help the transition to a more circular economy, but it needs to be aligned with general changes in the general socio-economic environment and address sustainability through circular business models (Upadhyay et al., 2023). **In this sense, IA's current model is still not able to deal with the impacts of the 4th industrial revolution but Impact Assessment can benefit from a greater integration with Circular Economy strategies to overcome this challenge of the 21st century**.

Proposition 01: Even though Impact Assessment and Circular Economy aim for Sustainability as a convergence point, the literature points to the practice of Impact Assessment being more directed to Strong Sustainability than current Circular Economy policy measures.

The second group is the one with the most notorious direct and indirect links. The 'Life Cycle Assessment' or 'Life Cycle Impact Assessment' is understood by some, such as (Kim & Wolf, 2014), as a type of Impact Assessment *per se*, while others, such as (Manuilova et al., 2009) and (Tukker, 2000), understand LCA as a tool to be used in the IA process. The connection between IA and CE through the LCA method can be understood by the fact that this is one of the main Impact Assessment methods used to measure how Sustainable Circular Economy actions are (Schaubroeck, 2020). It is important to note that many LCA studies do not adequately incorporate environmental impacts related to land use and natural resource degradation (Navare et al., 2021), and integrated impact assessment methods aimed at sustainability (such as those that incorporate techniques, and socioeconomic assessments) can produce more reliable and accurate results (Bellezoni et al., 2022). **Therefore it is more indicated that the LCA is incorporated along with other IA techniques within the process evaluation method to achieve better results for CE measures and results more focused on Sustainability**.

Most of the overlapping articles (IA ∩ CE) use LCA as an impact assessment technique to analyze the environmental impact of Circular Economy measures. Some assessed technological alternatives (Muñoz et al., 2023; Santos et al., 2022) However, most of them are related to the LCA applied to the agriculture sector, such as (Ferronato et al., 2023), (Silalertruksa et al., 2022) and (da Costa et al., 2022) and who assessed alternative options for organic waste valorization and used LCA to assess its environmental impacts compare them with other treatment options. In this context, the Circular Economy (CE) is posed as a viable solution for supporting sustainable, restorative, and regenerative 'agriculture' in the current context of scarce resources, climate change, environmental degradation, and rising food demand (Velasco-Muñoz et al., 2021). Agricultural waste can be converted into resources through processes that potentially deliver sustainable bio-products such as fertilizers, energy, minerals, and molecules (Gontard et al., 2018). Additionally, the environmental impacts of recovering nutrients and water from wastewater treatment can also be assessed using LCA, and this can be seen within the retrieved documents (Lima et al., 2022; Magalhães et al., 2022). Only a few of the most recent articles do not use LCA, such as (Abdelzaher et al., 2023), who designed a desalination system that is integrated with renewable energies applied to agriculture to lower environmental contaminants as a result of reduced energy usage and freshwater transfer. Many works addressed assessed the impacts of waste valorization to produce ‘renewable energy’, renewable energy, reduce landfills and tray to achieve sustainable waste management (G. Colangelo et al., 2023; Ghisellini et al., 2023; Kuo et al., 2021) while using LCA as a technique to assess the environmental impacts.

Proposition 02: Even though, Life Cycle Assessment is the most used Impact Assessment tool to evaluate the environmental impacts of Circular Economy measures, an integrated Impact Assessment process that incorporates other techniques is needed.

‘Environment’ was the third group in which the two disciplines connected. One of the fundamental benefits of the Impact Assessment, and seen as one of its main purposes for the practice, is the protection of the environment (Morrison-Saunders et al., 2014). The environment is the center of decision-making supported by the IA because both the positive and negative results of the evaluated actions will be perceived by the communities and the biophysical environment (João et al., 2011). The Circular Economy proposes to prevent environmental impacts, aiming to be a new economic model that opposes the current linear model of production and consumption, and therefore also aiming to have the environment at its center. However, Circular Economy actions need to be carefully evaluated because some actions can reduce environmental impacts in one stage of the product's life cycle, but increase them in others (Sauvé et al., 2016) leading to most of the Circular Economy practice is currently a practice focused on Weak Sustainability.

The most difficult current environmental problem for IA and CE to deal with is ‘climate change’. Because recent worldwide important problems such as resource consumption, biodiversity, and climate change have to be considered at global scales, it is challenging to assess them even at strategic levels of IA (A. Bond & Dusík, 2020). The Circular Economy concept, ideally, can deal with environmental problems and the effects of climate change (Bonciu, 2020). This is because efficient Circular Economy practices can increase the efficient use of resources by slowing, closing, and narrowing material and energy loops, which can help mitigate climate change (Gallego-Schmid et al., 2020). In the context of institutional Climate Change negotiations, the main problem is that the dominant logic, instead of being directed to environmental sustainability, is dominated by the economic growth discourse, especially the economic development driven by the fossil fuel industry (Banerjee, 2012). Additionally, the climate change measures in place are not effective since they are centered on market processes like carbon trading as one of the main ways to reduce emissions, which some include emphasizing voluntary rather than mandatory action (Böhm & Dabhi, 2009). The assumption made by the carbon 'cap and trade' system that any reductions achieved anywhere are equivalent globally, is theoretically valid, but Climate Change impacts are most threatening for poor populations across the world (Banerjee, 2012; Böhm & Dabhi, 2009). Therefore, instead of waiting for climate change voluntary organization agreements, and due to the many different interests involved in Climate Change politics as well as the urgent environmental challenges it poses, there is a need for effective regulation to be in place (Allwood, 2014). **If Impact Assessment is to help assess circular activities and promote a shift to a Circular Economy, as well as being effective in leading to better global environmental**

protection, it needs to move further ahead of being a set of procedural requirements and recommendations, and being legally binding (Therivel, 2020)**.**

Proposition 03: Impact Assessment and Circular Economy are both environmentally centered, but struggle to deal with Climate Change environmental impacts.

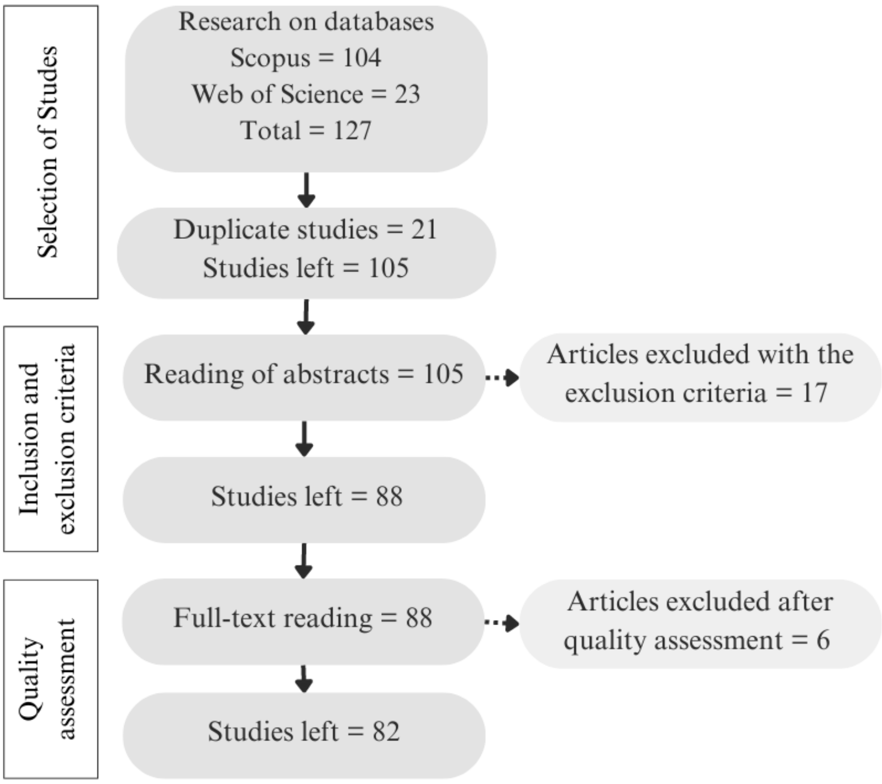
The main themes associated with the "environment" thematic area that appeared only related to relation to one of the research areas were 'health impact assessment' and 'air pollution'. One of the primary types of impact assessment is Health Impact Assessment (HIA) (João et al., 2011), and being unrelated to the circular economy may point to a gap that needs to be filled by study and practice in both IA and CE fields. **In other words, because CE measures are expected to have a beneficial impact on human health** (Kirchherr et al., 2023; Salguero-Puerta et al., 2019)**, Impact Assessment can help Assess the social impacts Circular Economy**.

Finally, considering that Environmental Impact Assessment is a form of IA and Life Cycle Assessment is an Impact Assessment tool (see Tables 4 and 5), Sustainability is the most important connection found through this Content Analysis. Also, Sustainability is the most relevant direct link (most keyword occurrences). Therefore, there is a need for a Systematic Literature Review that analyses full texts considering that IA and CE are connected through their theoretical origin, their literature discussions, and their policy practices toward Sustainability.

4.2. Systematic Literature Review

With Bibliometric Analysis it was possible to observe the emergence of Sustainability as the main theme that connects Circular Economy and Impact Assessment. Considering the evident Sustainability connection, this Systematic Literature Review aims to further understand the relationship between Impact Assessment and the Circular Economy, under the Sustainability discussion umbrella. In other words, the Bibliometric Analysis provided the basis for the SLR keyword word choice: 'Circular Economy', 'Impact Assessment" and 'Sustainability'. Therefore, this SLR focuses on the IA and CE overlapping articles that explicitly target Sustainability.

Figure 14. Systematic Literature Review Results



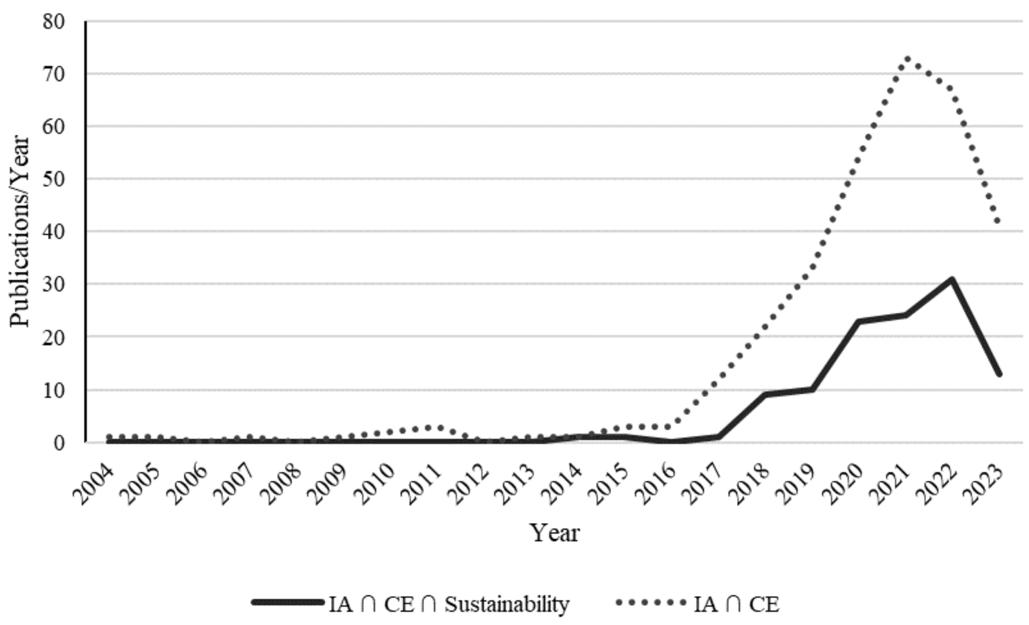
Source: Authors (2023)

The first stage of the SLR consisted of the Bibliometric Analysis and the prior coding led to the SLR's keyword choice. The second stage of an SLR consists first of applying the pre-defined search strings in Scopus and Web of Science databases. This Step resulted in 105 studies after the exclusion of duplicate documents (Figure 16). All those 105 documents' titles and abstracts are read to the application of inclusion and exclusion criteria. After this step, 17 articles were removed. For the remaining 88 articles, a quality assessment was applied to guarantee the methodological quality of the articles. This resulted in a group of 82 articles being submitted for data extraction and synthesis.

Descriptive analysis

The descriptive analysis presented and discussed below consists of the results of the simple set of categories defined in the methodology and with the use of the extraction forms, the categories are annual scientific production (based on the annual number of articles), most cited documents (based on the total number of citations), most relevant authors, most relevant sources (journals). The annual scientific production (Figure 16) shows the emergence of the joint discussion of IA and CE, under the umbrella of Sustainability only in 2014. The result supports the findings of the annual scientific production results of IA ∩ CE (Figure 12). It seems that joint discussions between IA and CE fields explicitly focusing on sustainability only started in 2014, one year before the European Union's 2015 approval of the Circular Economy package (EC, 2015a). The growth in the number of publications started after 2016, but the number of publications is still much lower if compared to the annual scientific production that did not include the evaluation of the Sustainability framework (Figure 12). This might indicate a need for more Sustainability-related discussions even though Sustainability is one of the most relevant themes for each of the fields if analyzed separately and together.

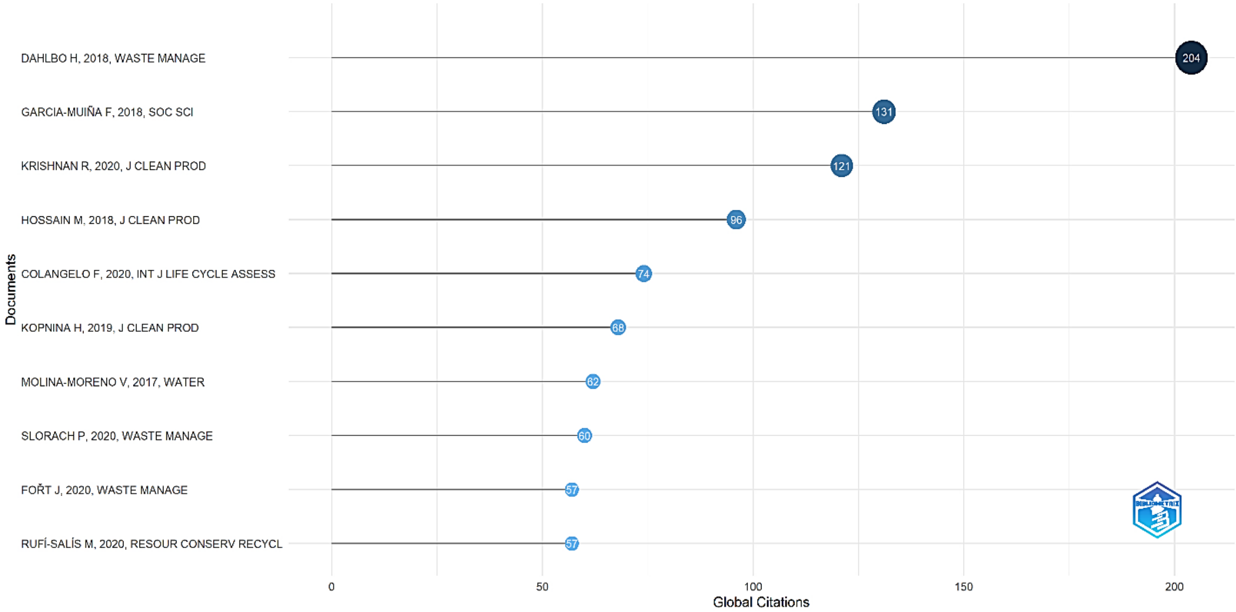
Figure 15. Annual scientific production (IA ∩ CE ∩ Sustainability)



Source: Authors (2023)

The most cited documents can indicate foundational knowledge, influential research, or key trends within the area that are dedicated to the overlapping fields of Impact Assessment and Circular Economy, focused on achieving Sustainability. All of the most cited documents are recently published and corroborate with the theory of three fields arguing that the concepts of Circular Economy (Blomsma & Brennan, 2017; Johansson & Henriksson, 2020), Impact Assessment (Fonseca, 2022b), and Sustainability (Oliveira et al., 2009) are ones in dispute and strongly depend on the policy context they are inserted. An important document among the most cited that shows how the debate might be theoretically shaped is (Kopnina, 2019) which discusses Circular Economy *Best Practices* and advises that de-growth and steady-state economies be emphasized in sustainable business curricula, making these radical production alternatives the main emphasis of education for responsible citizen. Another critical debate made among the most cited articles is about the Paradigms of Industry 4.0 and Circular Economy. (Garcia-Muiña et al., 2018) use the Industry 4.0 environment's digitalization of production processes, to implement Impact Assessment tools (such as LCA), to provide Sustainability indicators. The most cited documents also indicate a clear research trend that has drawn the interest of scientists recently: waste management. This interest area is indicated by recycling (F. Colangelo et al., 2020; Dahlbo et al., 2018; Fořt & Černý, 2020), food waste (Krishnan et al., 2020; Slorach et al., 2020) and wastewater (Molina-Moreno et al., 2017) being central themes within the highly cited documents.

Figure 16. Most Cited Documents (IA ∩ CE ∩ Sustainability)

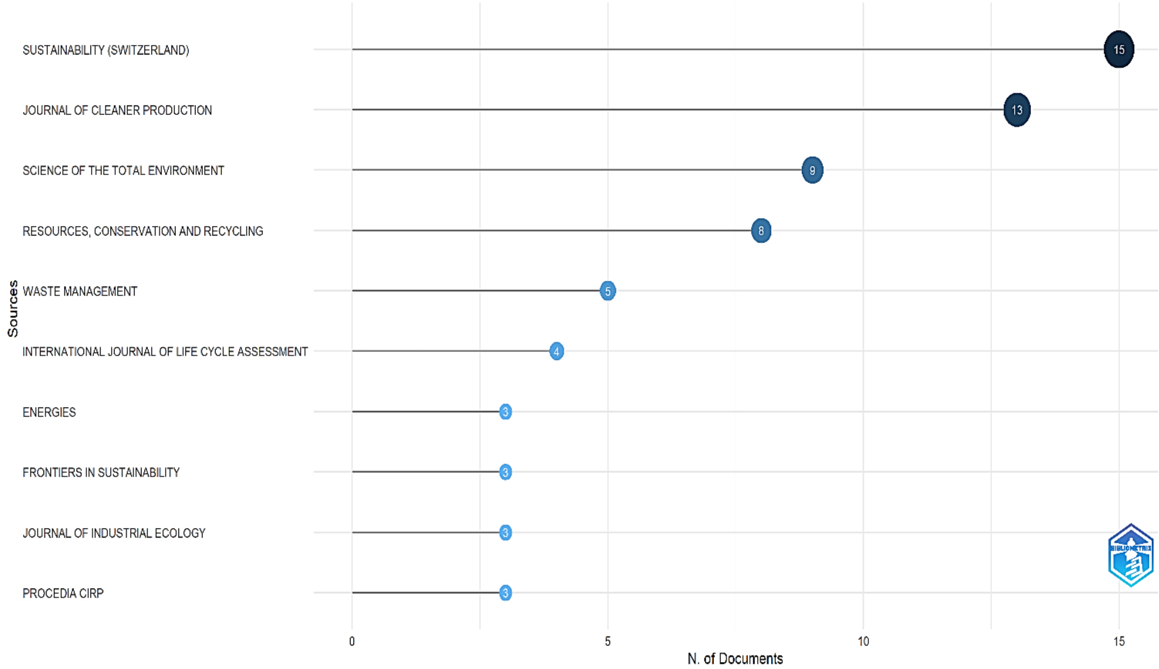


Source: Authors (2023)

The most relevant sources may indicate trends of the field analyzed, in this case, the overlapping area that studied Impact Assessment and Circular Economy, with a focus on Sustainability. The biggest portion of the publications was published by the Sustainability Journal which shows that the major field within the studies analyzed by this SLR is centered in the Sustainability research area. The second and third Journals that concentrate the most number of articles are the Journal of Cleaner Production and Science of the Total Environment and they both are, as the first one, also environmental and sustainability centered. The 3rd and 4th on the list of most relevant sources show the importance that waste management is given within the discussion of assessing the impacts of Circular Economy measures. The 5th most relevant source is the International Journal of Life Cycle

Assessment, which might demonstrate the priority of the field in utilizing this Impact Assessment tool to measure the impacts of CE strategies implementation.

Figure 17. Most Relevant Sources



Source: Authors (2023)

Thematic analysis

This part of the analysis outlines what is known and established from data-extraction forms and the core contributions those pieces of information have to the literature and practice. The thematic analysis differs from the descriptive analysis because it goes further than only describing the data extracted, but it also aims to be an aggregative and interpretative approach to the Circular Economy Principles found in this SLR as well as the main Relationship Types between IA and CE. Because the CE Principles are not always clear in the text, each document was carefully examined looking for a CE practical strategy that would fit under an Operational Principle. Because a 'principle' is a notion that clarifies how something occurs or functions (Suárez-Eiroa et al., 2019), each operational principle is a goal to be met to achieve Circular Economy.

The importance of understanding the prevalence of the Circular Economy Principles within the reviewed literature relies first on identifying which CE principles are more frequently mentioned or stressed to determine current research trends and areas of concentration in the field of Circular Economy that relate to Impact Assessment and

Sustainability. Second, identifying any gaps or imbalances in underrepresented CE principles related to Impact Assessment is crucial to identify the need for additional research and study in these areas. Third, understanding common CE principles related to IA can help policymakers and practitioners make better decisions, concentrating on widely accepted and researched CE principles (aligning CE activities with proven research) while trying to provide data to fill the gaps.

The first two CE Principles comprehend the *Target Operational Principles* which serve as direct link routes between CE's theoretical goals and real implementation strategies. These two principles are: adjusting inputs to the system to regeneration rates and adjusting outputs from the system to absorption rates. The analysis of the 82 studies found that less than half of the documents (25 articles; 30%) discuss **adjusting outputs from the system to absorption rates –** principle 2 (see Table 7, APPENDIX B, and Figure 6). This discussion encourages solutions that reduce and eliminate technology waste outputs while adjusting biological waste outputs within planetary limits (Suárez-Eiroa et al., 2019). In this context, not only the reduction of waste but also resource efficiency and sustainability become important strategies within the concept of a wider material management framework (Elia et al., 2017). A similar amount of documents (24 articles, 29%) discuss **adjusting outputs from the system to absorption rates** which discuss the minimization and eradication of nonrenewable resource inputs and the adjustment of renewable resource extraction rates to acceptable values for planetary limits (Suárez-Eiroa et al., 2019).

The findings show that the literature on Impact Assessment and Circular Economy is more focused on making the processes more eco-efficient (principle 2) – producing less waste - than on diminishing resource extraction (principle 1). Even though the number of articles is almost the same for both principles, most articles within the first principle apply strategies that substitute non-renewable with renewable input, such as using bio-based materials and renewable energy as inputs in the process (eg.: (Estévez et al., 2022; Rufí-Salís et al., 2021; Sadhukhan & Christensen, 2021; Wiprächtiger et al., 2020), instead of discussing strategies that save energy and materials (eg.: (Lokesh et al., 2020; Withers et al., 2018). CE theory supports these findings by supporting the belief that if all waste is turned into secondary materials there would be a reduction of the demand for primary resources, and therefore less environmental impacts (Fellner et al., 2017). However, the contradiction lies in the Circular Economy's efforts to minimize consumption and to eliminate waste, at the same time that companies that recover waste are expanding globally and relying on constant flows of waste. CE strategies are undermined by the growth of waste infrastructures and would jeopardize the stability of these industries' economies and finances (Savini, 2021).

For an Impact Assessment process, it is considered that resources produced by the environment cannot always be replaced and, therefore, the quantification of the loss of resources needs to allow for distinguishing between reversible and irreversible effects (Glasson & Therivel, 2019). Additionally, the selection criteria for the screening process for development projects considers both natural resource extraction and waste generation (Glasson & Therivel, 2019). Regarding Impact Assessment literature that discusses the impacts of diminishing resource extraction (principle 1), most of the articles are LCA-related. **Because most Life Cycle Assessments (LCA) have focused on impacts from resource extraction, LCA can improve the efficiency of Impact Assessment of Circular Economy strategies at various stages of the process** (Larrey-Lassalle et al., 2017; Stewart & Weidema, 2005).

Principles 3, 4, and 5 comprehend the *Core Operational Principles*, which define the core of the Circular Economy as a tool and can channel methods that indirectly adjust resource inputs to the system and waste and emissions from the system. These three principles are: closing the system, maintaining resource value within the system, and reducing the system's size. The analysis of the 82 studies found that more than half of the documents (56 articles; 68%) discuss **closing the system**, which means linking the resource-acquiring phase with waste management (principle 3). This principle involves strategies related to valorization and energy recovery for items and components that are difficult to reuse and recycle and only then is the landfill option on the table (Suárez-Eiroa et al., 2019). The 4th principle is closely related to the 3rd and it discusses **maintaining resource value within the circle** through, mainly, reducing obsolescence and improving the circulation of resources (34 articles; 41%). The difficulty in achieving these goals might explain the fewer articles that discuss Principle 4 when compared to Principle 3. The lower frequency does not mean this is a less important principle. The main CE policy goals of CE cannot be met without regulating planned obsolescence (Malinauskaite & Erdem, 2021). Finally, the 5th principle is about **minimizing the size of the circle**, and it was the principle less discussed within the literature researched (6 articles; 7%; see Table 7). The strategies to achieve the goal set by this principle are related to the reduction of production and consumption, which is the most effective waste prevention approach.

Before discussing the frequency distribution of CE principles, it is important to note that the main difference between the 2nd and the 3rd principles is that the second principle focuses on waste prevention (through the adjusting of products and processes for example) and the third is about making sure it stays in the production chain as long as possible (through strategies such as re-using and recycling). The 3rd principle (closing the loop) being the most frequent among the results of this RSL shows that an important area of connection between Impact Assessment and Circular Economy can be found in themes related to waste management. This can be explained first by Circular Economy roots in *Industrial Symbiosis,* which was an idea used to transform the output from one industry into an input for another industry (Chertow, 2008). Second, waste management is currently at the center of Circular economy policymaking (European Commission, 2014, 2023; Fitch-Roy et al., 2021; Savini, 2021). On the other hand, the 5th principle (reducing the system's size) being the least discussed among the results from this SLR points to a potential literature gap in the field of Impact Assessment that relates to Circular Economy. **Therefore, even though the fields of Impact Assessment and Circular Economy seem to approach and discuss waste management problems, the fields don't seem to have discussed together the root of waste management problems, which is growing production and consumption.**

To achieve the 5th principle, many authors discuss that, for a transition to a Circular Economy, there is a need to decrease economic growth or to achieve a steady-state economy (Dzhengiz et al., 2023; Schroeder et al., 2019). The idea of a growing economy, individualism, competition, maximization of profit, and other ideas embedded in capitalism must be fundamentally altered for the real slowing and narrowing of the cycles to occur (Bonciu, 2020; Dzhengiz et al., 2023). Additionally, not only economic growth is incompatible with environmental sustainability, particularly in the North's high-consumption nations, but it also denies poor access to environmental resources and services (Martínez-Alier, 2012). In this sense, Impact Assessment has an important role to play in the transition to a Circular Economy, especially in minimizing the size of the system (Principle 5). IA has the potential to challenge the idea of continuous economic growth through strong and independent Environmental Protection Agencies that can enforce environmental regulations (Khan & Chaudhry, 2021), and delay or stop development projects that cause significant environmental impacts.

The *Target Operational Principles* are crucial for the development of the other principles since they encompass strategies that are key for the development of a Circular Economy. Those principles are: designing and educating for Circular Economy. Both received little attention compared to the total number of articles analyzed. When compared to the other principles, **designing for Circular Economy** did not receive much attention among all the articles analyzed (33 articles; 40%), but received significantly more focus than the topic of education (principle 7) within this important group of principles. Designing to achieve a more Circular Economy is crucial because it can guarantee not only re-use, refurbishment, recycling, and processes with less hazardous substances but also can increase the durability of the product (Elia et al., 2017; Murray et al., 2017) leading to overall less production and consumption. However, designing for longevity is not always environmentally advantageous because many durable items use more energy and produce more entropy than the ones designed for a shorter life but with a natural outcome (Murray et al., 2017). Here lies an important reason for assessing the impacts of Circular Economy strategies, especially during the design stage of the projects.

Educating for Circular Economy was one of the principles less discussed in the literature that relates to Circular Economy and Impact Assessment (11 articles, 13%). In Public Policy, the Circular Economy Promotion Law of the People's Republic of China attributes the state the responsibility to encourage encourages, not merely the publicity, but also the education of circular economy and the popularization of scientific knowledge and international cooperation in the development of circular economy (Circular Economy Promotion Law of the People’s Republic of China, 2008). Additionally, CE Chinese national policy attributes to citizens the duty of improving awareness of conserving resources, protecting the environment, reasonable consumption, and saving resources. Educating for Circular Economy is very important for the producer since putting into practice CE strategies requires a diverse set of values, knowledge, and skills that must be combined (Andrews, 2015; De los Rios & Charnley, 2017). It is also very important for citizens to have access to diverse communicative measures, such as mass educational programs and mandatory reporting, to raise CE awareness and understanding (Geng et al., 2012). Informed and educated citizens can ensure that not only required regulatory measures are incorporated into long-term development objectives (Geng et al., 2012) but also can demand an improving quality and access to environmental resources and services. Education, debate, and public participation can transform social norms and human attitudes, particularly in wealthy countries. where lifestyles are more directed toward resource consumption (Velenturf & Purnell, 2021b). Education influences cultural norms, which play a significant role in shaping people's conduct toward environmental protection (Wiedmann et al., 2015).

Table 7. Frequency of CE principles in the studied literature

P1	P2	P3	P4	P5	P6	P7
24	25	56	34	6	33	11
Transversal operational principles		**Core operational principles**			**Target operational principles**	
49		96			44	

Source: Authors (2023)

After tracing the principles within the articles, we focused on retrieving important sentences that could indicate the relationship type from the documents to be submitted for semantic analysis. The results of the semi-supervised technique used in this study to extract semantic relations from the manually labeled samples are presented in Table 8. At least one sample was extracted from each article (APPENDIX C), and not only taxonomic but also non-taxonomic relationships between pieces of information were extracted to determine the type of relationship. The relationship types were not expressly stated in the examined literature nor were they pre-defined. The patterns developed throughout the content analysis.

Wiprächtiger et al. (2020) state that CE-related closed-loop activities do not always lead to lesser environmental impacts than open-loop activities and argue that the most notable Impact Assessment approaches suggested and used to evaluate CE are material flow analysis (MFA) and life cycle assessment (LCA). Similarly, Sandanayake et al. (2022) perform a LCA to assess the environmental impacts and evaluate new materials as sustainable alternatives. On the same note, (Cai & Waldmann, 2019) describe the life cycle assessment (LCA) of structures as an enabler of the evaluation of the environmental effects of all construction-related activities, from the extraction of raw resources to their demolition or recycling/reuse. Marrucci et al. (2022) used LCA as an Impact Assessment tool to compare the baseline scenario with no circular actions and a circular scenario to avoid circular procedures that have minimal positive effects on the global overall environmental impact. In most of the articles reviewed (62 of them; 76%), the relationship between Impact Assessment and Circular Economy is one of Impact Assessment being used to assess the impacts of Circular Economy activities. Among those, few articles propose an assessment of CE strategies at the policy level. In this sense, Foster et al. (2020)

propose a Framework that can be applied to assess the new CE policy instruments, such as guidelines for grant or procurement funding for adaptive reuse of cultural heritage buildings at the local or regional level. Building on this, we develop our 4th proposition:

Proposition 04: Impact Assessment is related to the Circular Economy by the environmental impacts appraisal of Circular Economy measures and policies implementation.

LCA, in most of the articles reviewed, was the Impact Assessment tool chosen to evaluate the impacts of CE activities. Laso et al. (2018) state that using environmental tools like Life Cycle Assessment (LCA), which have been more popular in recent years, is needed for assessing the most sustainable Circular Economy scenarios, which in their case was the valorization of food waste. Also using LCA to assess the impacts of waste were (Iodice et al., 2021), who used LCA to evaluate the sustainability of different construction and demolition scenarios to develop the *Best Practice* scenario. LCA was also used to assess the social impacts of Circular Economy measures as did Garcia-Muiña et al. (2018) and Aranda et al. (2021), who were able to measure, through Social Life Cycle Assessments, potential positive and negative impacts along a product's life cycle as well as offer sustainability performance indicators.

Preposition 05: Life Cycle Assessment (LCA) is the most used Impact Assessment tool to assess the impact of Circular Economy measures’ and policies’ implementations

A stronger relationship is proposed by Ncube et al (2022) and Foteinis (2020) who understand that the Impact Assessment of environmental implications of the suggested circular solutions is not only necessary but crucial to achieving environmental sustainability. Similarly, Iturrondobeitia et al., (2022) and W. Zhou et al. (2022) also state the urgency and criticality of assessing the environmental impacts of specific circular strategies to achieve sustainable outcomes, such as cathode-recycling approaches and recyclable epoxy asphalt. Additionally, some articles assessed Circular Economy Strategies to improve the performance of the strategy being assessed. That was the case of F. Colangelo et al. (2020) who stated that Impact Assessment (through LCA) can be used not only for evaluating the environmental impacts of one of the most common Circular Economy measures, which is waste management but also for identifying improvements to their performance. To maximize the reduction of carbon emissions and material flow, Mercader-Moyano et al. (2020) noted that circularity (implementation of CE practices) and sustainability need to be considered over the whole life cycle of the project implementation (a building construction in the article case). Therefore, the literature analyzed pointed to the need for managers and policymakers to use techniques to assess the impacts of CE scenarios to increase the adoption and implementation of the CE strategy (Bressanelli et al., 2019).

Most articles that assess the impacts of Circular Economy activities focus on strategies related to waste management (Banias et al., 2020; F. Colangelo et al., 2020; Sandanayake et al., 2022). This might indicate that most Circular Economy strategies are currently focused on waste management activities, especially those related to promoting and improving downcycling, recycling, and upcycling of wastes (e.g...: (F. Colangelo et al., 2020; Subramanian et al., 2021; Wiprächtiger et al., 2020; Withers et al., 2018). Because the current implementation of CE seems to be limited to waste management strategies, assessing impacts on other levels might indicate a gap in the practice of assessing the Circular Economy. On the other hand, few articles use Impact Assessment to assess the impact of Circular Economy strategies related to design (Table 7), but only one included impact assessment as part of the development of the CE strategy instead of assessing the impacts during the design stage of implementation (Sumter et al., 2020). Rejeb et al. (2022) describe in their work the collaborative development approach for educational instruction to train engineers to consider the impacts of their innovations throughout their whole life cycles while also adhering to the principles of the circular economy. This is the only article that considers the impacts before the design phase, which may comprehend a literature gap within the Circular Economy and Impact Assessment literature.

Differently, for Sadhukhan & Christensen (2021) a Circular Economy strategy (as the knowledge that ensures the proper performance of a circular economy), is an important factor to take into account when assessing the impacts of the strategy on the environment. Similarly, Banias et al. (2020) state that a Circular Economy strategy (waste management in the case of the article) should be incorporated into the Impact Assessment process. Additionally, to assess the economic impacts of alternative methods for managing end-of-life waste (the CE strategy being evaluated), the impact assessment criterion chosen is resource conservation (Deshpande et al., 2020). These results are in line with the findings of Opferkuch et al. (2022) who found not only that few reports consider CE, but that Circular Economy is rarely, inconsistently, and largely unquantified in corporate sustainability reports which leads to the authors finding a limited connection between CE and sustainability assessment. Those articles indicate a need to insert Circular Economy principles within the Impact Assessment process, which can be beneficial for the implementation of and transition to a Circular Economy. In this sense, even though fewer articles point in this direction, **the Circular Economy relationship to Impact Assessment lies in the benefit CE strategies can have to the Impact Assessment process once they are incorporated.**

Table 8. Relationship Types between Circular Economy and Impact Assessment

Relationship types between the Circular Economy and Impact assessment				
General Direction	**Types of relationship**	**Impact assessment is seen as...**	**Examples in literature**	**Color code representation**
Assessment	Assessment relation	One of the tools/approaches to assess the impact of Circular Economy strategies	"Life cycle assessment (LCA) has been used to evaluate the potential environmental impacts of various wastewater-based phosphorus recovery and reuse opportunities"	Impact assessment information; **intensity**; relation; CE strategy
	Strong assessment relation	crucial/the main tool/approach to assess the impacts of Circular Economy strategies	"It is, therefore, **crucial** to assess the potential environmental impacts of the technological processes related to different management scenarios of this by-product."	
	Circularity assessment relation	One of the tools/approaches to assess the circularity impacts of a given project, besides assessing the environmental impacts	"life cycle assessment (LCA) is a widespread tool to assess the environmental benefits and burdens associated with waste management systems and to identify strategies that will **improve their performance**"	
	Assess-to-design relation	a tool/an approach that assesses a product/project/policy/program, to design a CE strategy	"This training is an opportunity to encourage CEA engineers to think in terms of the global impact of the technologies they develop on the three pillars of the eco-innovation throughout the entire life cycle while meeting the requirements of the circular economy"	
Addition	Beneficial additional relation	a tool/ approach that incorporates CE strategies, to assess a CE strategy	"The recycling of injection-molded PP material can be added to renewable energy technologies and used in environmental impact assessment."	

Source: Authors (2023)

Table 9. Frequency of appearance of each relationship type

Relationship types between the Circular Economy and Impact assessment		
General Direction	**Types of relationship**	**Frequency in the literature**
Assessment	Assessment relation	63
	Strong assessment relation	8
	Circularity assessment relation	5
	Assess-to-design relation	1
Addition	Beneficial additional relation	5

Source: Authors (2023)

CHAPTER 5 – FINAL REMARKS

This chapter will summarize the main findings of this dissertation's research, and discuss gaps as well as contributions and implications this work has for theory and practice. This dissertation aimed to understand how Circular Economy and Impact Assessment relate to each other in theory and practice through a literature review. How one can affect the other is a relation that has not been deeply researched. Both the Bibliometric Study and the Systematic Literature Review had the aim of finding the connection between Impact Assessment and Circular Economy. The first in a broader manner and the second in a more focused way. The results point to a convergence point between the fields of Impact Assessment and Circular Economy: both aim for Sustainability at their core. However, the literature reviewed points to literature points to the practice of Impact Assessment being more focused on trying to achieve Strong Sustainability, linking this goal to the effectiveness of the process (Loomis et al., 2022). However, Palerm (2022) argues that Strong Sustainability has remained the exception in IA practice and the close connection between a healthy environment and socioeconomic development has remained outside the scope of short-term planners and developers. This is in line with what (Morrison-Saunders & Retief (2012) demonstrate about the IA practice in South Africa, in many situations Strong Sustainability is already present very clearly in the regulations, proving that the challenge for IA is not in establishing the regulations, but in actually carrying out the legislations that already exist. On the other hand, current Circular Economy policy measures, are more directed to weak practices (Johansson & Henriksson, 2020). Most of the articles found through the Bibliometric Study's content analysis and SLR pointed to Impact Assessment being used to assess the impacts of weak Circular Economy measures (Arendt et al., 2022; Murray et al., 2017).

It is important to note that Weak Circular Economy measures are the ones that focus on the outflow of resources but do not discuss the minimization of inflow. In other words, if the use of secondary materials is imagined to increase, this is usually not mentioned in terms of substituting primary raw material, and when it is done superficially (F. Colangelo et al., 2020; Foteinis, 2020; Kopnina, 2019). Even though the most frequent relationship found between Impact Assessment and Circular Economy is that IA assesses the impacts of CE measures, the importance of assessing the impacts of Circular Economy measures to avoid weak approaches is highlighted by many authors analyzed throughout this dissertation (Albizzati et al., 2021; Bressanelli et al., 2019; Iturrondobeitia et al., 2022;

Kovačič Lukman et al., 2021; Laso et al., 2018; Marrucci et al., 2022; Ncube et al., 2022; Schaubroeck et al., 2021; Subramanian et al., 2021). Additionally, Impact Assessment can help fill Circular Economy practice gaps, by, for example, assessing the social impacts of Circular Economy measures, which is also an important result of this work (Aranda et al., 2021; Kovačič Lukman et al., 2021; Reinales et al., 2020; Subramanian et al., 2021). To assess the impacts of CE measures, the main Impact Assessment tool used is Life Cycle Assessment (LCA), but many articles discuss the need for a more integrated IA process that goes beyond the use of LCA (Balkenende & Bakker, 2015; Bressanelli et al., 2019; Saidani et al., 2021; Schaubroeck et al., 2021; Sumter et al., 2020; Verstraeten-Jochemsen et al., 2018). (Schaubroeck et al., 2021). Therefore, LCA can be incorporated along with other IA techniques within the Impact Assessment process evaluation to achieve better results for CE measures and for them to achieve results more focused on Sustainability. Also, because most Life Cycle Assessments (LCA) that were analyzed in this work have focused on impacts from resource extraction, LCA can improve the efficiency of Impact Assessment of Circular Economy strategies at various stages of the process In fact, the Impact Assessment is not only required by Circular Economy policies (EC, 2015c) but can actively contribute to the practice of the Circular Economy, assessing the impacts of circular activities and ensuring that they truly achieve Strong Sustainability.

As previously stated, Impact Assessment has procedural requirements that are embedded in Strong Sustainability ideals, but in practice, they do not lead to better environmental protection (Palerm, 2022; Therivel, 2020). In this sense, the articles analyzed which measure the climate change effect use the metric of GHG emissions (measured by CO_2-equivalent fluctuations) (Marrucci et al., 2022; Silalertruksa et al., 2022; Wiprächtiger et al., 2020). This metric usually works in theory, but it assumes that carbon reductions achieved anywhere are equivalent globally, but Climate Change impacts have different impacts across the globe, affecting mostly poor populations across the world (Banerjee, 2012; Böhm & Dabhi, 2009). Thus, it can be seen that even though CE is seen as a solution to the unsustainability of the current economic system, CE assessments can only deal superficially with the impact of Climate Change. Associated with the current mode of production and consumption, there is a change in energy supply pattern, loss of biodiversity space, and significant negative effects of climate change, which elevate the scales of impact as well as the difficulties for Impact Assessment to operate (A. Bond & Dusík, 2020). Therefore, another result of this dissertation was a point of convergence between Impact Assessment and Circular Economy being that they are both environmentally centered as being similar in struggling to deal with Climate Change environmental impacts. So, if Impact Assessment is to help assess circular activities and be effective in leading to better global environmental protection as well as to assess the climate change impacts, it needs to move further ahead of being a set of procedural requirements and recommendations and being legally binding.

Among the indirect links found, it is important to note that even though less frequent, some of them should be called attention for further research. (Josimović et al., 2021) discuss the ability of Strategic Environmental Assessment (SEA) to promote Circular Economy because SEA addresses changes and potential benefits to the environment and the society from implementing the concepts of a circular economy from the very beginning of planning. Omwoma et al. (2017) only superficially discuss that connection by suggesting the use of Strategic Environmental Assessment to deal with waste management problems in Africa. Another topic many of the results focus on is the developing or mixing of CE indicators to assess the sustainability of CE measures (Kovačič Lukman et al., 2021; Mercader-Moyano et al., 2022; Morsy & Thakeb, 2022; Picatoste et al., 2022). However, even though there are many circularity indicators the identified need is for frameworks to aid in the selection of CE indicators for sustainability assessments.

The findings of this dissertations, although pointed to Impact Assessment being used to assess the impacts of Circular Economy strategies, few articles discussed the incorporations of CE principles and strategies into the IA process. The potential benefits of this integration have emerged in the results of this work. Banias et al. (2020) state the importance of Impact Assessment (life cycle assessment tool) including an integrated solid waste management system, which is one of the most common Circular Economy strategies. Sadhukhan & Christensen (2021) discuss the importance of including CE strategies that consider the earlier life cycle stages and include resource acquisition. Differently from the previous, Balkenende & Bakker (2015) discuss how a CE strategy related to promoting knowledge that ensures the performance of the circular economy is not only useful to be considered for the end-of-life treatments of a product but also is critical in assessing the environmental impacts. These results are supported by (Topham et al., 2019) who discuss end-of-life strategies for assessing the impacts of the decommissioning phase of offshore wind farms, and by Opferkuch et al. (2022) who discuss the lack of Circular Economy being included within corporate sustainability reports. Therefore, Impact Assessment can benefit from a greater integration with Circular Economy strategies especially benefiting from CE insights to deal with challenges of the 21st century, such as the impacts of the 4th industrial revolution. Inserting CE strategies in the IA process may enhance the Impact Assessment's effectiveness, comprehensiveness, and sustainability. However, further research is needed to explore the previous potential benefits mentioned, since this integration can advance both the fields of IA and CE.

It is important to note that Impact Assessment practice would improve if looked at from a Circular Economy lens. First, through a Circular Economy lens, Impact Assessment would be required to consider the entirety of the lifecycle of projects, from resource extraction to end-of-life. In this sense, Abramic et al., (2022) state that the environmental impacts of the decommissioning of Offshore Wind Farms (OWF) and their related infrastructure are not entirely clear. Impact Assessment also benefits by emphasizing long-term and resilience approaches in all projects, plans programs, and policies it assesses brought by a deeper connection with Circular Economy. Circular Economy policy measures if meant to shift the current production mode, need to focus not only on the creation of value but mainly on the enhancement of general life quality through the creation, delivery, and capture of value by implementing circular strategies which extend the lifetime of resources within the system (Opferkuch et al., 2023). To this end, Circular Economy policy regulations show a focus on higher-ranking CE methods (like education, or taxation for increased resource extraction) instead of the current emphasis that is given to waste management (especially recycling-related rates) (Reike et al., 2018). In this sense Impact Assessment policy implementation is much more stable and has much more experience in many countries worldwide as a policy implementation and can guarantee the CE measures serve their purposes, thus being of extreme importance in achieving true Circular Economy.

Some of this work's limitations lie in the lack of two or more researchers for the literature reviewing phase which may cause bias in the analysis. Additionally, another limitation is related to the search strings used to achieve the main results of the Bibliometric Study and Systematic Literature Review. Many connections to explain the relationships found throughout this research were found in papers that were not contemplated by the dissertation. This probably happened because of the choice of keyword to refer to as 'Impact Assessment'. A well-established synonym that could have been used to analyze the relationship among the fields would have been 'Environmental Assessment'. This might have encompassed an important group of articles, that would add important insight to the analysis. This work aimed not to provide an answer but an overview of the relationship between two topics that mutually benefit each other as well as a relationship framework for future research. We hope that the results may be of use to companies' stakeholders, policymakers, and researchers given the importance of inserting Circular Economy principles in the Impact assessment as well as the urge to assess the impacts of Circular Economy action to achieve Environmental Sustainability.

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APPENDIX A – SYSTEMATIC LITERATURE REVIEW PROTOCOL

Objective: Investigate the relationship types between Impact Assessment and the Circular Economy

Research Strategies

Data bases: Web of Science and Scopus

Research categories: title, abstract, author keyword

Research words for circular economy field: TI="circular economy" OR AB= "circular economy" OR AK="circular economy"

Research words for impact assessment field: TI="impact assessment " OR AB="impact assessment " OR AK= "impact assessment"

Inclusion and Exclusion Criteria:

Type of documents excluded: revision article, editorial material, book chapter, letter, abstract report, report, data paper, conference review, book, short survey, note, review

Languages included: English and Portuguese

Year of publication: from 2001 to 2023

Information selected for download at WoS: Autor(es), Título, Fonte, Info conf./Patrocinadores, Contagem do número de citações, Número de acesso, Identificadores de autores, ISSN, ID PubMed, Resumo, Afiliações, Tipo de documento, Palavras-chave, Áreas de pesquisa, Referências citadas*, Idioma

Information selected for download at Scopus: Author(s), Author(s) ID, Document title, Year, EID, Source title, (volume, issue, pages), Citation count, Source & document type, Publication Stage, DOI, Open Access, Affiliations, Language of the original document, Abstract, Author keywords, Include references

Synonyms considered in data treatment:

- Life cycle assessment (lca), life cycle analysis (lca), life cycle impact(s) assessment (lcia), life cycle impact analysis (lcia), life cycle environmental analysis, life cycle environmental assessment, environmental life cycle assessment, environmental life cycle analysis, life cycle environmental impact(s), life cycle environmental impact assessment

- environmental impact(s) assessment (eia), environment impact(s) assessment, environmental impact(s) analysis, environment impact(s) analysis

- environment assessment, environmental assessment, environment analysis, environmental analysis

- environmental impact(s), environment impact(s)

- impact assessment, impact analysis

- health impact(s) assessment, health impact(s) analysis, health-related impact assessment, environmental health impact assessment

- Strategic environmental impact assessment (seia), strategic environment impact assessment, strategic environmental assessment (sea), strategic environment assessment, strategic impact assessment

- case study, case analysis, case research, case report, case study analysis, case study research, case-based learning, case-study research strategy, cross-case analysis, multiple-case study, case-crossover study/analysis

APPENDIX B – CIRCULAR ECONOMY PRINCIPLES

ARTICLE TITLE	CE PRINCIPLES						
	P1	P2	P3	P4	P5	P6	P7
A construction and demolition waste management model applied to social housing to trigger post-pandemic economic recovery in Mexico (Mercader-Moyano et al., 2022)			X	X			
A framework for sustainable and circular system design: Development and application on thermal insulation materials (Wiprächtiger et al., 2020)	X	X	X	X			
A Life Cycle Analysis Approach for the Evaluation of Municipal Solid Waste Management Practices: The Case Study of the Region of Central Macedonia, Greece (Banias et al., 2020)		X	X	X			
A material and component bank to facilitate material recycling and component reuse for a sustainable construction: concept and preliminary study (Cai & Waldmann, 2019)			X	X		X	
A new framework for assessing the environmental impacts of circular economy friendly soil waste-based geopolymer cements (Sandanayake et al., 2022)		X					
Achieving Sustainable Phosphorus Use in Food Systems through Circularisation (Withers et al., 2018)	X	X	X		X	X	
An In-Depth Life Cycle Assessment (LCA) of Lithium-Ion Battery for Climate Impact Mitigation Strategies (Sadhukhan & Christensen, 2021)		X	X				
Assessing the impacts of Circular Economy: a framework and an application to the washing machine industry (Bressanelli et al., 2019)				X	X	X	X
Boosting circular economy via the b-corporation roads. The effect of the entrepreneurial culture and exogenous factors on sustainability performance (Boffa et al., 2023)						X	X
Capital-based life cycle sustainability assessment (Subramanian et al., 2021)		X	X				
Circular Economy Competencies for Design (Sumter et al., 2020)						X	X
Circular economy for phosphorus supply chain and its impact on social sustainable development goals (El Wali et al., 2021)			X			X	X
Circular Economy in Apple Processing Industry: Biodiesel Production from Waste Apple Seeds (Tasić et al., 2022)			X			X	
(Ncube et al., 2022)	X			X	X	X	
Circularity and life cycle environmental impact assessment of batteries for electric vehicles: Industrial challenges, best practices and research guidelines (Picatoste et al., 2022)						X	
(La Scalia et al., 2021)			X			X	
Combined application of Life Cycle Assessment and linear programming to evaluate food waste-to-food strategies: Seeking for answers in the nexus approach (Laso et al., 2018)		X		X			
Combining LCA and circularity assessments in complex production systems: the case of urban agriculture (Rufí-Salís et al., 2021)	X	X	X	X			
Combining Life Cycle Assessment and Circularity Assessment to Analyze Environmental Impacts of the Medica ln Remanufacturing of Electrophysiology Catheters (Schulte et al., 2021)	X		X				
Comparative evaluation of the environmental impacts of geosynthetic Mechanically Stabilized Earth walls (Morsy & Thakeb, 2022)		X					
Comparative LCA of concrete with recycled aggregates: a circular economy mindset in Europe (F. Colangelo et al., 2020)	X	X	X				
Comparing Life Cycle Impact Assessment, Circularity and Sustainability Indicators for Sustainable Design: Results from A Hands-on Project with 87 Engineering Students (Saidani et al., 2021)						X	X

Counting Gains to beyond Zero-impact Futures (Jones et al., 2020)						X	
Design of Indicators of Circular Economy as Instruments for the Evaluation of Sustainability and Efficiency in Wastewater from Pig Farming Industry (Molina-Moreno et al., 2017)	X	X	X			X	
Developments and Challenges in Design for Sustainability of Electronics (Balkenende & Bakker, 2015)			X	X		X	
Does increased circularity lead to environmental sustainability? (Boldoczki et al., 2021)			X	X			
Eco-Efficient Analysis of a Refurbishment Proposal for a Social Housing (Mercader-Moyano et al., 2020)	X	X					
Environmental assessment of four waste cooking oil valorization pathways (Frota De Albuquerque Landi et al., 2022)			X				
(Iturrondobeitia et al., 2022)		X	X				
Environmental sustainability in the food-energy-water-health nexus: A new methodology and an application to food waste in a circular economy (Slorach et al., 2020)	X	X	X				
Environmental Sustainability of Waste Circulation Models for Sugarcane Biorefinery System in Thailand (Silalertruksa et al., 2022)			X				
Estimating environmental and societal impacts from scaling up urine concentration technologies (Gunnarsson et al., 2023)	X	X	X	X			
Exploring an alternative to the Chilean textile waste: A carbon footprint assessment of a textile recycling process (Espinoza Pérez et al., 2022)		X	X				
Exploring nutrient recovery from hydroponics in urban agriculture An environmental assessment (Rufí-Salís et al., 2020)	X		X	X			
Extended producer responsibility: How to unlock the environmental and economic potential of plastic packaging waste? (Andreasi Bassi et al., 2020)	X	X	X			X	
From Innovation to Eco-Innovation: Co-Created Training Materials as a Change Driver for Research and Technology Organisations (Rejeb et al., 2022)						X	X
From the sea to the table: The environmental impact assessment of fishing, processing, and end-of-life of albacore in Cantabria (Fernández-Ríos et al., 2022)		X	X	X			
Gearing up sustainability thinking and reducing the bystander effect – A case study of wastewater treatment plants (Seifert et al., 2019)			X				X
Green-washing or best case practices? Using circular economy and Cradle to Cradle case studies in business education (Kopnina, 2019)						X	X
High-value products from food waste: An environmental and socio-economic assessment (Albizzati et al., 2021)			X	X			
How decentralized treatment can contribute to the symbiosis between environmental protection and resource recovery? (Estévez et al., 2022)	X	X	X				
How small daily choices play a huge role in climate change: The disposable paper cup environmental bane (Foteinis, 2020)			X	X			
Hybridised sustainability metrics for use in life cycle assessment of bio-based products: resource efficiency and circularity	X	X	X	X		X	
IMPACT: a tool for R&D management of circular economy innovations (Lokesh et al., 2020)		X	X	X		X	X
Innovative options for the reuse and valorization of aquaculture sludge and fish mortalities: Sustainability evaluation through Life-Cycle Assessment (Cristiano et al., 2022)		X	X	X			
Integrating Circularity in the Sustainability Assessment of Asphalt Mixtures (Mantalovas & Di Mino, 2020)	X		X			X	
Leather tanning: Life cycle assessment of retaining, fatliquoring and dyeing (Tasca & Puccini, 2019)	X	X					

Life Cycle Environmental Impacts of Wastewater-Derived Phosphorus Products: an Agricultural End-User Perspective (Lam et al., 2022)	X						
Life cycle environmental sustainability of valorization routes for spent coffee grounds: From waste to resources (Schmidt Rivera et al., 2020)		X	X	X			
Life cycle impact assessment of safety shoes toe caps realized with reclaimed composite materials (Bianchi et al., 2022)	X	X	X	X			
Liquid fertilizer production from organic waste by conventional and microwave-assisted extraction technologies: Techno-economic and environmental assessment (Fernández-Delgado et al., 2022)		X	X	X			
Managerial Energy in Sustainable Enterprises: Organizational Wisdom Approach (Stelmaszczyk et al., 2021)							
Multi-criteria decision analysis (MCDA) method for assessing the sustainability of end-of-life alternatives for waste plastics: A case study of Norway (Deshpande et al., 2020)			X				
Multi-product biorefinery with sugarcane bagasse: Process development for nanocellulose, lignin and biohydrogen production and lifecycle analysis (Katakojwala & Venkata Mohan, 2022)				X			
Number of Times Recycled and Its Effect on the Recyclability, Fluidity and Tensile Properties of Polypropylene Injection Molded Parts (Huang & Peng, 2021)			X				
Preliminary design of recyclable epoxy asphalt: Regeneration feasibility analysis and environmental impact assessment (W. Zhou et al., 2022)	X		X			X	
Recycling potential of post-consumer plastic packaging waste in Finland (Dahlbo et al., 2018)			X				
Redesigning a food supply chain for environmental sustainability - an analysis of resource use and recovery (Krishnan et al., 2020)	X	X	X			X	
"Slowing" and "Narrowing" the Flow of Metals for Consumer Goods: Evaluating Opportunities and Barriers (Dominish et al., 2018)			X	X	X		
Social impact analysis of products under a holistic approach A case study in the meat product supply chain (Aranda et al., 2021)						X	X
Social life cycle assessment of product value chains under a circular economy approach A case study in the plastic packaging sector (Reinales et al., 2020)						X	X
Socio-economic impact assessment of large-scale recycling of treated municipal wastewater for indirect groundwater recharge (Manisha et al., 2023)			X	X			
Sustainability assessment of circular economy over time: Modelling of finite and variable loops & impact distribution among related products (Schaubroeck et al., 2021)			X	X			
Sustainability assessment of Construction and Demolition Waste management applied to an Italian case (Iodice et al., 2021)			X	X			
Sustainability Assessment of two Digestate Treatments: a Comparative Life Cycle Assessment (Schaubroeck et al., 2021)		X	X	X			
Sustainability Assessment with Integrated Circular Economy Principles: a Toy Case Study (Kovačič Lukman et al., 2021)	X		X	X		X	
Sustainability Impact Assessment of Increased Plastic Recycling and Future Pathways of Plastic Waste Management in Sweden (Milios et al., 2018)			X				
Sustainable management of spent fluid catalytic cracking catalyst from a circular economy approach (Alonso-Fariñas et al., 2020)			X	X			
Sustainable production of marine equipment in a circular economy: deepening in material and energy flows, best available techniques and toxicological impacts (Zapelloni et al., 2019)	X	X	X				

The environmental challenges of AI in EU law: lessons learned from the Artificial Intelligence Act (AIA) with its drawbacks (Pagallo et al., 2022)	X	X				X
The future of circular environmental impact indicators for cultural heritage buildings in Europe (Foster et al., 2020)	X		X	X		
The Paradigms of Industry 4.0 and Circular Economy as Enabling Drivers for the Competitiveness of Businesses and Territories: The Case of an Italian vCeramic Tiles Manufacturing Company (Garcia-Muiña et al., 2018)	X	X			X	X
The SPPD-WRF Framework: A Novel and Holistic Methodology for Strategical Planning and Process Design of Water Resource Factories (Kehrein et al., 2020)		X				X
Toward sustainable reprocessing and valorization of sulfidic copper tailings: Scenarios and prospective LCA (Adrianto et al., 2023)	X		X	X		
Towards sustainable aquaculture systems: Biological and environmental impact of replacing fishmeal with Arthrospira platensis (Nordstedt) (spirulina) (Napolitano et al., 2022)		X	X	X		
Transition to circular economy in the construction industry: Environmental aspects of waste brick recycling scenarios (Fořt & Černý, 2020)			X	X		
Upcycling Shipping Containers as Building Components - an environmental impact assessment (Bertolini & Guardigli, 2020)			X	X		X
Urban forests: Bioeconomy and added value (Mihailova, 2019)						X
Using a life cycle assessment to identify the risk of “circular washing” in the leather industry (Marrucci et al., 2022)		X		X		X
Waste Management for Lunar Resources Activities- Towards a Circular Lunar Economy (Pino et al., 2022)			X			
Whole life cycle environmental impact assessment of buildings Developing software tool and database support for the EU framework Level(s) (De Wolf et al., 2023)						X

APPENDIX C – RELATIONSHIP TYPES BETWEEN IA AND CE

ARTICLE TITLE	METHODOLOGIES OF IA	RELATIONSHIP BETWEEN IA AND CE		
		Occurrences	Relation extraction	IA is seen as:
A construction and demolition waste management model applied to social housing to trigger post-pandemic economic recovery in Mexico	Mix	"the proposed methodology is determinant to implement federal and state legislation for CDW recovery"	Assessing the impacts of a (CE strategy) is crucial to implement a (CE strategy)	Circularity assessment relation
A framework for sustainable and circular system design: Development and application on thermal insulation materials	MFA and LCA	"to assess CE, different tools have been proposed and applied, most prominently material flow analysis (MFA) and LCA"	proposed and applied to assess (CE strategy)	Assessment relation
A Life Cycle Analysis Approach for the Evaluation of Municipal Solid Waste Management Practices: The Case Study of the Region of Central Macedonia, Greece	LCA and others	"An integrated MSW management system [...] should be incorporated into a life cycle assessment"	incorporates (CE strategy)	Beneficial additional relation
A material and component bank to facilitate material recycling and component reuse for a sustainable construction: concept and preliminary study	LCA and others	"The life cycle assessment (LCA) of structures allows to assess environmental impacts [...] spanning from the extraction of raw materials to demolition or recycling/reuse "	assess (CE strategy)	Assessment relation
A new framework for assessing the environmental impacts of circular economy friendly soil waste-based geopolymer cements	LCA and others	"Several studies have undertaken LCA on new materials as sustainable alternatives"	assess (CE strategy)	Assessment relation
Achieving Sustainable Phosphorus Use in Food Systems through Circularisation	framework development	"A greater understanding of the knowledge flows in the food chain, and	improve a (CE strategy) to downstream environmental impacts/assess different CE	Assessment relation

		how these can be improved to increase awareness of food system inefficiencies and downstream environmental impacts could help to engender a culture of greater sustainability amongst all stakeholders"/" The philosophy of a circular economy provides the stimulus to move away from current food production systems that rely on risk averse P management strategies that do not consider resource requirements, efficiencies of use or the upstream or downstream environmental impacts"	scenarios throughout the text	
An In-Depth Life Cycle Assessment (LCA) of Lithium-Ion An In-Depth Life Cycle Assessment (LCA) of Lithium-Ion Battery for Climate Impact Mitigation Strategies	LCA	"[...] life cycle impact assessment [...] stresses the importance of consideration of life cycle stages, i.e., fundamental resource acquisition, beyond the manufacturing, use and recycling stages of LCA.	stress the importance of consideration/applicate (CE strategy)	Beneficial additional relation
Assessing the impacts of Circular Economy: a framework and an application to the	LCA and others	"in order to enhance the adoption of the CE approach, managers and	To better adopt a (CE strategy), we need to assess the impact of a (CE strategy)	Circularity assessment relation

washing machine industry		policymakers need systemic and holistic methods to evaluate ex-ante the impacts of CE scenarios"/"One of the main factors limiting the implementation of a CE scenario is the lack of assessment methods of CE impacts"		
Boosting circular economy via the b-corporation roads. The effect of the entrepreneurial culture and exogenous factors on sustainability performance	Generalized linear model estimation	"the role of the entrepreneurial culture related to the CE, seem to actively stimulate the sustainability performance of B-corporations toward a CE, as measured through the B-Impact Assessment Score developed by B-Lab"	measures the impact of a (CE Strategy)	Assessment relation
Capital-based life cycle sustainability assessment	LCSA (Life cycle sustainability assessment)	"Therefore this study aims to review and assess the environmental and socio-economic implications of an IS (industrial symbiosis) network by using life cycle sustainability assessment (LCSA)"/"a social, economic, and environmental impact assessment be further developed to capture the impacts of product life	assess the impact of a (CE strategy)	Assessment relation

Circular Economy Competencies for Design	LCA and others	cycle on the different capitals" "designers, when aiming to extend product lifetime, **need** to be able to assess the environmental consequences of their design interventions. This falls within the normative competency as the underlying ability to estimate environmental impact relates to making assessments about circular solutions."	assess (CE strategy) to better implement a (CE strategy)	Circularity assessment relation
Circular economy for phosphorus supply chain and its impact on social sustainable development goals	MFA and SLCA	"Estimation of social impact of P circularity at regional and global scale by 2050"/ "Assessment of effect of linear and circular flows on P supply chain by 2050"	assess the impact of a (CE strategy)	Assessment relation
CIRCULAR ECONOMY IN APPLE PROCESSING INDUSTRY: BIODIESEL PRODUCTION FROM WASTE APPLE SEEDS	Mix	"environmental impact assessment of biodiesel production from apple seed oil obtained from apple pomace (waste)"	assess (CE strategy)	Assessment relation
Circular economy paths in the olive oil industry: a Life Cycle Assessment look into environmental performance and benefits	LCA	"Likewise, it is **essential** to thoroughly assess and quantify the potential environmental impacts of the proposed circular solutions to avoid miscalculations	assess the impact of a (CE strategy)	Strong assessment relation

Circularity and life cycle environmental impact assessment of batteries for electric vehicles: Industrial challenges, best practices and research guidelines	LCA e outros	in pursuing the target of sustainability" "the environmental analysis of the CE strategies applied in the design and life-cycle management of electric vehicle batteries requires system thinking supported by robust holistic science-based tools, such as life-cycle assessment (LCA)"	assess the impact of a (CE strategy)	Assessment relation
Coffee biowaste valorization within circular economy: an evaluation method of spent coffee grounds potentials for mortar production	multi-criteria approach	"we compare eight formulations by means of multi-criteria approaches that are nowadays claimed as a useful and effective decision aiding support instrument to assess the development of new sustainable construction materials"	assess (CE strategy)	Assessment relation
Combined application of Life Cycle Assessment and linear programming to evaluate food waste-to-food strategies: Seeking for answers in the nexus approach	LCA and others	"the evaluation of the most environmentall y-friendly FL management scenarios requires the use of environmental tools, such as Life Cycle Assessment (LCA), which have been increasingly used in recent years."	evaluate (CE strategy)	Assessment relation
Combining LCA and circularity assessments in complex	LCA and others	"After assessing the baseline scenario with	evaluate the effect of a (CE strategy)/evaluate the circularity and	Assessment relation

production systems: the case of urban agriculture		LCA and MCI, we defined a set of strategies aimed at evaluating the effects of CE implementation in the system"/"This study aimed to evaluate the circularity and environmental performance of applying circular strategies in urban agricultural systems"	the impact of a (CE strategy)	
Combining Life Cycle Assessment and Circularity Assessment to Analyze Environmental Impacts of the Medica ln Remanufacturing of Electrophysiology Catheters	LCA and others	" Since the CE provokes innovation, LCA and circularity assessment can be applied and referenced to ensure that innovations lead to decreased environmental impacts"/"Currently, most CE indicators and assessment methods aim to measure the circularity degree of resource flows yet fail to quantify the product preserving cycles, such as reuse or remanufacturing"	ensure that (the CE strategy) is effective/measure level of (CE strategy) implementation	Assessment relation
Comparative evaluation of the environmental impacts of geosynthetic Mechanically Stabilized Earth walls	LCA	"The study comprises a detailed life cycle assessment [...] The structure of masonry walls was found to have less impact on the	assess (CE strategy)	Assessment relation

		environment than the construction of comparable gravity and cantilever walls.[...].The structure of masonry walls was found to have less impact on the environment than the construction of comparable gravity and cantilever walls.		
Comparative LCA of concrete with recycled aggregates: a circular economy mindset in Europe	LCA and others	"life cycle assessment (LCA) is a widespread tool to assess the environmental benefits and burdens associated to waste management systems and to identify strategies that will improve their performance"	assess the impact of a (CE strategy) to improve the (CE strategy)	Circularity assessment relation
COMPARING LCA, CIRCULARITY AND SUSTAINABILITY INDICATORS FOR SUSTAINABLE DESIGN: RESULTS FROM A HANDS-ON PROJECT WITH 87 ENGINEERING STUDENTS	LCA e outros	"We use Life Cycle Assessment (LCA) and the Material Circularity Indicator (MCI) to assess the baseline scenario of a Mediterranean rooftop greenhouse and the application of 13 circular strategies"	assess a CE strategy	Assessment relation
COUNTING GAINS TO BEYOND ZERO-IMPACT FUTURES	LCBA (life cycle benefit assessment)	"Results of LCIA and LCBA studies with comparable uncertainty and spatiotemporal resolution are shown for a	measures, among other things, (circularity)	Circularity assessment relation

Design of Indicators of Circular Economy as Instruments for the Evaluation of Sustainability and Efficiency in Wastewater from Pig Farming Industry	mix	range of applications, damages, benefits and circularity scores." "[...]the necessity of designing [CE] indicators that allow for assessing the advance obtained regarding the efficiency in terms of reduction, reutilization, and recycling of waste generated in the linear economy model"/"the introduction of the indicators of circular economy in the present work could facilitate the development of new [CE] strategies"/" these indicators showed us [...] the possibility to assess the minimization of waste generation and the efficiency of the use of resources"	assess (CE strategy)	Assessment relation
Developments and Challenges in Design for Sustainability of Electronics	Design guidelines for recyclability	"This paper will give an overview of the product requirements, business models and environmental assessment methods needed to enable this transition to a circular economy. "/" This implies	enable the transition to a (CE) / (CE principles) are critical for assessing (CE strategies)	Beneficial additional relation

		that knowledge on the end-of-life treatments of a product is not only **essential** to take into account during the design stage, but also is a **critical** starting point in assessing the environmental impact."		
Does increased circularity lead to environmental sustainability?	LCA and dMFA	"We therefore combine a material flow and an environmental perspective to enable a comprehensive evaluation of CE activities that also accounts for possible burden shifting"/"The aim is to [...] investigate impacts of different policy decisions"	evaluation of (CE strategy)/ investigate impacts of (CE policy)	Assessment relation
Eco-Efficient Analysis of a Refurbishment Proposal for a Social Housing	LCA and others	"an integral assessment towards implementing the principles of the circular economy **must** incorporate the environmental impact of the materials"/ "circularity and sustainability **need** to be assessed over the whole life cycle of the building to optimize reduction of carbon emissions and material flow"	Assess the circularity of the project	Circularity assessment relation
Environmental assessment of four waste cooking oil	LCA	"This work aims at investigating the potential	investigate the impact of (CE strategy)	Assessment relation

valorization pathways		impact of different recycling pathways of waste oil from household units through the LCA perspective, as key low-carbon material from local waste management"		
Environmental Impact Assessment of LiNi1/3Mn1/3Co1/3O2 Hydrometallurgical Cathode Recycling from Spent Lithium-Ion Batteries	LCA	"the environmental impact assessment of cathode-recycling approaches is **urgently** needed"	assess the environmental impact of a (CE strategy)	strong assessment relation
Environmental sustainability in the food-energy-water-health nexus: A new methodology and an application to food waste in a circular economy	LCA	"The impact on the nexus of four treatment options is quantified: anaerobic digestion, in-vessel composting, incineration and landfilling"	quantifies the impact of a (CE strategy)	Assessment relation
Environmental Sustainability of Waste Circulation Models for Sugarcane Biorefinery System in Thailand	LCA	"This study aims to assess the environmental sustainability of five CE models"	assess (CE strategy)	Assessment relation
Estimating environmental and societal impacts from scaling up urine concentration technologies	multi-criteria approach	"The aim of this study was to provide guidance to technology developers and policymakers by assessing the environmental and societal impacts of urine concentration [on wastewater] technologies"	assess the environmental impact of a (CE strategy)	Assessment relation
Exploring an alternative to the Chilean textile	LCA	"This study includes the assessment of	assess (CE strategy)	Assessment relation

waste: A carbon footprint assessment of a textile recycling process		textile waste mix remanufacturing for material reuse, avoided emissions at landfills, and those related to replaced products from primary sources"/"In this study, the environmental impacts are assessed from the moment when the collected textile waste enters the recycling facilities until the treatment of residues generated in the recycling process has been performed"		
Exploring nutrient recovery from hydroponics in urban agriculture An environmental assessment	LCA	"To do so, we study the recovery rates of these macronutrients and conduct a life cycle assessment (LCA) to evaluate the environmental impacts and benefits of nutrient recovery."	evaluate the environmental impacts of a (CE strategy)	Assessment relation
Extended producer responsibility: How to unlock the environmental and economic potential of plastic packaging waste?	LCA	"The overall aim of this study is to provide a consistent framework for evaluating the environmental and economic impacts of selected packaging plastic waste management solutions"	evaluation of (CE strategy)	Assessment relation

From Innovation to Eco-Innovation: Co-Created Training Materials as a Change Driver for Research and Technology Organisations	educational training	" This requires transforming innovation processes to eco-innovation which considers not only technological progress but the purpose, usage and global impact of technology on the economy, the environment and society" / "This training is an opportunity to encourage CEA engineers to think in terms of the global impact of the technologies they develop on the three pillars of the eco-innovation throughout the entire life cycle while meeting the requirements of the circular economy"	IA is part of the development of the (CE strategy)	Assess-to-design relation
From the sea to the table: The environmental impact assessment of fishing, processing, and end-of-life of albacore in Cantabria	LCA	" the evaluation of packaging waste management and valorization of fish waste only accounted for less than 10% of the credits, something far from real sustainability"	evaluation of (CE strategy)	Assessment relation
Gearing up sustainability thinking and reducing the bystander effect – A case study of wastewater treatment plants	LCA	"WWTPs [wastewater treatment plants] are somewhat familiar with Life Cycle Assessment (LCA) as a tool to quantify	quantifies environmental impacts of a (CE strategy)	Assessment relation

		environmental impacts and influences. However it is not applied due to resource restrictions and experienced difficulties in setting the boundaries."		
Green-washing or best case practices? Using circular economy and Cradle to Cradle case studies in business education	mix	"The students' research shows that the first case, which describes the impact of a hybrid material bottle, does not meet circularity criteria."	assess to check if (CE strategies) meet circularity criteria	Assessment relation
High-value products from food waste: An environmental and socio-economic assessment	LCA	"The overarching goal is to assess the sustainability of high-value products obtained from mixed food waste by quantifying environmental and socio-economic impacts through LCA and LCC"	quantifies environmental and socio-economic impacts of a (CE strategy)	Assessment relation
How decentralized treatment can contribute to the symbiosis between environmental protection and resource recovery?	LCA and ELCC (Environmental Life Cycle Costing)	"A holistic and comparative assessment between both treatment options, as well as activities related to the reuse of recovered flows, should be carried out in the context of an environmental and economic assessment"	assessment of (CE strategies)	Assessment relation
How small daily choices play a huge role in climate change: The disposable paper cup	LCA and others	"To identify paper cup's consumption and disposal environmental impacts the	assessment of (CE strategies)	strong assessment relation

environmental bane		LCA methodology was used, which is a **key tool** for environmental sustainability assessments"		
Hybridized sustainability metrics for use in life cycle assessment of bio-based products: resource efficiency and circularity	LCA	"The overall aim of this study was to develop and investigate the performance of a unique environmental methodology that assesses the resource efficiency and circular characteristics of products and processes"	assessment of (CE strategies)	Assessment relation
IMPACT: a tool for R&D management of circular economy innovations	IMPACT tool	"[...] for the analysis of the impact on sustainability on the thorough assessment level, LCA and CBA studies are combined to calculate the impact on resources, environmental and economic level"	assessment of (CE strategies)	Assessment relation
Innovative options for the reuse and valorization of aquaculture sludge and fish mortalities: Sustainability evaluation through Life-Cycle Assessment	LCA	"The environmental costs and impacts related to current and innovative processes, including the reuse of by-products,[...] were estimated through a selection of indicators"	estimates environmental costs and impacts related to (CE strategies)	Assessment relation
Integrating Circularity in the Sustainability Assessment of Asphalt Mixtures	LCA and others	"The implementation of this methodology to asphalt mixtures could [...] eventually constitute a	evaluates how environmentally sustainable (CE strategies) are	Assessment relation

		tool [capable of weighting the aggregated environmental impacts of an asphalt mixture with RA, using as a weighting factor its own circularity] for the involved decision-makers for evaluating how environmentally sustainable their circular practices and choices are."		
Leather tanning: Life cycle assessment of retanning, fatliquoring and dyeing	LCA	" the Life Cycle Assessment method was applied to estimate impacts on the environment and human health of retanning, fatliquoring and dyeing"	estimate impacts of (CE strategies)	Assessment relation
Life Cycle Environmental Impacts of Wastewater-Derived Phosphorus Products: An Agricultural End-User Perspective	LCA	"Life cycle assessment (LCA) has been used to evaluate the potential environmental impacts of various wastewater-based phosphorus recovery and reuse opportunities"	evaluate impacts of (CE strategies)	Assessment relation
Life cycle environmental sustainability of valorization routes for spent coffee grounds: From waste to resources	LCA	"The main goal of this study is to estimate and compare the environmental impacts associated with different SCGs management and valorization routes"	estimate and compare impacts of (CE strategies)	Assessment relation
Life cycle impact assessment of safety shoes toe	LCA	" a reclaim method for prepreg scraps	assess (CE strategy)	Assessment relation

caps realized with reclaimed composite materials		and the relative manufacturing process for toe caps are assessed from the environmental point of view"		
Liquid fertilizer production from organic waste by conventional and microwave-assisted extraction technologies: Techno-economic and environmental assessment	economic and environmental evaluation	"This study presents a comparative economic and environmental assessment to produce liquid fertilizers from organic waste such as MMWC. "	assess (CE strategy)	Assessment relation
Managerial Energy in Sustainable Enterprises: Organizational Wisdom Approach	Regression analysis and structural equation modeling (SEM	"Managerial energy (ME) positively influences the organizational wisdom (OW) of a company operating based on the circular business model (CBM)."/ " The article aims to analyze the impact of a manager's energy on organizational wisdom, focusing on its activity in the circular business model."	analyse the impact of a (CE strategy)	Assessment relation
Multi-criteria decision analysis (MCDA) method for assessing the sustainability of end-of-life alternatives for waste plastics: A case study of Norway	multi-criteria aproach	"we assess the environmental, economic, and social impacts of landfilling, incinerating, and recycling of waste fishing gears in Norway."/"Four criteria were shortlisted to assess the economic impacts of EOL (CE strategy) alternatives: i) C1. Resource	(CE criteria) used to assess impacts of (CE strategy)	Beneficial additional relation

		conservation, [...] The first criterion is aimed at quantifying the resources conserved within the system through each EOL alternative for handling waste FGs and ropes.		
Multi-product biorefinery with sugarcane bagasse: Process development for nanocellulose, lignin and biohydrogen production and lifecycle analysis	LCA and others	"In addition to the environmental impact analysis, economic viability of the process was assessed to ensure the overall sustainability [of a biorefinery (CE strategy)]."	assessment of a (CE stretegy)	Assessment relation
Number of Times Recycled and Its Effect on the Recyclability, Fluidity and Tensile Properties of Polypropylene Injection Molded Parts	experimental test	"The recycling of injection-molded PP material can be added to renewable energy technologies and used in environmental impact assessment."	(CE strategy) can be added and used in impact assessment	Beneficial additional relation
Preliminary design of recyclable epoxy asphalt: Regeneration feasibility analysis and environmental impact assessment	experimental test	"it is **critical** with recyclable epoxy asphalt to assess the environmental impacts before it is employed"	assess (CE strategy)	strong assessment relation
Recycling potential of post-consumer plastic packaging waste in Finland	experimental test	"The environmental and economic impacts of the required processes [processes needed for recycling] need to be assessed in the planning phase so that the chain **can be optimized**	assess (CE strategy)	Assessment relation

		to generate both environmental and economic benefits to society and operator"		
Redesigning a food supply chain for environmental sustainability - an analysis of resource use and recovery	LCA	"it is **essential** to assess the environmental impact of resources consumed across all the stages of the FSC [food suply chain] and to identify mitigation opportunities." [to improve FSC]/ "The main aim of this research is to identify the inefficiencies present in the FSC through environmental impact assessment and propose a framework for redesigning the FSC using practices that improve operational efficiency and resource recovery practices for environmental sustainability"	assess (CE strategy) to improve (CE strategy)	strong assessment relation
"Slowing" and "Narrowing" the Flow of Metals for Consumer Goods: Evaluating Opportunities and Barriers	qualitative assessment	"Based on this qualitative assessment, we have identified the strategies that have the clearest potential for material efficiency benefits with the broadest applicability across different"/	assess (CE strategy)	Assessment relation
Social impact analysis of	S-LCA	"Thus, the Social Life	assess (CE strategy)	Assessment relation

products under a holistic approach A case study in the meat product supply chain		Cycle Assessment methodology can be used to assess different innovative practices of product manufacturing, under a circular economy approach, by identifying potential positive as well as negative impacts along products' life cycle"		
Social life cycle assessment of product value chains under a circular economy approach A case study in the plastic packaging sector		"Once the subcategories and indicators have been established, a scoring system was defined in order to assess the social impacts arising from the innovations introduced under the circular economy approach"	assess social impacts of (CE strategies)	Assessment relation
Socio-economic impact assessment of large-scale recycling of treated municipal wastewater for indirect groundwater recharge	Socio-economic impact assessment	"The focus of this study is to quantify the socio-economic impact of large-scale recycling of STW for indirect GW recharge"	quantify the impact of a (CE strategy)	Assessment relation
Sustainability assessment of circular economy over time: Modelling of finite and variable loops & impact distribution among related products	LCA and others	" the existing limitations of the circular economy concept, "circularity" as such should ideally not be evaluated but rather the sustainability of the circular system, comprising economic,	assess the sustainability of a (CE strategy)	Assessment relation

		environmental and social effects"		
Sustainability assessment of Construction and Demolition Waste management applied to an Italian case	multidimensional sustainability framework	"the current study is aimed at presenting the results of a sustainability assessment of the CDW management"	assess (CE strategy)	Assessment relation
SUSTAINABILITY ASSESSMENT OF TWO DIGESTATE TREATMENTS: A COMPARATIVE LIFE CYCLE ASSESSMENT	LCA	" it is therefore **crucial** to assess the potential environmental impacts of the technological processes related to different management scenarios of this by-product."	assess (CE strategy)	strong assessment relation
Sustainability Assessment with Integrated Circular Economy Principles: A Toy Case Study	E-LCA, LCC, S-LCA	"Our results suggest that processes and products **require** a sustainability assessment that provides a holistic aspect, and the integration of circular economy principles is beneficial"/Different options based on the principles of the circular economy have been analysed and proposed in relation to the material used. " [...] the proposed improvement options show a significant reduction in environmental impact, especially in eutrophication potential, which is a	assess (CE strategy)	Assessment relation

		significant concern in our case study"		
Sustainability Impact Assessment of Increased Plastic Recycling and Future Pathways of Plastic Waste Management in Sweden	integrated approach	"Considering the results of the waste flow model and impact assessment, potential future pathways of plastic waste management in Sweden are identified and qualitatively assessed in terms of environmental, economic and social sustainability. "	assess (CE strategy)	Assessment relation
Sustainable management of spent fluid catalytic cracking catalyst from a circular economy approach	LCA	"An attributional life cycle assessment [...] has been employed to estimate the environmental impacts of the proposed FCC-SC management procedure. "	estimate (CE strategy)	Assessment relation
Sustainable production of marine equipment in a circular economy: deepening in material and energy flows, best available techniques and toxicological impacts	Material and Energy Flow, Best Available Technique, Toxicological Impact Assessment	"This work aims to analyse the marine equipment manufacturing sector using fibre reinforced polymers (that potentially emits VOC with the consequently toxicological impact) from the circular economy rospective to identify sustainable solutions for the manufacturing process stage"/ "The application of these	assess (CE strategy)	Assessment relation

		techniques in an improved system, allows reducing the amount of material and emissions reducing the impact. "		
The environmental challenges of AI in EU law: lessons learned from the Artificial Intelligence Act (AIA) with its drawbacks	multidisciplinary approach	"Innovative models based on a closer relationship with customers, mass customisation [...] will not only accelerate circularity but also the dematerialisation of our economy and make Europe less dependent on primary materials"/" As occurs with several regulations of EU law, e.g. the general regulation on civil aviation and drones, it is up to the Commission the review of existing policies and Union legislations, to assess their consistency with the climate neutrality end"	assess (CE strategy)	Assessment relation
The future of circular environmental impact indicators for cultural heritage buildings in Europe	comprehensive framework	"The [Circular Environmental Impact Indicator] Framework may be applied to assess the completeness of new CE policy instruments, such as procurement or grant rules for	applied to assess (CE strategy)	Assessment relation

		funding ARCH at the municipal or regional level"		
The global environmental costs of mining and processing abiotic raw materials and their geographic distribution	LCA	"we aim to determine the negative environmental impacts of mining and processing materials on a global level using LCA"	applied to determine the impacts of CE strategy	Assessment relation
The Paradigms of Industry 4.0 and Circular Economy as Enabling Drivers for the Competitiveness of Businesses and Territories: The Case of an Italian vCeramic Tiles Manufacturing Company	LCA, LCC, LCC, S-LCA	"Industrial companies must respond to this new social awareness and assess the effects of their policies on workers' and consumers' health, on the economic and social structures of the countries where they operate and, above all, on the physical environment and the environmental sustainability of development "/" The orientation towards sustainability therefore requires a set of environmental, economic and social performance indicators that can assess, represent, and monitor sustainability, and that are comparable in time and space"/ "The S-LCA, on the other hand, represents the	assess the impact of a product to design a (CE strategy)	Assessment relation

		new frontier of the life cycle approach because it is proposed to introduce a social dimension to the LCA's own quantitative assessments in order to quantify the potential social impacts caused to people as a result of a product's life cycle"		
The SPPD-WRF Framework: A Novel and Holistic Methodology for Strategical Planning and Process Design of Water Resource Factories	quantitative and semi-quantitative	"After the marketability, technical feasibility, economic performance, and environmental impacts of innovative WRF processes have been assessed, an uncertainty analysis of the applied assessment criteria is proposed"	assess (CE strategy)	Assessment relation
Toward sustainable reprocessing and valorization of sulfidic copper tailings: Scenarios and prospective LCA	LCA	"This study aims to quantify the environmental benefits, impacts, and tradeoffs of large-scale deployments of copper tailings reprocessing and mineral valorization technologies in the EU"/"Assessing novel metallurgical processes and improving the recoverability of these elements/miner	assess (CE strategy) to achieve sus	Assessment relation

		als may open doors for additional ecological benefits"/" Environmental performances for different scenarios are explored by incorporating projections in the energy transition, technological improvements for the primary copper sector, and resource-recovery technologies for copper tailings.		
Towards sustainable aquaculture systems: Biological and environmental impact of replacing fishmeal with Arthrospira platensis (Nordstedt) (spirulina)	LCA	"LCA environmental impacts associated with the production of spirulina grown on aquaculture wastewater as well as on the standard culture medium (Zarrouk medium) were assessed and compared by means of a gate to gate" analysis"	asses the environmental impact of a (CE strategy)	Assessment relation
Transition to circular economy in the construction industry: Environmental aspects of waste brick recycling scenarios	LCA	" the potential of waste brick recycling is assessed from the environmental point of view as the recycling options of waste bricks attract an eminent attention due to rationalization and optimization of material streams, including	assess (CE strategy)	Assessment relation

		transformation to the circular economy model according to the EU commitments."		
Upcycling Shipping Containers as Building Components - an environmental impact assessment	LCA	"The primary goal of this article is to evaluate the environmental benefits coming from the use of shipping containers upcycled into building components.	evaluate a (Ce strategy)	Assessment relation
Urban forests_ Bioeconomy and added value	ToSIA - Tool for Sustainability Impact Assessment	" The objective of this research is to calculate and trace the change of added social and economic value if urban forest are created and become part of the urban infrastructure"	calculate and trace the change caused by a (CE strategy)	Assessment relation
Using a life cycle assessment to identify the risk of "circular washing" in the leather industry	LCA	"The LCA enabled us to evaluate the overall performance of circular economy to mitigate climate change. We identified key areas where a circular economy creates opportunities for mitigating climate change and for improving the overall resource efficiency of the tanning process"	evaluate the performance of (CE strategies) in achieving their goals	strong assessment relation
Waste Management for Lunar Resources	multidimentional assessment	"In sight of this bright cohort of imminent	asses the environmental	Assessment relation

Activities- Towards a Circular Lunar Economy		perspectives, it's imperative for the global community to properly assess the potential effects and consequences of the forthcoming space resources activities, with the goal of including sustainability in the foundations of the ongoing progress and ensuring its enforcement in every future endeavour. Within this context, this paper addresses the topics of Moon mining waste management and a lunar circular economy as key issues in the sustainable utilization" of space resources	impact of a (CE strategy)	
Whole life cycle environmental impact assessment of buildings Developing software tool and database support for the EU framework Level(s)	iterative consultation process	"A last aspect to highlight is that users of Level(s) are also interested in software tools and data that can help them in assessing LCC, as well as material stocks and flows that give them a sense of the circularity of a building project"	assess the circularity of a project	Circularity assessment relation

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