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Bruna Oliveira Rosa

Influence of Circular Economy Adoption in European SME's Performance

Tese de Doutorado

Thesis presented to the Programa de Pós-graduação em Administração de Empresas of PUC-Rio in partial fulfillment of the requirements for the degree of Doutor em Administração.

Advisor: Prof. Fábio de Oliveira Paula

Rio de Janeiro
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Abstract

Rosa, Bruna Oliveira; Paula, Fábio de Oliveira (Advisor). **Influence of Circular Economy Adoption in European SME's Performance**. Rio de Janeiro, 2024. 174p. Tese de Doutorado - Departamento de Administração, Pontifícia Universidade Católica do Rio de Janeiro.

This study provides an examination of the relationship between circular economy (CE) practices and firm performance in small and medium-sized enterprises (SMEs) in Europe, following a multi-level approach. The research project outlines the stages involved to reach this goal. The first stage (paper 1) examines the trends in the existing research. We verified the variables used, the type of data, the method of analysis, the type of industry, the size of the company, the size of the sample and the topic to which the article belongs. The results indicate that there is no clear consensus on the best way to measure and operationalize CE practices and firm performance, however the variables identified can be used as a guide for future research on CE and firm performance. The second stage (paper 2) we investigate how the economic, social, and environmental performance indicators of the SME country moderates the relationship between CE practices and firm performance. In summary, the results support that the financial impact of adopting CE is positive, and it is affected by the level of national economic and environmental performance. The third stage (paper 3) the aim is develop and test empirical model include moderation by meso-level. We examined the function of intermediaries in involving SMEs in CE activities, and how the presence of Industrial Symbiosis Networks (ISN) affects SMEs' performance. The findings affirm that ISNs can boost CE adoption and intermediaries can assist SMEs in surmounting CE obstacles.

Keywords

Circular Economy; firm performance; SMEs; multi-level

Resumo

Rosa, Bruna Oliveira; Paula, Fábio de Oliveira. **Influência da Adoção da Economia Circular no Desempenho das PME Europeias**. Rio de Janeiro, 2024. 174p. Tese de Doutorado - Departamento de Administração, Pontifícia Universidade Católica do Rio de Janeiro.

Este estudo fornece uma análise da relação entre as práticas da economia circular (EC) e o desempenho nas pequenas e médias empresas (PME) na Europa, seguindo uma abordagem multinível. O projeto de pesquisa descreve as etapas envolvidas para atingir esse objetivo. A primeira etapa (artigo 1) examina as tendências da pesquisa existente. Verificamos as variáveis utilizadas, o tipo de dados, o método de análise, o tipo de indústria, o porte da empresa, o tamanho da amostra e o tema ao qual o artigo pertence. Os resultados indicam que não existe um consenso claro sobre a melhor forma de medir e operacionalizar as práticas de EC e o desempenho das empresas, no entanto as variáveis identificadas podem ser utilizadas como guia para futuras pesquisas sobre EC e o desempenho das empresas. Na segunda etapa (artigo 2), investigamos como os indicadores de desempenho econômico, social e ambiental do país PME moderam a relação entre as práticas de EC e o desempenho da empresa. Em resumo, os resultados apoiam que o impacto financeiro da adoção da EC é positivo e é afetado pelo nível de desempenho nacional econômico e ambiental. A terceira etapa (artigo 3) tem como objetivo desenvolver e testar o modelo empírico que inclui moderação por nível meso. Examinamos a função dos intermediarios no envolvimento das PME nas atividades de EC bem como a presença de Redes de Simbiose Industrial (ISN) afeta o desempenho das PME. As conclusões afirmam que as ISN’s podem impulsionar a adopção da EC e os intermediários podem ajudar as PME a superar os obstáculos da EC.

Palavras-chave

Economia Circular; desempenho empresarial; PME; multinível

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1
Introduction

1.1.
Background and Research Problem

The origin of thoughts related to Circular Economy (CE) can be traced back to 1758, with Quesnay's "Tableau Economique". It addressed issues of surplus value in cyclical inputs, while Simmonds, from 1814 to 1897, conducted studies regarding closing material loops (Reike et al., 2018). From 1950 to 1968, Von Bertalanffy developed the General Systems Theory, which discusses systemic thinking, meaning that all organisms should be considered systems (Ghisellini et al., 2016). This assumption was proven to be relevant for CE in the following decades. The ecological economist Boulding, in 1966, indicated the limitation of natural resources availability for human activities. In addition, he further developed the proposition of a closed system – expressing, thereby, that the economy and the environment must coexist in balance (Geissdoerfer et al., 2017; Ghisellini et al., 2016; Merli et al., 2018). In 1976, the research of Stahel and Reday can be related to CE, as they introduced the concept of loop economy (Geissdoerfer et al., 2017). Environmental economists Pearce and Turner, in their work traced back to 1990, were the first to introduce the concept of circular economic (Andersen, 2007; Geissdoerfer et al., 2017; Ghisellini et al., 2016; Merli et al., 2018; Reike et al., 2018; Su et al., 2013). Figure 1 is the timeline that summarizes the CE origins tracked.

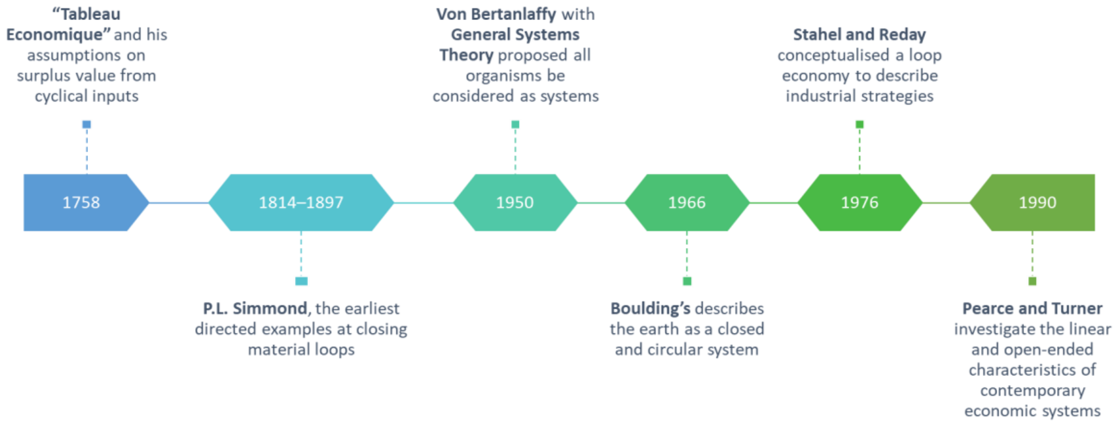


Figure 1: Timeline of the CE origins

An extensive analysis of literature of CE reveals that the concept is based on several theoretical backgrounds (Ghisellini et al., 2016). It is possible that its capacity to connect strategies from different schools of thought is one cause of CE's expansion (Matus et al., 2012). Table 1 represents some of CE's schools of thought found in literature review. We classify it from most to less cited.

Table 1: School of thought of CE

Schools of thought of CE	**References that link with CE**	**Schools of thought of CE**	**References that link with CE**
Industrial Ecology	(Ghisellini et al., 2016); (Reike et al., 2018); (Geissdoerfer et al., 2017); (Merli et al., 2018); (Kalmykova et al., 2018) and (Korhonen et al., 2018).	Industrial Symbiosis	(Merli et al., 2018) and (Korhonen et al., 2018).
Cradle to cradle	(Ghisellini et al., 2016); (Geissdoerfer et al., 2017); (Suárez-Eiroa et al., 2019); (Merli et al., 2018); (Kalmykova et al., 2018) and (Korhonen et al., 2018).	Laws of ecology	(Geissdoerfer et al., 2017), (Homrich et al., 2018)
Looped and performance economy	(Ghisellini et al., 2016); (Reike et al., 2018); (Geissdoerfer et al., 2017); (Merli et al., 2018); (Kalmykova et al., 2018) and (Korhonen et al., 2018); (Merli et al., 2018); (Kalmykova et al., 2018) and (Korhonen et al., 2018).	Zero waste	(Korhonen et al., 2018), (Ghisellini et al., 2016), (Suárez-Eiroa et al., 2019), (Homrich et al., 2018)
Regenerative design	(Ghisellini et al., 2016); (Merli et al., 2018) and (Geissdoerfer et al., 2017).	Bioeconomy	(Merli et al., 2018)

Biomimicry	(Ghisellini et al., 2016); (Korhonen et al., 2018) and (Geissdoerfer et al., 2017).	Spaceman economy	(Kalmykova et al., 2018)
Eco-industrial parks	(Merli et al., 2018); (Reike et al., 2018) and (Korhonen et al., 2018).	Limits to growth	(Kalmykova et al., 2018)
Blue economy	(Ghisellini et al., 2016) and (Geissdoerfer et al., 2017).	Industrial eco-systems	(Korhonen et al., 2018).
Steady-state economy	(Kalmykova et al., 2018) and (Ghisellini et al., 2016).	Eco-efficiency	(Korhonen et al., 2018).
Cleaner production	(Suárez-Eiroa et al., 2019) and (Korhonen et al., 2018).	Resilience of social-ecological systems	(Korhonen et al., 2018).
Product-service systems	(Merli et al., 2018) and (Korhonen et al., 2018).	Natural capitalism	(Korhonen et al., 2018), (Homrich et al., 2018)

Industrial Ecology, cradle to cradle alongside with looped and performance economy are the most cited schools of thought related to CE. From the beginning, CE was a concept studied in connection with industrial ecology: it is possible to understand this relevance on the citations. As a result, the variety of scientific disciplines and semi-scientific concepts used to understand CE is notable (Korhonen et al., 2018). Nevertheless, precisely because of this large spectrum of principles and proposals, the definition of CE has been formulated in the last decades and it is still not a consolidated concept (Merli et al., 2018).

The literature reveals the dynamic evolution of CE over time and its main theoretical perspectives and research domains. It remains unclear what the authors define as circular economy. Would it be a paradigm, a strategy, a tool? As noted, CE is presented as a field of study employed by different schools of thought. This fact increases the difficulty to consolidate a singular definition. We identified some relevant authors who developed a concept for CE on their studies. The concepts are listed in Table 2, from the most recent to the least recent.

Table 2: CE concepts

Author	Year	Concept
Suárez-Eiroa et al. (2019, pg. 958)	2019	Circular economy is a **regenerative** production- consumption **system** (…)
Homrich et al. (2018, pg. 534)	2018	CE is a **strategy** that emerges to oppose the traditional open-ended system (…)
Prieto-Sandoval et al., 2018, pg. 613)	2018	Defined circular economy as an **economic system** that represents a change of paradigm in the way that human society is interrelated with nature (…)
Kirchherr et al. (2017, p. 224)	2017	A circular economy describes an **economic system** that is based on business models (…)
Geissdoerfer et al. (2017, p. 766)	2017	A **regenerative system** in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. (…)
Ghisellini et al. (2016, p. 16)	2016	CE as a new **economic model** similar to growth, degrowth and steady state, with focus placed on the trend of economy's size and performance. (…)

There is no consensus among the authors: some studies characterize CE as a model or economic system, others as a strategy or as a regenerative system – they do not agree on its definition. According to Gallie (1956), a concept becomes essentially contested (ECC) if there is an agreement on the principles and objectives, but there are disagreements on how to define it. Korhonen et al. (2018) suggest that CE can fit this concept of essentially contested. Analyzing CE under the sustainable development framework could be a useful objective to optimize efforts of policymakers, organizations and the general society. Geissdoerfer et al. (2017) identified in their study the most evident similarities and differences between sustainability and CE, and they concluded that the CE is viewed as a condition for sustainability.

CE implementation studies follow a multi-level approach of action (Figure 2): i) macro level, which aims on adjusting industrial composition and structure of the entire economy; ii) meso level, which focuses on eco-industrial parks as systems and industrial symbiosis and iii) micro level, which considers products, individual enterprises and what needs to be done to increase their circularity (Ghisellini et al., 2016; Kirchherr et al., 2017; Merli et al., 2018). To increase essential changes, implementing CE must be simultaneously at the micro, meso and macro systems, enabling a holistic and systemic approach (Khitous et al., 2020; Kirchherr et al., 2017).

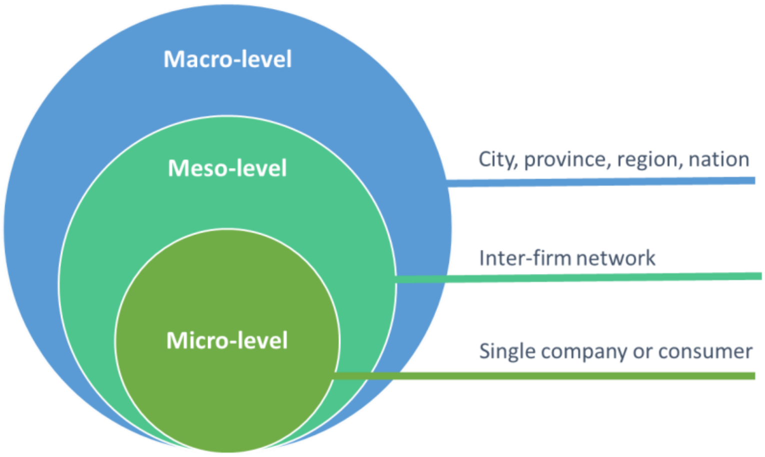


Figure 2: Multi-level framework

At macro level, the legislation is the central instrument of action (Feng & Yan, 2007). The publications of cases are mainly concentrated in China and in Europe, with focus on some production patterns, sectors and material. At meso level the main implementations mentioned were the Kalundborg Park in Denmark and the industrial parks in China (Ghisellini et al., 2016; Kalmykova et al., 2018). The cases of micro level emphasize the role of Product-Service Systems, Circular Design, Circular Business Models (CBMs) and sustainable supply chain strategies (Khitous et al., 2020). The Ellen MacArthur Foundation has, in the context of an emerging research field, a critical role in providing cases of CE practice implementations between firms. The Ellen MacArthur Foundation catalyzed the concept in business and created the ‘Butterfly Diagram’ as a way to visualize a hierarchy of circularity strategies, which combine business and resource perspectives (Bocken et al., 2017; MacArthur, 2013). The butterfly diagram focuses on the biological and technical closed loops as a continuous flow of materials through the value circle, without focusing on one particular circular loop but in the understanding of how these loops work (Ellen MacArthur Foundation, 2013).

In general, the analysis of scholars is performed in separate levels and it is important to consider systemic interdependencies between levels to help the transition (Khitous et al., 2020). The academy must embrace a more active role in reaching consensus when conceptualizing the CE to assist the practitioners, contributing to an increase in practice (Reike et al., 2018). Khitous et al. (2020) incentive scholars from the Business and Economics fields to investigate the viability and profitability of CE strategies.

The CE studies has been developed mainly in large industries and it is observed that the practice is not widespread sufficiently across small and medium-sized enterprises (SMEs) (Ormazabal et al., 2018). Even though SMEs represent 99% of all businesses in the EU and that they have created most of the new jobs, specific research on CE practices in the SME segment is scarce. As an exception, some recent literature focuses particularly on the topic of barriers and enablers of SMEs implementing CE (e.g., Rizos et al., 2016a), and the European Union recently funded some projects fostering CE practices in these type of firms (European Commission, 2020a). To the SMEs, it is usually easier to see environmental benefits rather than economic ones. This is because the implementation of CE practices often involves making extra investments that may not be considered profitable to the firms (Dalhammar, 2016).

In this research, we seek to address some of the research gaps: the lack of multi-level studies, the lack of studies in SMEs and the lack of studies related to viability and profitability of CE strategies. CE is a complex and multi-faceted concept that requires consideration at various levels, including micro (individual businesses), meso (networks or industrial ecosystems), and macro (city, region, or national economies). However, there is a noted lack of comprehensive multi-level studies that integrate these different scales. SMEs play a crucial role in the transition to a circular economy, but they face unique challenges due to limited resources and expertise. Despite this, there is still a need for more in-depth research focused on SMEs and their specific needs and constraints in adopting CE practices. The viability and profitability of CE strategies are critical for their adoption by businesses. However, more detailed studies on the financial implications of CE strategies, especially in the context of SMEs, are necessary to provide a clearer understanding of their economic impact. In summary, while the number of researches is growing on various aspects of the circular economy, gaps remain in multi-level studies, researches focused on SMEs, and detailed analyses of the economic viability and profitability of CE strategies. These areas present opportunities for further investigation to support the transition to a more sustainable and circular economy.

Therefore, this research attempts to answer the question: *How does the adoption of CE activities influence SMEs performance, following a multi-level approach?*

1.2. Research Goals

Our main goal is to analyze how the adoption of CE activities influence SMEs performance, following a multi-level approach. To achieve this objective, the study will be carried out in three stages (papers): each stage will be defined in three secondary objectives of the study, as shown:

- Aim 1: Identify trend topics in the literature regarding the adoption of circular economy on firm performance and the measures used in quantitative studies.

When categorizing the relevant studies according to each topic, it becomes easier to understand the different aspects and subtopics within the subject area. This categorization allows for a comprehensive analysis of the data, which can then be utilized to define the measures used by the studies to quantify CE and firm performance. By examining the trends and the measures in the existing research, researchers can identify areas that require further investigation and outline the direction for future studies in this field.

- Aim 2: Develop and test empirical model to analyze the CE adoption on the SMEs performance moderated by country performance (micro and macro level)

To develop a robust model, the first step is to identify the variables based on existing literature. Once identified, a suitable secondary database is sought to ensure a better fit with the research objectives. Consolidating secondary data from various sources within the chosen database is then done to thoroughly test the model's efficacy. Validating the model involves checking its performance against expected outcomes. Additionally, the moderating effect of country performance variables is examined, shedding light on how these variables influence the model's relationships and outcomes.

- Aim 3: Develop and test empirical model to analyze the role of intermediaries in engaging SMEs in Circular Economy (CE) practices, and the role of the existence of Industrial Symbiosis (IS) networks (micro, meso and macro level)

To build the model, the first step is to identify the meso level variables based on the existing literature. After identifying these variables, the next step is to search for a secondary database that provides a better fit for the research objectives. Once the suitable secondary database is identified, it is essential to consider the moderating effect of both country and industry performance variables within the model.

1.3. Research structure

To achieve the listed objectives, quantitative research methods will be used, which naturally fits the positivist epistemology. The orientation will be hypothetical deductive. Deductive theory represents the most common view of the nature of the relationship between theory and research (Bryman & Bell, 2015). This view of the role of theory in relation to research is very much the kind of role that Merton had in mind in connection with middle-range theory, which, he argued, 'is primarily used in sociology to guide empirical inquiry' (Merton 1967: 39). CE studies are predominantly of qualitative research with single case (Khitous et al., 2020), thus we consider relevant to use this quantitative approach of research so that it contributes to theoretical advance.

Figure 3 presents the quantitative research process and its relationship with each papers' aim. Research is rarely as linear and as straight-forward as the figure implies, however its aim is to capture the main steps and to provide a rough indication of their interconnections.

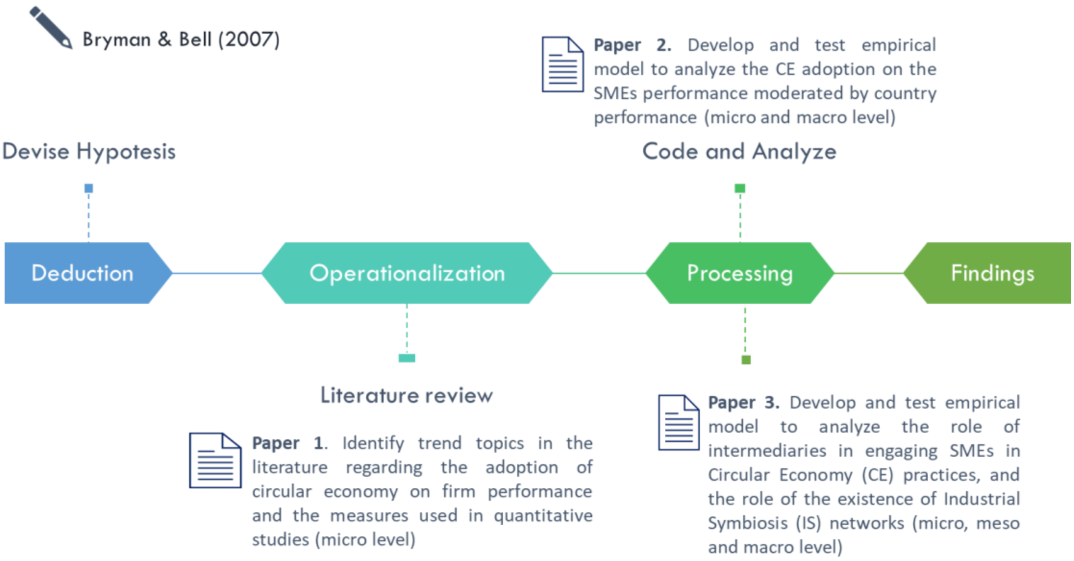


Figure 3: Quantitative research process

The main steps of quantitative research often involve deducing a hypothesis from theory and subjecting it to empirical testing. Researchers rely on their knowledge of a specific domain and theoretical considerations to deduce hypotheses, which are then translated into operational terms. This step includes devising measures for the concepts of interest, ensuring there are indicators that accurately represent these concepts. A systematic literature review is typically conducted to identify relevant concepts for measurement. To address this step, we will develop Paper 1. The next step involves processing the gathered information and transforming it into quantifiable data. This prepares the data for quantitative analysis. Multiple techniques of quantitative data analysis will be employed to examine the relationships between variables, which will be the focus of Paper 2 and 3. Upon analyzing the data, the researcher must interpret the results and draw meaningful findings. This stage involves considering the connections between the emerged findings and the research's underlying concerns.

To enhance visualization and analysis, we present a diagram (Figure 4) that outlines the methodological process employed. In Table 3 we provide specific details regarding the data sources, decisions, and activities involved in the development of each article. These visual aids assist in clarifying the research process and facilitating a comprehensive understanding of the study.

Table 3: Methodological approach

Aim	*Paper 1*	*Paper 2*	*Paper 3*
Research type	Systematic Literature Review	Quantitative	Quantitative
Data source	Bibliographic database (Google Scholar; Scopus e WoS)	Database (Eurostat, Flash Eurobarometer 441)	Database developed, Eurostat and Flash Eurobarometer 441
Data collect	Documentary research	Secondary data	Secondary data
Sample	CE adoption and firm performance papers	European SME's (4400 cases)	European SME's (4400 cases)
Data analysis	Topic Modeling (LDA)	Statistical model (two stage regression)	Statistical model (two stage regression)

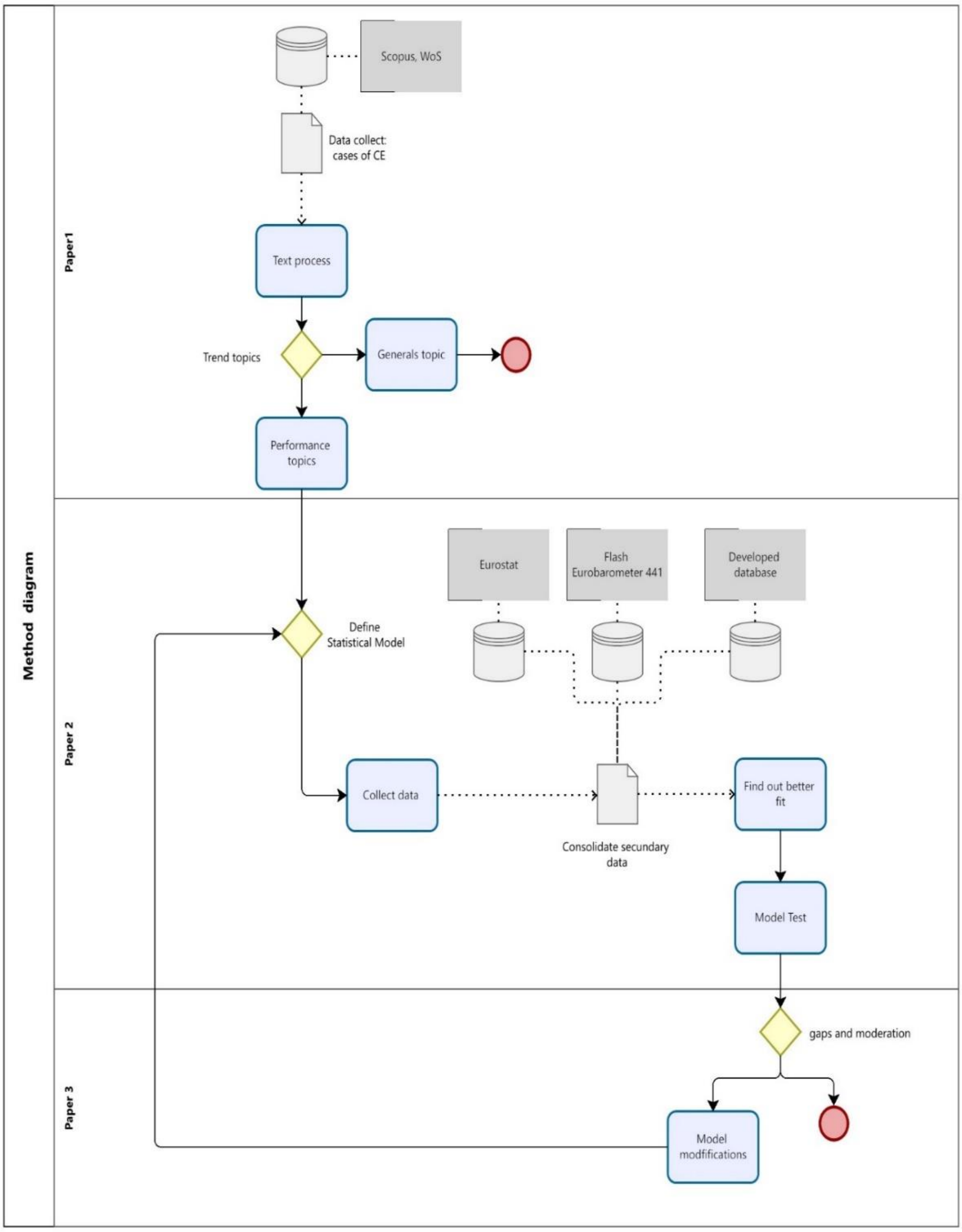


Figure 4: Methodological process

1.4.
Research relevance

This study holds significant theoretical value as it aims to explore the performance relationship within the three levels of Circular Economy (CE) implementation, namely micro, meso, and macro. While definitions by Fang et al. (2007) and Linder et al. (2017) mention the simultaneous implementation of CE at these three levels, they have not been empirically tested as suggested in our study. Typically, scholars analyze CE within separate levels, failing to consider the systemic interdependencies that exist between these levels, which are crucial for facilitating a successful transition to CE, as noted by Khitous et al. (2020). By addressing this gap, our research aims to provide a comprehensive understanding of the interplay between the micro, meso, and macro levels in achieving CE goals. The study is also in line with the type of research published in the main business journals. Recent publications have focused on how circular economy practices can enhance business performance, sustainability, and competitive advantage. Khan et al. (2022) conducted a systematic literature review focused on 91 articles published in the past decade (2016–2021) in renowned peer-reviewed journals, emphasizing the importance of CE practices in business research. Research growth is evident, with a staggering 8,314% increase in the number of researchers publishing on CE during the period from 2005–2008 to 2017–2020 (Meseguer-Sánchez et al., 2021). Between 2016–2019, a total of 3,391 records were published analyzing and relating to the CE (Camón Luis & Celma, 2020). These statistics reflect the growing academic interest and the importance of CE in the business sector, as well as the increasing emphasis on sustainability in business practices.

Moreover, this study also holds practical significance. Suárez-Eiroa et al. (2019) have established principles to guide effective practical strategies for implementing CE, emphasizing the importance of education in attaining CE objectives. Therefore, our study can assist managers and practitioners by shedding light on the relationship between CE and performance, thus encouraging the adoption of CE practices. By providing insights into the practical implications and benefits of CE implementation, this research can guide decision-making and support the development of effective strategies for adopting CE principles in various industries and organizations.

Our research involves the execution of a systematic literature review, encompassing a considerable number of papers relevant to the topic. What sets our study apart is the utilization of a methodological technique that has not been previously employed in studies focused on Circular Economy (CE). This approach allows us to discern emerging trends and to identify gaps within the existing literature. By doing so, we have been able to steer the direction of subsequent articles and research efforts in the field. Furthermore, our study entails an in-depth analysis of a large dataset comprising empirical data extracted from secondary databases. This comprehensive approach enables us to tap into a substantial body of empirical evidence, strengthening the reliability and significance of our research findings.

1.5. Research delimitations

Delimitations play a pivotal role in research, setting the boundaries and scope of a study. The reliability on secondary data introduces complexity, as the data's availability and quality significantly influence the constructs of the model. Consequently, the study's spatial, temporal, and conceptual delimitations are inherently linked to data accessibility.

Spatial delimitations refer to the geographical boundaries within which the research will be conducted. For this study, the focus is narrowed to the countries within the European Union (EU). Temporal delimitations define the study timeframe, which, in this case, is restricted to the years 2015 and 2016. Conceptual delimitations are related to the specific concepts and theories that frame the research. Conceptual delimitations help focus the study on particular ideas or models, excluding others that are not relevant to the research objectives. Conceptually, at the micro level, the study examines the boundaries of companies within the CE, specifically targeting small and medium-sized enterprises (SMEs) and excluding specific discussions about consumers or products. At the meso level, we explore the network of actors between several types of industries, not just eco-industrial parks. At the macro level, we discuss countries, without addressing regions, provinces, or cities. We employ the concept of the circular economy (CE) as "a strategy that emerges to oppose the traditional open-ended system," as defined by Homrich et al. (2018, p. 534). This CE strategies within enterprises are commonly known as circular practices. Circular practices are a set of strategies and actions that support the circular economy. Some examples are maintenance, reuse, refurbishment, remanufacture, recycling and composting. In terms of firm performance, we only address financial aspects, excluding others such as environmental and social dimensions.

While this spatial, temporal and conceptual delimitation provides a specific context for the study, it is important to acknowledge that the findings may not necessarily be generalizable to other sectors, regions, or time periods beyond the defined scope. Researchers ought to be cautious in interpreting and applying the results of the study outside of the specified spatial and temporal boundaries.

2
Paper 1 – Circular Economy and Firm Performance: Topic Modeling Approach

2.1. Abstract

This paper aims to explore the relationship between Circular Economy and Firm Performance using a topic modeling approach. A topic modeling analysis allows for a comprehensive historical examination of the topic and enables the inclusion of a larger number of articles in the analysis. The results of the topic modeling analysis reveal the main thematic clusters and their corresponding key findings, providing valuable insights into the literature landscape. This approach allows for a comprehensive analysis of the literature landscape and provides a holistic understanding of the topic. We verified the variables used, the type of data, the method of analysis, the type of industry, the size of the company, the size of the sample and the topic to which the article belongs. These results indicate that there is no clear consensus on the best way to measure and operationalize CE practices and firm performance, and that more research is needed to establish a coherent and consistent framework for this field. Future studies should aim to address the gap by incorporating multilevel analysis into their empirical models.

Keywords: Circular Economy, Firm Performance, topic modeling

2.2. Introduction

In recent years there has been a proliferation of scholars' publications on the Circular Economy _ CE (e.g. Corvellec et al., 2022; Geissdoerfer et al., 2017; Ghisellini et al., 2016; Homrich et al., 2018; Kalmykova et al., 2018; Khitous et al., 2020; Kirchherr et al., 2017; Korhonen et al., 2018; Merli et al., 2018; Prieto-Sandoval et al., 2018).

However, the CE has garnered some criticisms with regards to its perceived diffuse limitations, ambiguous theoretical grounds, and the structural obstacles it faces during implementation (Corvellec et al., 2022). CE is presented as a field of study employed by different schools of thought. (e.g. Industrial Ecology, Cradle to cradle, Industrial Symbiosis, Product-Service Systems). This feature increases the difficulty to consolidate a singular definition. According to Korhonen et al. (2018) CE can fit as an Essentially Contested Concept (ECC), when has an agreement on the principles and aims but disagreements on how to define it (Gallie, 1956). To critics, CE falls short of the lofty promises extolled by its proponents, as it faces significant challenges and limitations that cast doubt on its true potential. To Corvellec et al. (2022), CE appears as a "*theoretically, practically, and ideologically questionable notion*". However, it is argued that studies focusing on the implementation of circularity could contribute to a better understanding of its limitations.

CE implementation studies follow a multi-level approach of action: i) macro level, which aims on adjusting industrial composition and structure of the entire economy; ii) meso level, which focuses on eco-industrial parks as systems and industrial symbiosis and iii) micro level, which considers products, individual enterprises and what needs to be done to increase their circularity (Ghisellini et al., 2016; Kirchherr et al., 2017; Merli et al., 2018). To Sarja et al. (2021) the changes at the organizational level (i.e., micro level) are one of the most important to study, because is where concrete CE changes are implemented. As companies are facing obstacles in making the transition to CE, researching and disseminating CE transition success stories can enable wider CE adoption. However, on the micro level, the papers generally focus on indicators to measure CE (e.g. Kristensen & Mosgaard, 2020; Sacco et al., 2021), CE barriers (e.g. Sinha, 2022) and business models (e.g. Centobelli et al., 2020) Usually, the studies do not handle the impacts of CE implementation on the firm. This is the reason why Khitous et al. (2020) incentive scholars from the Business and Economics fields to investigate the viability and profitability of CE strategies.

This paper seeks to address the research gap by investigating the historical trends in the adoption of Circular Economy (CE) at the firm performance level. The primary focus of this paper is to understand how the topics related to CE at the firm performance changes over time, and how they are been analyzed, in order to gain insights into the dynamics and trends of this emerging field.

2.3. CE related literature review papers

Sarja et al. (2021) categorized other literature reviews related to CE into three categories: 1) concept reviews (e.g. Kalmykova et al., 2018; Kirchherr et al., 2017; Schöggl et al., 2020); 2) transversal or general reviews (Merli et al., 2018) and finally 3) more focused reviews (e.g. Camacho-Otero et al., 2018; Masi et al., 2017; Sassanelli et al., 2019). The future research needs to look beyond the conceptual understanding or definitional aspect towards the role of CE in enhancing social, economic, and environmental impacts. Geissdoerfer et al. (2017) recommended that future research needs to investigate the relationship between CE and emerging concepts, such as performance economy and sharing economy, and new business forms and structure, like benefit corporations.

In a survey, eighteen CE reviews were analyzed by Goyal et al. (2021) regarding the research objective. Goyal found that most of these literature review papers focused on elaborating on the concept of CE by reviewing the conceptual framework, definitions, drivers, role in sustainability, and country-level adoption. Further, only three used bibliometric analysis (Nobre & Tavares, 2017; Türkeli et al., 2018a) the other studies used qualitative methods (literature review, citation analysis and coding analysis). Most of the papers focus on more recent decades, only two of them have analyzed CE since the 1950s, and both papers are qualitative (Geissdoerfer et al., 2017; Lieder & Rashid, 2016)

When we analyze literature reviews that emphasis on the micro level of CE, we usually find reviews that address three main themes: 1) CE barriers and drivers, 2) business models and 3) CE indicators or evaluation metrics.

CE barriers and drivers refer to the factors that hinder or promote the adoption of CE practices. According to de Jesus & Mendonça (2018) some of the soft barriers to circular economy adoption include a lack of awareness, knowledge, and skills among stakeholders, as well as resistance to change. Hard barriers include regulatory and legal frameworks that do not support CE, as well as a lack of infrastructure and technology. On the other hand, some of the drivers of circular economy adoption include economic benefits such as cost savings and increased competitiveness, environmental benefits such as reduced waste and emissions, and social benefits such as job creation and community development. Bilal et al. (2020); Grafström & Aasma (2021) and Sinha (2022) represent examples of literature review about CE barriers and drivers. Sinha (2022) study concludes that clear policies for collaboration and by understanding customer perception organizations can help make a smooth transition from a linear model to CE. While Grafström & Aasma (2021) examine, from a theoretical economics perspective, how four barriers – technological, market, institutional and cultural – can prevent the implementation of a circular economy.

On the other side, a circular business model is described as a type of business model that aims to create a closed-loop system by maximizing the reuse, repair, remanufacturing, and recycling of resources while minimizing consumption practices. The development of circular business models requires collective and collaborative action from various stakeholders, including businesses, governments, and consumers (Lieder & Rashid, 2016). Exemplifying reviews of CE business models, we can cite the studies of Centobelli et al. (2020) and Lewandowski (2016). The paper of Centobelli et al. (2020) shows that, in order to design a circular business model, companies have to implement some managerial practices that are specific for each dimension of the business model: value creation, value transfer, and value capture. The Lewandowski (2016) investigation redefine the components of the business model canvas in the context of the circular economy.

CE indicators are specific metrics or measures used to assess the extent to which a company is implementing circular economy principles in its operations. These indicators can include measures of resource efficiency, waste reduction, product design for circularity, and closed-loop supply chain management, among others. The reviews of Sacco et al. (2021) and Kristensen & Mosgaard (2020) are samples of the ones that emphasis the CE indicators. The study of Sacco et al., 2021; arranges insights from 130 documents belonging to scientific and practitioners' literature reviews on existing CE metrics, and organizes them according to a new circular Value Chain framework. While Kristensen & Mosgaard (2020) study reviews 30 CE indicators, the majority of indicators focus on recycling, with the number of indicators decreasing when include reuse, repair or maintenance.

According to the EMF (2015), CE indicators can provide insights into a company's circularity performance across different areas such as materials management, product design, business models, and end-of-life strategies. However, it is important to note that CE indicators alone do not necessarily guarantee improved firm performance. A company's success in implementing CE principles may impact its overall performance in various ways, such as reducing costs through more efficient resource use or improving brand reputation through sustainable practices. While CE indicators can be used as a tool to measure a company's progress towards circularity and sustainability goals, they are just one aspect of overall firm performance. The firm performance refers to how well a company is achieving its goals and objectives. This can include financial performance (e.g., profitability, revenue growth), operational performance (e.g., efficiency, productivity), and social and environmental performance (e.g., sustainability, social responsibility). As noted, firm performance is a broader concept that encompasses many different aspects of a company's operations and can be influenced by various factors such as strategy, management practices, and external market conditions.

On the micro level, the CE adoption normally is encouraged due to its attractiveness for business potential and possibility to reduce costs, improve profitability and competitiveness (Sarja et al., 2021). Adoption of CE does improve operational efficiency by closing material and product loops, but at the same time, it may lead to increased production and consumption levels (Abreu & Ceglia, 2018; Heyes et al., 2018). Sarja et al. (2021) concludes that "*money is the most often mentioned catalyst for CE implementation. The companies expect profits when applied to a CE approach in their business*" (Sarja et al., 2021, pg. 12). Goyal et al. (2021) consider that CE economic performance measures include: cost savings, revenue increase in foreign investments, and economic performance at country or industry level. Using data from 308 China manufacturers, (Yu et al., 2022) empirically investigated the influence of CE practices on companies' performance and reveals new paths through which the CE improves financial performance. The literature review of Uhrenholt et al. (2022) abord somehow the CE activities and financial performance. However, the study limits the analysis just of one CE activity: the product take-back system (when manufacturers and sellers "take back" the products that are at the end of their lives). The author uses a structured literature review to explore the factors affecting the financial performance The paper finds a total of 12 factors, most of which have the potential of affecting the cost or value of the product take-back system both positively and negatively. Even that scholars agree about the CE potential of increase the firm performance, few literature reviews connect the two themes: circular economy and firm performance. This paper differs of other literature reviews when propose analyze the state of the research when we search CE related to firm performance, with the aim to understand the needs and gaps to the CE transition on micro level.

This literature review sets itself apart from others in several key aspects. Firstly, while many studies rely on qualitative methods that restrict the analysis to a limited number of articles, and often only focus on recent publications, this review adopts a novel approach using topic modeling analysis. By employing this method, a larger number of articles can be included in the analysis, allowing for a comprehensive historical examination of the topic.

Furthermore, unlike studies that primarily focus on theoretical concepts or solely concentrate on micro-level analysis without considering firm performance, this review addresses the relationship between CE and firm performance. By incorporating the dimension of performance, this review goes beyond existing research that tends to focus on specific regions or activities when analyzing performance outcomes. The utilization of the topic modeling method, combined with a micro-level organizational analysis and the inclusion of performance-related factors, enables a more holistic understanding of how CE impacts firm performance.

2.4. Method

Due to the multi-disciplinary nature of CE, a single study may contain multiple topics. Thus, this paper applies topic modelling to capture the published research trends about the relation of CE adoption and the firm performance since its inception. We used the Latent Dirichlet Allocation (LDA), the usual application of LDA in topic modeling is to automatically identify topics or themes in a collection of documents. LDA is an unsupervised machine learning algorithm that can identify latent topics by analyzing the distribution of words across documents. It has been widely used in various fields such as natural language processing, information retrieval, and text mining. LDA has been used also in social media analysis to identify topics and themes in large volumes of social media data (Chen & Skiena, 2014; Paul & Dredze, 2012). This method uses quantitative statistical algorithms to extract semantic information from text. The process does not require any prior understanding of the corpus documents to comprehend the thematic concepts (Agrawal et al., 2018). According to (Mo et al., 2015), using LDA to topic modelling can result in a more informative representation of studies, allowing reviewers to quickly identify key themes and topic. Overall, the use of topic modeling for systematic reviews has the potential to save time and resources while improving the accuracy and efficiency of the review process.

2.4.1. Search terms

The search themes will be used to download papers from the Scopus and from the Web of Science (WoS). According to Mongeon & Paul-Hus (2016), english-language journals are overrepresented to the detriment of other languages, and the language is an important factor for modeling topics.

According to Goyal et al. (2021) the majority of the existing CE related literature review articles used “circular economy” as the primary search keyword. Few literature review studies used “circular economy” in combination with context-specific secondary keywords, like “sustainability”, “product service system”, “sharing economy”, “zero waste”, and others. Thus, the main search term in this literature review was ‘circular economy’, the search term ‘circular* econom*’ was used, as suggested by Türkeli et al. (2018), as this can capture phrases such as circularity, circular-economy and circular economic, which may yield papers otherwise not found in a traditional search on ‘circular economy’.

The others terms we will use for the search, to categorize the firm performance is “firm perform*” OR “organiz* perform*” OR “cost sav*” OR “profit* OR , “viability” OR, “Revenue generation” OR, “economic*”, “financ*” and “business case*” OR “competitive advantage” suggest themes bring by the Goyal et al. (2021 and Uhrenholt et al. (2022). As not all the papers were research papers required for the processing, we filter to consider only “Reviews” and “Articles”, and only papers from “Journals”, and only papers written in English. Since a notable overlap between the papers from Scopus and WoS occurred, duplicates also required removal.

The final combined list remained 3456 papers for topic modelling processing. Full articles were used for the analysis, not just abstract, titles and keywords. The idea is to find topics that are faithful to the content of the articles, to reduce author bias. It was necessary to download the articles in pdf format for text processing, a step that will be explained in the next topic.

2.4.2. Process

In summary, the flow that takes place in this type of modeling is a reduction of the analyzed texts; the application of model generates topics (similar the models that generate clusters, for example), where each topic incorporates a few words; and finally classify the analyzed documents according to the topics raised, indicating which topic best fits (Hecking & Leydesdorff, 2019; Maier et al., 2018).

The raw captured bibliometric text requires pre-processing to prepare it for analysis. The pre-processing steps will be performed to transform the text into a format suitable for analysis (Eker et al., 2019). The flowchart (Figure 5) represents the steps for modeling topics for this study.

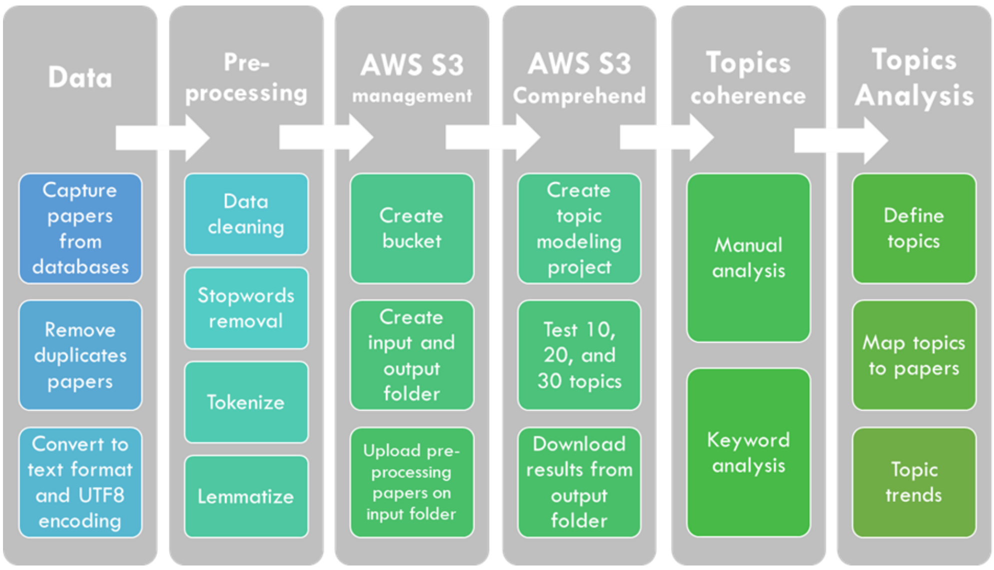


Figure 5: Steps to topic modeling

To transform the download pdf papers into a format that can be read by the Python algorithm and the AWS Comprehend, we run a code with PyPDF2 library to transform the extracted papers into txt format and UTF-8 encoding.

The second step is pre-processing the papers, this includes: data cleaning, stopwords removal, tokenisation and lemmatisations. We use a code with the Python's SpaCy library to perform this pre-processing.

- Data Cleaning: The text contains unwanted words (e.g. published, copyright, Elsevier, crossreference, etc.), punctuations, numbers, capitalized letters, special characters, and redundant spaces.
- Stopwords removal: The stopwords tend to be common words, such as "as", "and", "the", "if", "a", etc., not adding meaning to the text.
- Tokenization:. Tokenisation extracts the linguistic building blocks for sentences as words using the spaces in between.
- Lemmatisation. Lemmatization also normalises and reduce text dimensionality by combining derivatives of words, such as plurals and past tenses.

The Amazon Comprehend is an application of Amazon services that uses natural language processing (NLP) to extract insights about the content of documents. The Amazon Comprehend read the texts form the AWS S3 Management to perform the LDA algorithm analysis.

Some measures can be used to assess the quality of topics generated by the topic model and help to find the optimal number of topics that produce coherent and distinct topics. One way to justify the number of topics is to perform a manual analysis of the topics generated by the model. The keyword analysis is a simple technique that can be used to assess the similarity between words within a topic. It involves identifying the most common words in a topic and comparing them to words in other topics. We ran models, with 30, 20 and 10 topics to analyze consistency. For the final analysis, 20 topics were the ones that showed the greatest coherence of the topics and the greatest similarity between words of the same topic.

2.4.3. Finding variables and measures models

To review the quantitative literature on the relationship between circular economy (CE) practices and firm performance, we used a python code to search directly in the full text of the papers, using the following filter: [‘variables’, ‘quantitative’, ‘correlations’, ‘regression’, ‘significant’, ‘performance’, ‘circular’, ‘economy’, ‘firm’, companies’, ‘organization’, ‘barrier’, ‘driver’]. The filter resulted in 284 papers. The topics Methodology and Results of each paper have been analyzed, aiming to identify whether the paper provides a model to measure the relationship between firm performance and CE. We selected articles that included CE practices in the model related to firm performance (financial, economic, sustainable, etc.), resulting in 39 articles. We then conducted an analysis of the main variables used in the models. We also examined the methodological approaches, data sources. In addition, we verified the type of industry, the size of the company, the size of the sample and the topic to which the article belongs.

2.5. Results

This section presents a bibliometric analysis conducted on the sample papers. This analysis includes the number of papers, citations, insights into the coverage research, and the examination of journals and research areas. Additionally, the results showcase the outcomes of the topic modeling analysis, revealing the main thematic clusters and their corresponding key findings. These results offer a comprehensive overview of the literature landscape, shedding light on the research trends, prominent areas of study, and important contributions within the field.

2.5.1. Number of papers and citations

Firstly, the complete data set of 3456 papers are presented in the Figure 6 over the years. Years of publication will be important for the analysis of trend topics. We noticed that articles on CE involving firm performance date back to 1897, however, the massive amount of publications started from 2010, gradually increasing until 2023.

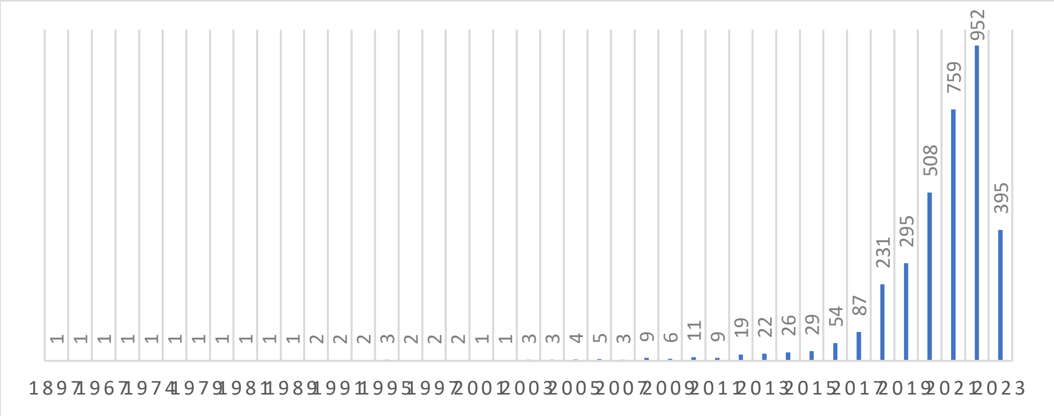


Figure 6: Years of publications

A growing evolution can be seen from 2016, when the number of publications almost doubled compared to 2015. The number of publications in the last 5 years (2018 - 2023) are substantially higher, annual publications exceed 200 papers. Comparing the periods 2012-2017 and 2018-2023, there was a growth of 1225% in publications.

The oldest work in the sample is that of Meyer (1897) which deals with the cooperation work for the organization of the Prussian railway system. The most recent work is by (Corsini & Frey, 2023) which explores the success determinants of crowdfunding campaigns for sustainable products. The Table 4 shows the most cited papers along the publications.

Table 4: Citations

Papers	Source title	Citations	JCR	AIF
(Sheldon, 2017)	Green Chemistry	748	11.034	9001.4
(Lewandowski, 2016)	Sustainability (Switzerland)	712	3.889	3481.0
(Genovese et al., 2017)	Omega (United Kingdom)	702	8.673	6790.4
(Merli et al., 2018)	Journal of Cleaner Production	562	11.072	6784.5
(Lopes de Sousa Jabbour et al., 2018)	Annals of Operations Research	542	4.82	3154.4
(Cucchiella et al., 2015)	Renewable and Sustainable Energy Reviews	500	16.799	8899.5
(Sheldon, 2018)	ACS Sustainable Chemistry and Engineering	479	9.224	4897.3
(Geissdoerfer et al., 2018)	Journal of Cleaner Production	476	11.072	5746.3
(Zink & Geyer, 2017)	Journal of Industrial Ecology	471	7.202	3863.1
(Rizos et al., 2016b)	Sustainability (Switzerland)	459	3.889	2244.1

Sheldon, 2017) presents the paper with the major number of citations, the paper is a review of the last 25 years of research and development in the field of resource efficiency and waste minimization. The principal conclusion is that the principles of green chemistry and sustainability have had a significant impact on the chemical and allied industries, with the pharmaceutical industry in particular making substantial progress in integrating these principles into their processes. Overall, there has been a paradigm shift from a focus on chemical yield to one that is motivated by optimizing resource efficiency and eliminating waste.

2.5.2. Coverage of research

The main papers countries are listed in Figure 7. The two countries with the most evidence of publications are Italy and the United Kingdom, followed by China and Spain. The greater interest of European Union countries and China can be justified by the implementation of the European Circular Package in December 2015 by the European Commission and the Chinese Circular Economy Promotion Law in 2008. The European Circular Package is a policy framework that aims to promote circular economy practices across the EU. It includes measures such as eco-design, extended producer responsibility, and sustainable production and consumption (Oncioiu et al., 2018). The Chinese Circular Economy Promotion Law is a law that was enacted in 2008 to promote the development of circular economy in China. The law aims to establish a legal framework for the promotion of circular economy, and to encourage the efficient use of resources, reduction of waste, and sustainable development (National People's Congress of the People's Republic of China, 2008)

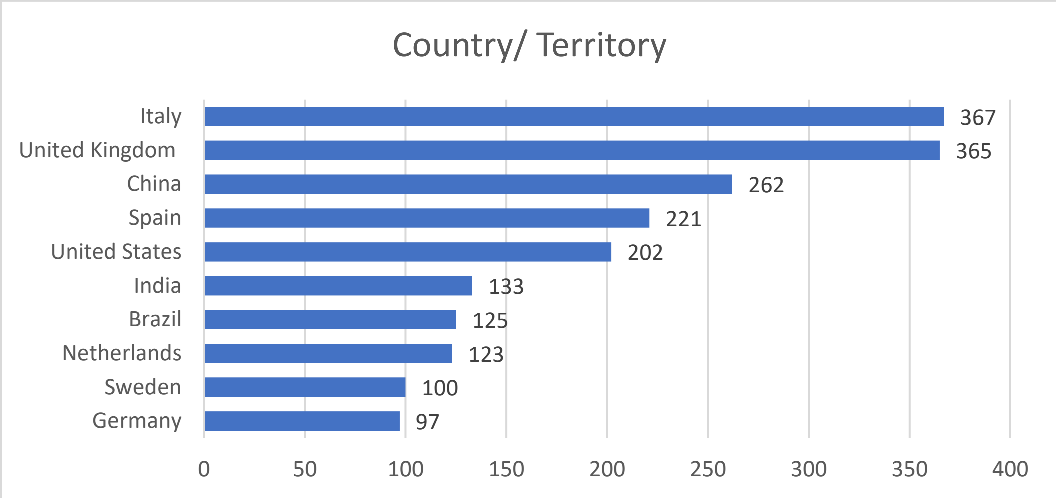


Figure 7: Papers country

The results in Table 5 show that the author with the highest total number of citations in the references of the sampled works is Nancy Bocken, from UK.

Table 5: Principal Authors

Author	Affiliation	Country	Papers	Sample citations	Total citations	H-index	i10-index
Bocken, Nancy M.P.	Maastricht University	United Kingdom	18	1563	27107	61	110
D'Adamo, Idiano	Sapienza University of Rome	Italy	16	1022	5984	47	94
Tseng, Ming-Lang	Asia University	Taiwan	16	187	19842	79	268
Jabbour, Charbel Jose Chiappetta	NEOMA Business School	France	14	1508	25713	81	231
Mangla, Sachin Kumar	University of Plymouth	United Kingdom	14	1003	12485	64	138
Khan, Syed Abdul Rehman	Tsinghua University	China	12	473	9546	56	121
Charnley, Fiona	University of Exeter	United Kingdom	12	803	3130	23	34
Iraldo, Fabio	Sant'Anna School of Advanced Studies	Italy	12	499	9341	48	101

Nancy Bocken is a well-known sustainability expert and academic who has published extensively on topics related to sustainable business models, circular economy, and sustainable innovation. She is currently a Professor of Sustainable Business at Lund University in Sweden and has previously held academic positions at the University of Cambridge and Delft University of Technology. Her research focuses on how businesses can transition towards more sustainable practices and how new business models can contribute to a more circular economy.

2.5.3. Journals and research areas analysis

Research areas typically refer to the specific fields or topics that researchers are studying or investigating. The principals research areas of the sample are “Science and Technology”, “Engineering” and “Business & Economics”. Circular Economy (CE) research in the Business and Economic area has been growing rapidly in recent years, with scholars exploring various aspects of CE adoption, implementation, and performance. According with the sample, the number of publications in the “Business & Economics” area started to increase from 2020, that is, they are extremely recent.

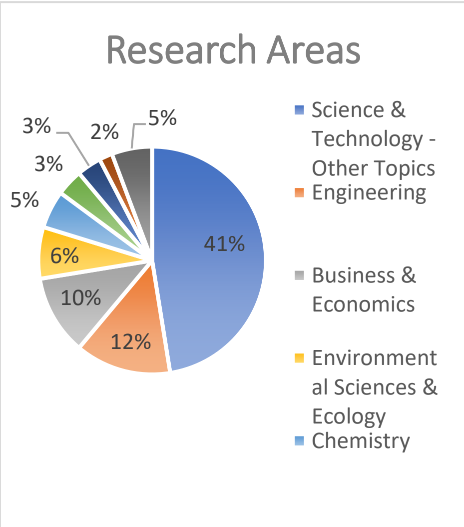


Figure 8: Research areas

Table 6: Journals

Journals	Papers	JCR 2021
Journal of Cleaner Production	447	11.072
Sustainability (Switzerland)	393	3.889
Resources, Conservation and Recycling	110	13.76
Business Strategy and the Environment	104	10.801
Energies	86	3.252
Sustainable Production and Consumption	82	8.921
Waste Management	53	8.816
Science of the Total Environment	51	10.754
Journal of Environmental Management	49	8.91
Environmental Science and Pollution Research	35	5.19

The most productive journal on the sample is the Journal of Cleaner Production, whose impact factor is 11.072, and published 447 works, which were cited 20,165 times, and 92.4% of the works were cited at least once.

2.5.4. Topics analysis

The LDA algorithm only cluster documents by their topics without identifying a name for each topic. The Table 7 presents the terms associated to each topic, these terms represent the most used words in each cluster of papers. A manual analysis, with domain knowledge, is applied to interpret the LDA results and associated bibliometric data to assign a descriptive topic to each cluster of terms.

Table 7: Terms associated with topics

topic	terms		topic	terms	
Financial growth strategies	economic firm market financial price	social growth capital investment finance	Bioenergy Production Scenario	production biogas plant energy biomass	produce anaerobic organic manure treatment
Waste Management	process acid production high biomass	waste chemical water treatment produce	Circular economy indicators	company sustainability circular business indicator	report economy industrial social case
Sustainable Business Education	sustainability sustainable social development company	environmental business indicator report corporate	Cost Savings	cost price scenario process plant	production water economic investment unit
Sustainable Agriculture	system water food package collection	farm heat rate plant treatment	Recycle and Recovery	recycle material battery waste plastic	metal recovery collection rate weee
Circular Economy Drivers	circular economy resource business economic	design transition development circularity model	Solid Waste Management	waste management solid recycle collection	municipal msw plastic compost country
Industrial Symbiosis and Eco-industrial Parks	industrial industry development china resource	policy symbiosis economic technology manufacture	Circular Business Model	business model circular innovation sustainable	company customer sustainability research case
Firm sustainable development goals	firm performance environmental management practice	innovation green effect research capability	Sustainable Construction	material build construction recycle waste	concrete design project demolition reuse
Life-cycle assessment	environmental impact life cycle scenario	assessment lca kg study analysis	Green Supply Chain Management	supply chain management green supplier	circular practice performance logistic product
Circular Economy Barriers	barrier industry technology study circular	management research chain manufacture lack	Circular Consumption	product remanufacture consumer price market	design manufacturer strategy service customer
Circular Design Products	design product circular build economy	component remanufacture disassembly process service	Renewable Energy	energy renewable power heat emission	electricity consumption fuel solar system

Thus, we have 20 topics along the study of CE related to performance: Sustainable Agriculture, Recycle and Recovery, Cost Savings, Industrial Symbiosis & Eco-industrial Parks, Circular Design Products, Firm sustainable development goals, Circular economy indicators, Circular Consumption, Green Supply Chain Management, Life-cycle assessment, Bioenergy Production Scenario, Sustainable Business Education, Financial growth strategies, Circular Economy Drivers, Renewable Energy, Solid Waste Management, Circular Economy Barriers, Sustainable Construction, Circular Business Model and Waste Management.

Based on history, it is possible to trace an evolutionary process of the CE. Prieto-Sandoval et al. (2018) classify the path that society has traveled to reach the CE into three stages: linear economy (18^{th} century to 1970); greener economy (1970 to 1990) and circular economy (1990 to present). In addition to the idea of CE evolution, Reike et al. (2018) named the same period of “greener economy stage” as CE 1.0 and they divided the “circular economy stage” into two phases: CE 2.0 (1990 to 2010) and CE 3.0 (2010 to present).

We will use this evolutionary definition to define the set of years that will be analyzed. Due to the small number of articles up to the 1970s, we chose to combine the publications and analyze the period up to the 1990s. We will analise the period of CE 3.0 in two fases, because in December 2015 the European Commission (the body responsible for proposing new EU legislation) published its Circular Economy Package, with the objective of “closing the loop” of product lifecycles, thus will be interesting analyze the publications after this legislation. We analyze, for each topic, the period in which it appears with the greatest intensity along the years.

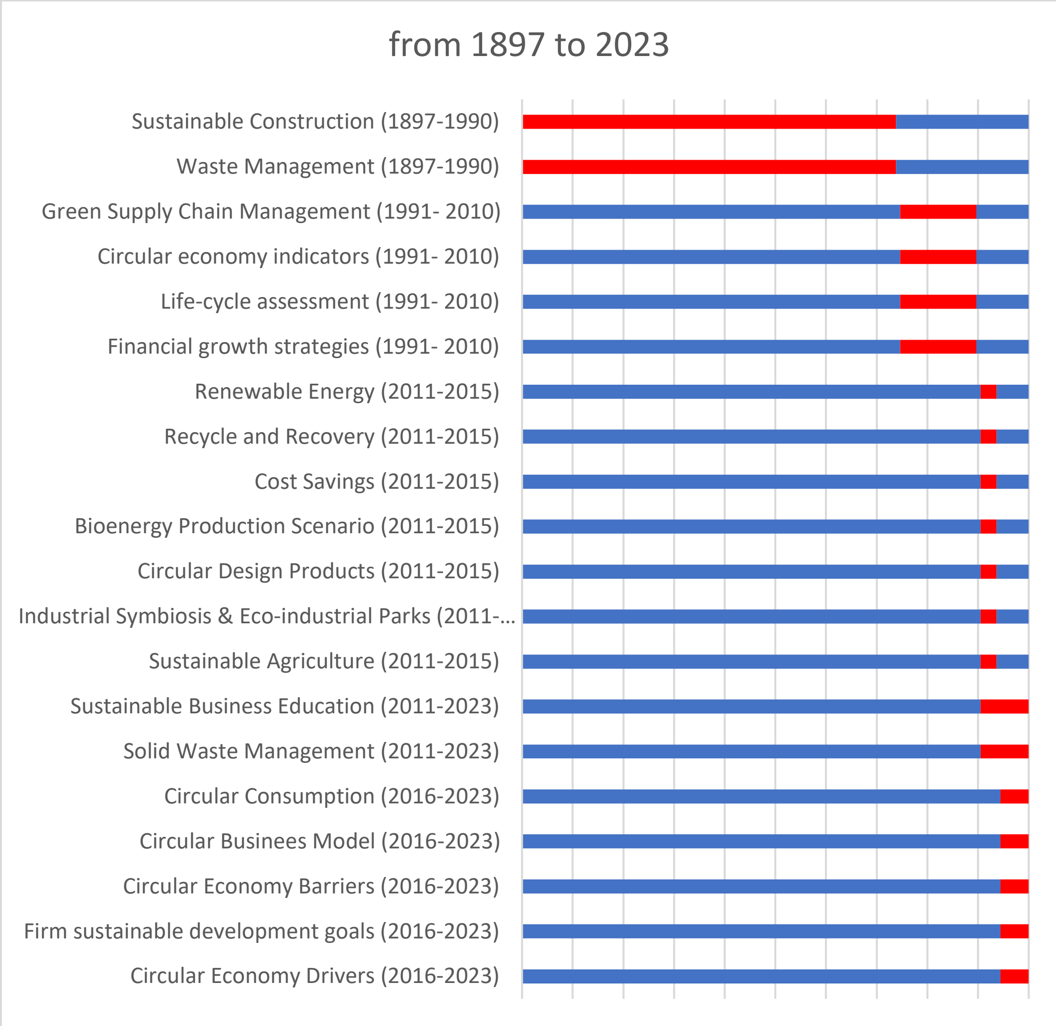


Figure 9: Trend topics

As show in Figure 9, the topic from the early years (1897-1990) does not have much to do with CE, which is understandable, since this is a period in which CE had not yet been established as a discipline. The term “circular economy” was used for the first time. with the study of Pearce and Turner (1990). Since 1990, we can identify the intensification of studies focused on the CE and firm performance (Financial growth strategies, Circular economy indicators, Green Supply Chain Management, Life-cycle assessment).

Since 2008, the Chinese Circular Economy Promotion Law has had a significant impact on promoting the development of circular economy in China, and maybe help with the increase of papers publications about “Industrial Symbiosis and Eco-industrial Parks". The law focused on the creation of industrial parks, and establishing a large and all-inclusive eco-economic model combining industrial parks, industrial chains, arterial industries and venous industries, etc. According to Wang et al., 2020) apart from the input side and output side material flow indicators, China's circularity rates also increased.

The most recent topics (2016-2023) are extremely related to the CE and are all focused on firm-level analysis (Firm sustainable development goals, Circular Consumption, Circular Economy Drivers, Circular Economy Barriers, Circular Business Model).

The intensification of studies related to companies can also be observed by the creation of The Ellen MacArthur Foundation, which was established in 2010 with the aim of accelerating the transition to the circular economy. The Ellen MacArthur Foundation has, in the context of an emerging research field, a critical role in providing cases of CE practice implementations between firms. The
Figure 10 shows the number of papers for each topic (a paper could be in more than one topic). The topic "Circular Business Model" appears in prominence, being only "Waste Management" topic with more published papers.

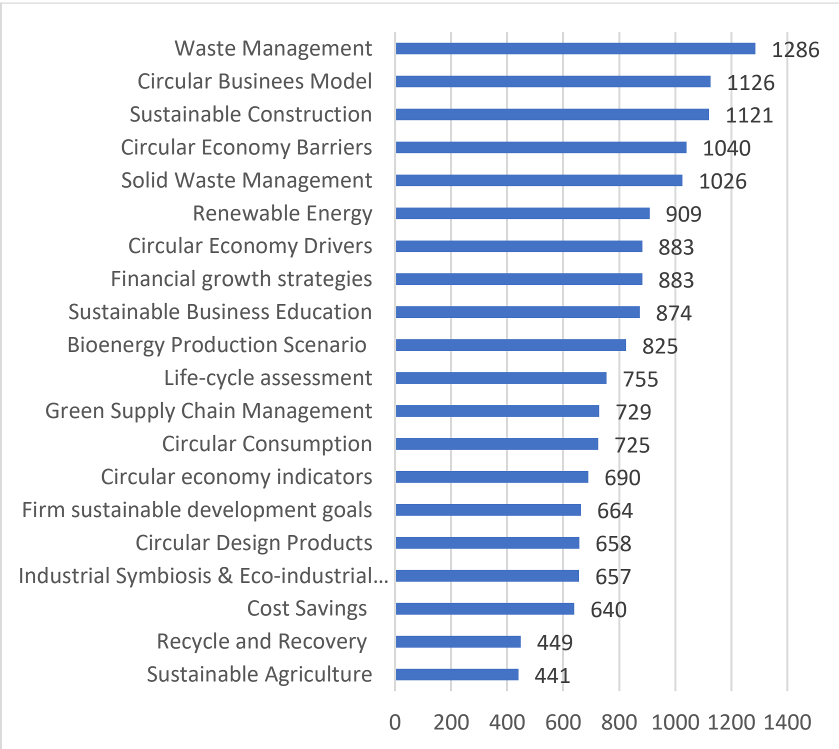


Figure 10: Number of papers per topic

2.5.5. CE practices and Firm Performance

Table 19 (Appendix A) summarizes the findings of 39 studies that investigated the relationship between circular economy (CE) and firm performance. The table shows the authors, variables, measure, analysis method, country, industry, firm size, sample, topic, and main topic of each study.

It presents a comprehensive overview of the variables used by various authors in their research on CE and firm performance. The CE variables are measured into different forms, including CE practices, CE fields of action, CE adoption level, CE targeted performance, and CE capability, among others. CE practices are the most commonly studied variables in the context of CE and firm performance (Zhu et al., 2010; Botezat et al., 2018; Kamble & Gunasekaran, 2023; Rodríguez-González et al., 2022; Chowdhury et al., 2022; J. Liu et al., 2022; Edwin Cheng et al., 2022; Rehman Khan et al., 2022; Yin et al., 2023; Triguero et al., 2023; Riggs et al., 2023). These practices include eco-design, investment recovery, and internal environmental management (Botezat et al., 2018). Eco-design involves designing products and services that are more sustainable and have a lower environmental impact. Investment recovery involves recovering and reusing materials and resources that would otherwise be wasted. Internal environmental management involves implementing sustainable practices within the organization, such as reducing energy consumption and waste generation (Botezat et al., 2018). CE fields of action is another important category of CE variables (Saha et al., 2021; Dey et al., 2022). The fields of action include design, procurement, production, distribution, usage, consumption, and reverse logistics (Dey et al., 2022). Design involves designing products and services that are more sustainable and have a lower environmental impact. Procurement involves sourcing materials and resources that are more sustainable and have a lower environmental impact. Production involves producing goods and services in a more sustainable and efficient manner. Distribution involves transporting goods and services in a more sustainable and efficient manner. Usage involves using goods and services in a more sustainable and efficient manner. Consumption involves consuming goods and services in a more sustainable and efficient manner. Reverse logistics involves recovering and reusing materials and resources that would otherwise be wasted (Dey et al., 2022). CE adoption level is another important category of CE variables (de Sousa Jabbour et al., 2022; Moric et al., 2020). This category includes adopters, planners, and non-adopters (Moric, Jovanović, et al., 2020). Adopters are companies that have adopted at least one type of activity related to CE. Planners are companies that have not implemented any type of practice related to CE, but plan to do so. Non-adopters are companies that have not adopted and do not plan to implement any activity related to CE (Moric, Jovanović, et al., 2020).

The most commonly used variables in the context of firm performance are economic performance (ECP), environmental performance (ENP), social performance (SCP), and operational performance (ORP) (Chiappetta Jabbour et al., 2020; de Sousa Jabbour et al., 2022; Rodríguez-Espíndola et al., 2022; Dey et al., 2022; J. Liu et al., 2022; Alamelu et al., 2023; S. A. R. Khan et al., 2022). ECP involves measuring the financial performance of firms, such as return on assets (ROA), revenue growth, and profitability. ENP involves measuring the environmental performance of firms, such as energy consumption, water withdrawal, CO2 emissions, and waste produced. SCP involves measuring the social performance of firms, such as employee well-being, health and safety, and social well-being. ORP involves measuring the efficiency and effectiveness of firms' operations, such as productivity, quality, and innovation (Chiappetta Jabbour et al., 2020). In addition to these variables, other firm performance variables include financial performance, such as total annual sales per employee, market share, brand reputation, and time-to-market (De Lima & Seuring, 2023; Sarfraz et al., 2019; D'Angelo et al., 2023; Fernando et al., 2023; Mazzucchelli et al., 2022; Rodríguez-González et al., 2022; Blasi et al., 2021; Bartolacci et al., 2018). These variables are used to measure the competitiveness and market position of firms.

In addition to the variables related to CE and firm performance, the table also includes a variety of other variables that are relevant to the study of circular economy (CE) and firm performance. These variables encompass a wide range of aspects, including big data analytics (Bag et al., 2022; Edwin Cheng et al., 2022; Ghaithan et al., 2023; Riggs et al., 2023), green supply chain management (Bag et al., 2022), eco-innovation (Bag et al., 2022), and organizational capabilities (Alcalde-Calonge et al., 2022; Edwin Cheng et al., 2022; Riggs et al., 2023; Khan et al., 2020). These variables are used to study the impact of various factors on the adoption and implementation of CE practices. The most common analysis method used in the studies is partial least squares structural equation modeling

(PLS-SEM), which is a multivariate technique that allows testing the causal relationships, as well as the mediating or moderating effects of other variables (Subramanian et al., 2019). Other methods include regression analysis, factor analysis, cluster analysis, confirmatory factor analysis (CFA), covariance-based structural equation modeling (CB-SEM), meta-analysis, Delphi method, etc. The studies cover a wide range of countries, mostly from Asia and Europe, but also from Latin America, Africa, and Oceania. The most frequently studied countries are China, India, and Italy. Some studies also adopt a cross-country or regional perspective, such as Europe, Latin America, or G7 countries. The studies also cover a wide range of industries, mostly from the manufacturing sector, but also from service, energy, waste management, bioeconomy, tourism, agriculture, etc. The most frequently studied industries are chemical, automotive, electronic, and textile and clothing. The studies vary in terms of firm size, with some focusing on small and medium-sized enterprises (SMEs), some on large or mixed firms. The choice of firm size may depend on the availability of data, the research objectives, and the context of the study. For example, some studies may focus on SMEs because they face more challenges and barriers in adopting green innovation, or because they represent a large share of the economy in some countries or regions (Bag et al., 2022; Rodríguez-Espíndola et al., 2022). The studies also vary in terms of sample size, ranging from 45 to 4237 firms. The sample size may depend on the data collection method, the analysis method, the population of interest, and the statistical power of the study. As an example, some studies use a large sample size to increase the generalizability and reliability of the results, or to apply more sophisticated analysis methods, such as PLS-SEM or meta-analysis (Andrade, 2020). The majority of the articles used secondary data from databases, surveys, or reports, and focused on specific industries such as manufacturing, electronics, or construction. The size of the company and the sample varied widely across the articles, as well as the topic of the article, which ranged from general CE concepts to specific aspects such as barriers, drivers, or strategies.

The findings presented in the papers provide valuable insights into the relationship between circular economy practices and various aspects of business performance. The implications of these results are significant for businesses and policymakers. They suggest that the adoption of circular economy practices can lead to improved environmental and economic performance, offering a pathway to sustainable development and competitive advantage. Furthermore, the findings underscore the importance of considering institutional pressures, stakeholder influences, and internal drivers when promoting circular economy practices, particularly in emerging economies (Chiappetta Jabbour et al., 2020; Sarfraz et al., 2022). The studies also emphasize the need for upskilling the workforce and interorganizational collaboration to successfully implement circular economy practices (Subramanian et al., 2019;. Del Giudice et al., 2021; Ghaithan et al., 2023; Kristoffersen, Mikalef, & Blomsma Fenna and Li, 2021). The empirical models examined in these studies predominantly focus on the micro-level, analyzing Circular Economy (CE) practices within individual companies. However, this approach overlooks the multilevel nature of CE, which encompasses interactions across various organizational and systemic levels. Consequently, there is a notable gap in empirical research adopting a multilevel perspective, which is essential for a comprehensive understanding of CE implementation and its broader implications. Future studies should aim to address this shortfall by incorporating multilevel analysis into their empirical models.

2.6. Conclusions

This paper provides a comprehensive analysis of the relationship between Circular Economy and Firm Performance through a topic modeling approach. The study found that there has been a proliferation of publications related to Circular Economy in recent years, however few literature reviews connect the two themes. This paper differs from other literature reviews by proposing to analyze the state of research when searching for CE related to firm performance, with the aim of understanding the needs and gaps in the CE transition on a micro level. The study used topic modeling, with LDA algorithm, to capture published research trends about the relation of CE adoption and firm performance since its inception. Topic models discover topics in the corpus, which represent real-world concepts by frequently co-occurring words. While LDA topic modeling is a powerful tool for analyzing large datasets and identifying key themes and topics, there are several difficulties associated with its use. One of the main challenges is selecting the appropriate number of topics to model. If the number of topics is too low, important themes may be missed, while if the number is too high, the model may become too complex and difficult to interpret. Another challenge is interpreting the results of the model. While LDA can identify key themes and topics, it can be difficult to understand how these themes relate to each other or to broader research questions. Additionally, LDA requires a significant amount of computational power and can be time-consuming to run on large datasets. Finally, LDA assumes that each document in the corpus contains a mixture of all possible topics, which may not always be true. Despite these challenges, LDA remains a valuable tool for researchers looking to analyze large datasets and identifying key themes and topics in their research area.

The final combined list contained 3,456 papers for topic modeling processing. Full articles were used for analysis, not just abstracts, titles, and keywords. The idea was to find topics that are faithful to the content of articles to reduce author bias. The results showed that there are several topics related to Circular Economy and Firm Performance. The majority of studies on the CE have experienced an increase in publication activity since 2016. Notably, publications in the fields of business and economics have gained more relevance starting from 2020. These studies span a wide range of time, with publications dating back to 1897, and many of them have received numerous citations in high-impact journals. The geographical distribution of these studies shows that the majority of publications are concentrated in Europe and China. Among the 20 topics analyzed, some of the most recent ones include: Firm sustainable development goals, Circular Consumption, Circular Economy Drivers, Circular Economy Barriers, Circular Business Model.

We also examined the methodological approaches, data sources, and limitations of some quantitative studies. The results of this study provide a comprehensive overview of the current state of the art in the quantitative research on CE and firm performance, and suggest directions for future research in this field. We verified the variables used, the type of data, the method of analysis, the type of industry, the size of the company, the size of the sample and the topic to which the article belongs. These results indicate that there is no clear consensus on the best way to measure and operationalize CE practices and firm performance, and that more research is required to establish a coherent and consistent framework for this field. The variables identified in the table can be used as a guide for future research on CE and firm performance. A systematic literature review has some limitations that help to focus the research on specific areas of interest while ensuring that the systematic review is manageable and the findings are relevant and actionable. The selection criteria of inclusion and exclusion for studies to be reviewed were the existence of empirical evidence of CE impact on firm performance. We identify the databases and journals to search for relevant literature and we filtered by english-language journals. Also, to finding variables and measures models, we analyzed only quantitative studies. Future studies should aim to address the gap by incorporating multilevel analysis into their empirical models. Researchers can use these variables to design studies that are more comprehensive and focused on specific aspects of CE and firm performance. Practitioners can use the variables to identify areas in which they can improve their performance and adopt more sustainable practices. The table provides a valuable resource for researchers and practitioners interested in studying the relationship between CE and firm performance. Overall, this paper highlights several key areas in which further research is needed and it provides recommendations for policymakers and practitioners looking to promote CE business practices.

3
Paper 2 – Circular Economy Adoption by European Small and Medium-Sized Enterprises: Influence on Firm Performance

3.1. Abstract

This study aims to analyze the elements that influence the adoption of CE activities by European small and medium enterprises (SMEs) and how these activities affect firm performance. In addition, we investigate how the economic, social, and environmental performance indicators of the firm's country moderates the latter relationship. We developed seven hypotheses and a theoretical model based on the literature review to answer the research question. The model and the hypotheses were tested according to the path analysis method, which is an extension of the regression model. CE may perform differently depending on location, copy-pasting solutions will not be effective. Each firm and region should plan based on its own challenges. Financial support to CE activities may be offered directly by the public sector or via other institutions. In addition, countries that already operate with a more present environmental legislation, with better environmental results, also help the firm performance by stimulating a reduction in the cost of raw materials, which makes the adoption of CE more attractive by the economic benefit generated. Our results support the view of some researchers that CE must be proposed with an integrated approach across various implementation levels.

Keywords - Circular Economy, Firm Performance, SMEs

3.2. Introduction

The importance of Circular Economy (CE) in the plans of policymakers and in the discussions inside firms has grown in recent times. The debate of policymakers concerning this subject emerges from the several policies implemented, for instance, the European Circular Package and the Chinese Circular Economy Promotion Law, and many firms' engagement in the discussion due to thematic organizations such as Ellen McArthur Foundation, which promoted the many studies in this area (Geissdoerfer et al., 2017).

CE implementation studies follow a multi-level approach (Ghisellini et al., 2016), considering the existence of a macro, a meso, and micro level (ibid.). The macro level aims to adjust industrial composition and structure of the entire economy,it can be global, national or regional, with the legislation being the central instrument of action; meso level focuses on industrial symbiosis, that means the inter-company level, as it involves physical exchanges between multiple organizations (M. R. Chertow, 2000), and; micro level considers mainly individual enterprises (Feng & Yan, 2007; Ghisellini et al., 2016; Kirchherr et al., 2017; Merli et al., 2018).

In the micro-level, the CE studies have been developed mainly focusing on large industries, and it is observed that the practice is not widespread sufficiently across small and medium-sized enterprises – SMEs (Ormazabal et al., 2018). Whereas 99% of firms in the European Union (EU) are SMEs and these firms create most of the new jobs, research focused on CE activities conducted by SMEs is scarce. Evidence of the relevance of SMEs in this matter is that the EU recently funded some projects fostering CE practices in these type of firms (European Commission, 2020b). Exceptions are some recent articles focusing particularly on the barriers and enablers of SMEs for implementing CE (Cantú et al., 2021; Mura et al., 2020; Rizos et al., 2016b; Scipioni et al., 2021). The SMEs that seek CE activities are more likely to deal with additional costs because of their low bargaining power among stakeholders in the supply chain (Rizos et al., 2016b; van Eijk, 2015; Wycherley, 1999). To SMEs, it is hard to visualize economic benefits as the implementation of CE practices often involves making extra investments that the SMEs may not consider profitable (Dalhammar, 2016). Thus, *our aim is to analyze the factors that influence SMEs to adopt CE activities and how these activities affect the firm performance.* Furthermore, to improve essential transformations, implementing CE must be simultaneously in the micro, meso, and macro systems; this is necessary to help underscore the holistic, systemic change that CE requires (Khitous et al., 2020; Kirchherr et al., 2017). To support this theory, we also test if the results of CE in micro-level (firm) are influenced by the macro-level (country). We assume that countries with better CE performance will provide firms with better results when they implement CE activities.

3.3. Literature Review

The term CE was used for the first time only in 1990 by Peace and Turner, when they inferred how the use of natural resources impacts the economy as inputs of industries and, simultaneously, how the outputs of the very same industries impact them. (Andersen, 2007; Geissdoerfer et al., 2017; Ghisellini et al., 2016; Merli et al., 2018; Reike et al., 2018; Su et al., 2013). The term 'Circular Economy' has been linked with a range of meanings by different research, but they generally have in common the concept of cyclical closed-loop system (e.g. Bocken et al., 2016; Murray et al., 2017; Stahel, 2016, 2019).

In 2006, CE started to become formalized and delineated with the Chinese policy, which included CE as the main purpose of the plans for National Economic and Social Development (Su et al., 2013). In such effort, the Chinese 'Circular Economy Promotion Law' intended to "improving resource utilization efficiency, protecting the natural environment and realizing sustainable development" (Geng et al., 2012 p. 216). In Europe, CE emerged later with the launching of the Circular Economy Package (Masi et al., 2017). Other countries implemented CE with different approaches as a guideline (George et al., 2015). Thus, CE's definition became notorious and the researchers started to use it (Ghisellini et al., 2016).

CE is typically implemented on firms (micro-level) considering two main areas of eco-innovation (EI): eco-design (which is a type of product innovation) and clean production (which is a type of process innovation) (de Jesus & Mendonça, 2018; Ghisetti et al., 2017). Eco-design, as product innovation, happens in different forms, such as by using recycled materials or redesigning products and services to reduce the use of raw materials (Demirel & Danisman, 2019). Regarding clean production, as an innovation process, we may cite the replanning of water usage to minimize the spending of this resource by stimulating reuse, usage of renewable energy, replanning to minimize energy usage, and reducing waste by recycling, reusing, or selling to other firms. These are typical examples of EI processes that utilize the principles of subsystem or system change to increase the operations' eco-effectiveness(Demirel & Kesidou, 2019; Kiefer et al., 2019). While product innovations improve performance by expanding the firm's market share or facilitating their entry into new markets; process innovations do it by enhancing efficiency and lowering costs (Coad et al., 2016; Doran & Ryan, 2016).

On this practitioner side, the Ellen MacArthur Foundation has a critical responsibility to encourage the adoption of CE practice among firms, being considered a reference in such practices (Merli et al., 2018). It made several evaluations confirming that the implementation of CE activities produces considerable cost reductions (EMF, 2015). CE became an EU policy priority, besides other proposals, as a reaction to high commodity prices and lack of resources.

Some researchers identified that the investment in CE can generate positive effects on firm performance (e.g., Aboulamer, 2018; Demirel & Danisman, 2019; Geissdoerfer et al., 2017; Kirchherr et al., 2017; Moric et al., 2020). Aboulamer (2018) claimed that adopting activities related to CE expands the useful life of a product while minimizing resource use and waste, which could directly reflect an increase in financial performance. The firms could profit from CE adoption through cost savings generated from reducing commodities use (e.g. metals and energy) or by creating new markets (Taranic et al., 2016). In other words, the major adoption of CE by firms as a new business model will help the use of resources in multiple cycles and waste and consumption reduction (Lüdeke-Freund et al., 2019). These arguments supported the first hypothesis.

Hypothesis 1: CE adoption is positively associated with firm performance.

Rizos et al. (2016) analyzed the frequency of different barriers to CE adoption mentioned by SMEs. The authors understood that it is an indication of how SMEs feel when confronted by a barrier. The study concludes that various barriers present challenges to SMEs in their transition to a CE (Rizos et al., 2016b).

The lack of capital is a relevant barrier for smaller companies (Hollins, 2011; Rademaekers et al., 2011). Kirchherr et al. (2018) found that high upfront investment cost is one of the most pressing barriers to CE adoption, as working with CE involves a significant adjustment in business planning and strategy and this shift causes additional investments. Some results of Rizzo's study reveal the concern of SMEs: "Because of our low turnovers, banks have always been hesitant in releasing funding to the business. It has been very challenging to secure a sufficient amount of funds to run our core business, let alone for greening the business" (Rizos et al., 2016, p.12) Neubaum et al. (2004) argued that this lack of resources and the concern with survival could have a negative impact on the adoption of CE. The authors believe that the leaders may use the argument of high upfront investment costs to abort a CE initiative (ibid.).

Another important barrier is the lack of technical skills. The transition to more circular businesses requires a fundamental rethinking of industrial processes and organizations (Wautelet, 2016). In some situations, in which SMEs intent to improve the environmental performance of their business, they are hindered by this barrier. The Kirchherr et al. (2018) study evaluated that there is a learning cost to implement CE, and some firms are waiting for others to invest first and rise in the learning curve. As a result, the current staff, in many cases with insufficient knowledge, operates the new technology, compromising its adoption. Usually, the lack of technical skills is not the only barrier as it is usually correlated to lack of resources and time for training to acquire the necessary skills. Overall, "technical bottlenecks stand out as the perceived source of the greatest challenges" (de Jesus & Mendonça, 2018). We use in this study the term' lack of technical skills as the: i) lack of human resources (Garcés-Ayerbe et al., 2019; García-Quevedo et al., 2020), ii) lack of competence to implement CE (Calogirou, 2010; Y. Liu & Bai, 2014; Rademaekers et al., 2011; van Eijk, 2015), iii) lack of knowledge regarding the benefits and necessary investments (Amec, 2013; Murillo-Luna et al., 2011; Rizos et al., 2016b) .

In contrast with the barriers, a crucial enabler to CE businesses is the organizational strategy. Generally, firms with a differentiation strategy (Porter, 1980) are more capable of being sensitive to changes in the markets and creating capacities to meet these changes (Koza & Lewin, 1998). According to Aboulamer (2018), the relationship between R&D investment and green activities is well-established in the literature, and it is possible that this relationship could extend to the adoption and implementation of circular economy principles. Companies that invest heavily in R&D activities tend to develop more internal innovative capabilities, which can enable them to develop new technologies, materials, and processes that align with circular economy principles. Additionally, companies that invest in R&D may be more likely to adopt circular economy principles because they tend to be aware of the potential benefits and opportunities associated with this new economic paradigm. Therefore, it is possible that R&D investment could be a key driver of the adoption and implementation of circular economy principles. The Yamakawa et al. (2011) study use R&D as an indicator of differentiation strategy level, and our study replicates the same logic. Considering these factors that influence positively or negatively the adoption of CE, we expect that:

Hypothesis 2a: A firm's choice for a differentiation strategy is positively related to CE adoption.

Hypothesis 2b: The lack of technical skills of a firm is negatively related to CE adoption.

Hypothesis 2c: A firm's financial capacity is positively related to CE adoption.

Although the all the countries of EU are subordinated to the same set of policies related to CE and recycling targets (Sakai et al., 2011), national plans, financing systems, the institutional context, and incentives are still very heterogeneous throughout countries, and this condition affects the involvement of SMEs in CE activities (Zamfir et al., 2017). Bačová et al. (2016) stated that geographic, environmental, economic, and social factors influence CE. For example, factors as the accessibility of the region can play a role: in less accessible areas, sharing economy could be a big challenge (ibid.). Analyzing the report of ESPON GREECO (Hansen et al., 2014), Bačová et al. (2016) showed that firms in higher performance countries might need less support with the transition to a circular economy than regions with low performance. It occurs because lower environmental performance countries do not have enough enforcement of environmental regulations, which does not encourage companies to adopt a circular business model. The lack of adequate market signals reinforced, such as low prices of raw materials, also reinforces this scenario. It makes firms purchase cheaper raw materials instead of using recycled ones, which often entails supplementary processing costs (Bicket et al., 2014). Similar discrepancies occur in other policy instruments, for instance the absence of "consumption taxes" to charge the use of polluting products, which could inhibiting their adoption by consumers (Geng & Doberstein, 2008). The diversity of territorial contexts translates into different needs and opportunities that any CE should address. (Bačová et al., 2016). Not only do environmental regulations in the national context affect the involvement of SMEs in CE activities, but geographic location (access) and market (price of raw materials) factors also affect them. The main issue is that firms in higher performance countries might need less support with the transition to a circular economy than regions with low performance. And this is what the model proposes to test: if the country's performance influences the transition.Exploring CE under the sustainable development context could be a valuable purpose for improving efforts by policymakers, companies, and the general society. In the context of CE performance, it is necessary adequate monitoring with indicators (Bačová et al., 2016). The EASAC (2016) defines an interesting CE indicators approach for sustainable development, consisted of a panel of indicators are grouped into the following groups: environment, material flow analysis, societal behavior, organizational behavior, and economic performance. In other words, these indicators represent the main objectives of sustainable development. In order to make valuable economic, social, and environmental analyses, it is necessary to adapt to the situation of each country. Considering these arguments, we hypothesize that:

Hypothesis 3a: The economic performance of the country in which the SME is located positively moderates the relationship between CE adoption and firm performance.

Hypothesis 3b: The social performance of the country in which the SME is located positively moderates the relationship between CE adoption and firm performance.

Hypothesis 3c: The environmental performance of the country in which the SME is located positively moderates the relationship between CE adoption and firm performance.

3.4. Method

We developed seven hypotheses and a theoretical model based on the literature review to answer the research question. The model and the hypotheses were tested according to the *path analysis method*, which is an extension of the regression model (Garson, 2013). A regression is performed for each dependent variable which the model suggests the causes exist. The observed correlation matrix for the variables is compared to the regression weights predicted by the model, a goodness-of-fit statistic is calculated, and the greatest model is chosen for the theory development (Garson, 2013). As shown in Figure 11, the model is composed of eight variables which are: i) Firm strategy; ii) Technical skills; iii) Financial capacity iv) CE adoption; v) Firm Performance; vi) Economic Performance; vii) Social Performance; and viii) Environmental Performance. The variables from 'i' to 'v' are related to micro level of analysis (firm) and the remaining are related to macro level of analysis (country). We also use the following control variables: age, sector, consumer type and size.

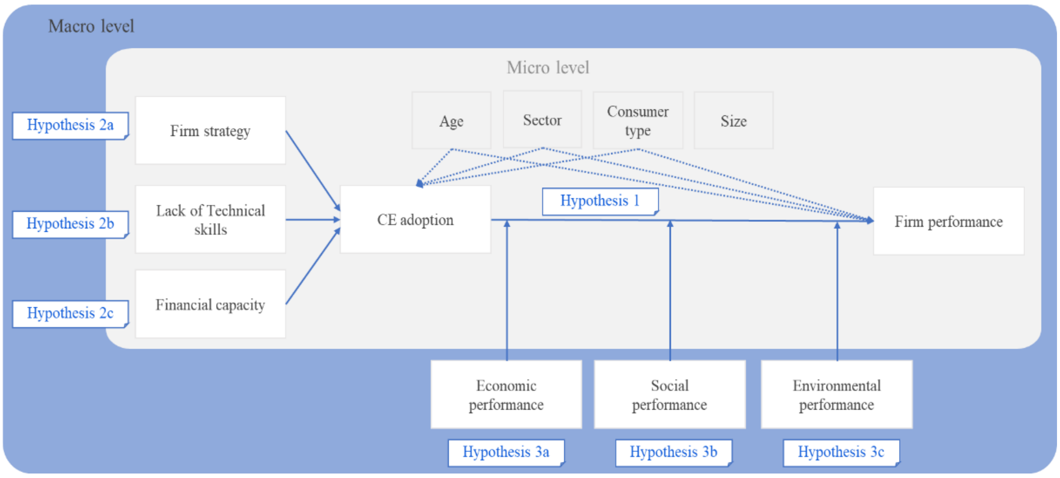


Figure 11: Empirical model

3.4.1. Description of the data

Our empirical analysis uses data from the Flash Eurobarometer 441 (European SMEs and the Circular Economy), survey self-reported by firms that was in 2016 in the 28 EU countries, including 10,618 interviews (European Commission, 2016) to measure the endogenous variables and the micro-level exogenous variables (described in the next section). Despite its limitations in terms of cross-sectional nature (which makes it difficult to establish causal relationships) and its reliance on Flash technology (specifically Computer-Assisted Telephone Interviewing – CATI –, which may introduce respondent biases), the survey we used as baseline encompasses a wide range of questions. These questions serve as the foundation for constructing the variables used in our analysis. Moreover, this data has been used by a significant number of studies (e.g. Bassi & Dias, 2019; Demirel & Danisman, 2019; Ghenţa & Matei, 2018; Kalar et al., 2021; Moric et al., 2020; Zamfir et al., 2017). For this research we disregarded firms that were missing relevant information for our analysis. Hence, our final sample contained 4,550 observations (Supplementary Data 2 – database).

Additional data from 2016 EUROSTAT database was used to measure the exogenous macro-level, or country-level variables of the analysis. To measure the environmental performance the Circular Material Use Rate was used, and the Gross Domestic Product was used to measure economic performance. The social performance was extracted from Human Development Report using the Human Development Index (HDI) from 2016 of the countries in this research.

3.4.2. Model Variable

3.4.2.1. Endogenous variables

Following earlier reports (Delmas & Pekovic, 2018; Friesenbichler & Peneder, 2016; Li, 2020; Moric, Jovanovic, et al., 2020), our dependent variable denoted 'Firm Performance' was reflected as the logarithm of sales per employee (euro). Measuring the productivity, it allows comparisons across countries as it is not influenced by firms' accounting and financing decisions (Li, 2020). The limitations of using this measure include the fact that it does not account for intermediate inputs. Additionally, the availability of this measure for all firms is not guaranteed, and the use of alternative measures (such as value added per employee) may reduce the sample size (Friesenbichler & Peneder, 2016).

The 3R-imperatives of 'reduce, reuse and recycle' are accepted principles of CE, and various R-imperatives are the 'how-to' of CE, and thus one of its core concepts (Kirchherr et al., 2017). The survey used in this study distinguishes five types of activities related to CE: (i) replan the way water is utilized to minimize usage and maximize re-usage, (ii) use of renewable energy, (iii) replan energy usage to minimize consumption, (iv) minimize waste by recycling, reusing, or selling it to another firm, and (v) redesign products and services to minimize the use of materials or use recycled material (European Commission, 2016).

We employ the logic used by Moric et al. (2020) to analyze the circularity activities in the firms, and we create the variable 'CE adopting'. They created four levels of CE adopting: (1) ‘Non-Adopters’ - firms that never planned to implement any activity related to CE; (2) ‘Planners’ - firms that did not implement any of the practices aligned to CE, but are planning to do so; (3) ‘Prospective Adopters’ - firms in the process of implementing at least one the types of activities aligned to CE; and (4) ‘Adopters’ - firms that adopted at least one of type of activities related to CE. We code the variable following this logic: 1, 2, 3 and 4 – according to the classification.

3.4.2.2. Exogenous variables

Concerning micro-level (or firm-level) variables, we previously discussed the influence of the organizational strategy for the firm to adopt the CE activities. We established the variable 'R&D investments', which represents the percentage of a firm's turnover allocated in Research & Development (R&D) activities as the organizational strategy variable, with higher levels indicating a strategic orientation towards differentiation (Yamakawa et al., 2011).

As micro-level variables, to measure the financial capacity of the firm to implement CE projects we also used the variable' Financial capacity', which is a dummy of the necessity of financing access (0) or not (1). Finally, to measure the firm' lack of technical skills' we created a dummy for the firms that declare lack of human resources, lack of competence to implement CE, lack of knowledge about the benefits and necessary investments: if the firm presents some of these issues, then (1); if not, then (0).

Regarding macro-level (or country-level) variables, the economic performance was measured using the logarithm of Gross Domestic Product of each country in the year of 2016: the variable name is defined as 'GDP'. As for the social performance, we used the Human Development Index (named 'HDI') of the same year, by country According to the United Nations Development Programme, the Human Development Index (HDI) is the geometric mean of normalized indexes of the three dimensions: a long and healthy life, being knowledgeable and having a decent standard of living. Finally, for the environmental performance we use the Circular Material Use rate, defined as 'CMU'. The CMU rate is defined as the ratio of the circular use of materials (U) to an indicator of the overall material use (M) (CMU=U/M): The indicator measures the share of material that is recovered and recirculated back in the economy - avoiding extraction of primary raw materials – in relation to the overall material used (European Commission, 2020c). In summary, the Circular Material Use Rate evaluates the proportion of materials that are being kept in circulation and utilized within a closed-loop system, contributing to a more sustainable and efficient use of resources. The moderator variables were created using the product of the mean-centered first-order effect variables (Little et al., 2006).

*(1) CE * GDP = (CE adopting – mean of CE adopting) * (GDP – mean of GDP)*
*(2) CE * HDI = (CE adopting – mean of CE adopting) * (HDI – mean of HDI)*
*(3) CE * CMU = (CE adopting – mean of CE adopting) * (CMU – mean of CMU)*

Finally, we used some control variables: (i) 'Age', which indicates the time frame in which the firm was established; (ii) 'Size', which represents the firm's number of employees; (iii) 'Consumer type', which indicates if a firm sells to firms (B2B), directly to customers (B2C) or both, and; (iv) 'Sector', which distinguishes between four types of sector: manufacturing (NACE category C) retail, service, and industry (NACE categories B/D/E/F).

3.4.3. Endogeneity test

To tackle endogeneity issues, we employed an instrumental variable approach (Instrumental Variable – IV), which consists of a two-step logistic estimation method (2SLS) for our dependent variable. In the first step, our independent variable of interest is regressed into two instrumental variables: *access to information on financing* and *government incentives*. After that, the resulting adjusted probabilities are used in the model. This approach is similar to the two-step least squares approach described by Bascle (2008), the most commonly used IV estimator.

3.5. Results

3.5.1. Sample characterization

Table 8 describes our EU SMEs' sample concerning the number of employees, firm age, percentage of turnover invested in R&D, consumer type, sector, environmental management issues, and financial capacity. Most firms have less than 10 employees (61.6%), started their operations before 2010 (84.8%), belong to retail (32.5%) and service (38.8%) sectors, and more than 75% had less than 5% of their turnover invested in R&D in 2015. Regarding the consumer type, we found that 42% of firms are B2B, most of the companies (63.7%) did not mention environmental management issues and they declare that they do not require financing to implement environmental projects (54%).

Table 8: Sample characterization (N=4,550)

	Non-adopters	Planners	Prospective adopters	Adopters	Total
CE adoption	18.5%	5.5%	20.2%	55.8%	100%
Number of employees					
1 to 9 employees	13.7%	3.7%	11.7%	32.4%	61.6%
10 to 49 employees	3.6%	1.3%	5.2%	14.2%	24.3%
50 to 250 employees	1.3%	0.5%	3.2%	9.0%	14.1%
Date firm established					
After 1 Jan 2015	0.3%	0.2%	0.3%	0.6%	1.3%

From 1 Jan 2010 to 1 Jan 2015	3.0%	0.8%	2.7%	7.3%	13.8%
Before 1 Jan 2010	15.3%	4.6%	17.1%	47.8%	84.8%
Sector					
Manufacturing (NACE category C)	1.4%	0.7%	3.2%	8.5%	14.0%
Retail	5.8%	1.6%	6.6%	18.4%	32.5%
Services	9.1%	2.2%	6.8%	20.6%	38.8%
Industry (NACE categories B/D/E/F)	2.2%	1.0%	3.5%	8.1%	14.8%
Consumer type					
B2C	3.5%	1.3%	3.2%	10.5%	18.5%
B2B	9.5%	2.1%	8.7%	21.7%	42.0%
Both	5.6%	2.2%	8.2%	23.5%	39.6%
Lack of Technical skills					
Not mentioned	11.6%	2.1%	13.4%	36.6%	63.7%
Have some lack	6.9%	3.5%	6.7%	19.1%	36.3%
R&D investments					
Less than 5%	16.1%	4.3%	15.5%	43.2%	79.2%
From 5% to 9.9%	0.9%	0.4%	2.3%	5.3%	9.0%
From 10% to 14.9%	0.6%	0.4%	0.9%	3.2%	5.2%
From 15% to 19.9%	0.0%	0.1%	0.4%	1.4%	2.0%
20% or more	0.9%	0.2%	1.1%	2.5%	4.7%
Financial capacity					
financing necessity	12.7%	4.0%	8.1%	21.2%	46.0%
no financing necessity	5.80%	1.60%	12.10%	34.60%	54.0%

As previously described, the “CE adoption” variable is classified into 4 categories. The category "adopters" represents 55.8% of the sample, meaning it accounts for more than half of the variable. As “CE adoption” is a central variable of the model, we understand that it would be important to add a more detailed description of its distribution. Table 9 and 11 present a more detailed description of the percentage of the type of activities that are adopted and also the amount of activities adopted by the firm.

We can identify that the activity most implemented by companies is "minimize waste by recycling, reusing, or selling it to another firm". This may be because these solutions are more mature and readily available, which makes it easier for companies to implement them. Most of the adopters implemented only one type of CE-related activity.

Table 9: Types of activities

Types of activities related to CE	% Adopters
(i) replan the way water is utilized to minimize usage and maximize re-usage	14.6%
(ii) use of renewable energy	13.9%
(iii) replan energy usage to minimize consumption	29.6%
(iv) minimize waste by recycling, reusing, or selling it to another firm	42.3%
(v) redesign products and services to minimize the use of materials or use recycled material	23.2%

Table 10: Number of activities

Number of activities adopt	% Activities
one of type of activities related to CE	40.7%
two of type of activities related to CE	28.9%
three of type of activities related to CE	17.3%
four of type of activities related to CE	10.2%
five of type of activities related to CE	2.9%

The following table represents the Pearson's correlations among all the variables of the model (Table 11). From an inferential perspective, we conclude that all SME characteristics (age, sector, consumer type and size) are statistically correlated with the CE adoption variable (p-value<0.01), and that the factors R&D investments, environmental management issues and financial capacity are also correlated. The correlation between firm performance and CE adopting shows significance (p-value<0.01). Among the moderating variables, only the moderation of environmental performance (CE*CMU) does not have significance when correlated with firm performance. Nevertheless, it is necessary to test these relations in the proposed model. To verify the multicollinearity of the independent variables, we calculate the VIF: a very common cutoff reference corresponds to a VIF value of 10 (Hair Jr et al., 2018). Our results show a low VIF to the control variables (age: 1,024; sector: 1,021; consumer type: 1,011, and; size: 1,036), as well as to the independent variables (firm strategy: 1,011; technical skills: 1,011; financial capacity: 1,041, and; CE adopting: 1,066). To the moderator variables we identify higher VIF value, but still lower than the cutoff value (CE*CMU: 1,218; CE*GDP: 7,271, and; CE*HDI: 7,244).

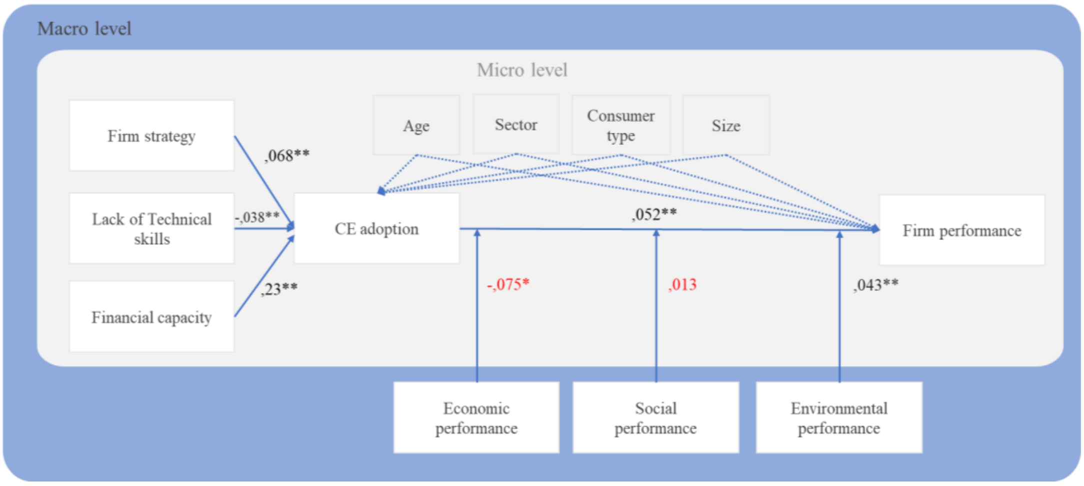
Table 11: Pearson's Correlation matrix

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Firm performance	1	0.109**	-0.027	-0.031*	-0.029	-0.070**	-0.061**	0.014	0.335**	0.316**	0.204**	0.082**	-0.057**	0.041**	-0.072**
2	CE adopting		1	0.056**	-0.054**	-0.237**	-0.066**	-0.046**	0.006	0.179**	0.145**	0.013	0.039**	-0.060**	0.060**	0.139**
3	R&D investments			1	0.054**	0.017	-0.035*	-0.039**	-0.011	-0.031*	-0.017	0.004	-0.036*	0.032*	0.020	-0.014
4	Lack of technical skills				1	0.148**	-0.027	-0.027	-0.014	-0.049**	-0.061**	-0.010	-0.010	0.017	0.034*	0.034*
5	Financial capacity					1	0.044**	0.049**	-0.002	-0.091**	-0.087**	0.010	0.005	-0.002	-0.045**	0.008
6	CE*GDP						1	0.928**	0.443**	-0.077**	-0.082**	-0.050**	0.043**	0.004	-0.038*	-0.013
7	CE*HDI							1	0.469**	-0.082**	-0.072**	-0.034*	0.046**	-0.003	-0.053**	-0.012
8	CE*CMU								1	-0.053**	-0.037*	0.144**	0.024	-0.018	0.007	0.016
9	GDP									1	0.917**	0.400**	-0.011	0.085**	0.037*	-0.067**
10	HDI										1	0.439**	-0.017	0.091**	0.047**	-0.065**
11	CMU											1	0.003	0.028	0.041**	-0.028
12	Age												1	-0.065**	0.001	0.198**
13	Sector														0.081**	-0.083**
14	Consumer type														1	0.049**
15	Size															1

** p < 0.01 (2-tailed)   * p < 0.05 (2-tailed)

3.5.2.
Empirical model results

Consistent with our goal, the results on the relationship between CE and firm performance are presented in Figure 12 and the hypotheses test results are present in Table 12. The adjusted model presents suitable results: Standardized Root mean square residual – RMSEA=0.067 (<0.08) and Standardized Root mean square error of approximation – SRMR = 0.0224 (<0.08). When we compare our model to a null model, the results are a match: Comparative fit index – CFI=0.986 (>0.95). The Squared Multiple Correlations (R^2) for the dependent variable 'Firm performance' is 0.142 and for the explanatory variable 'CE adopting' it is 0.127. R^2 values must be at least 0.10 for an endogenous construct to have its variance appropriately explained (Falk & Miller, 1992). When we run the model using only with the control variable, the R^2 for the dependent variable 'Firm performance' is 0.034 and for the explanatory variable 'CE adopting' it is 0.025, supporting the proposed model.



** p < 0.01 (2-tailed) * p < 0.05 (2-tailed)

Figure 12: Empirical model results

Table 12: Hypothesis test result

Relationship			Std Regression Weight	P	Hypothesis test
CE adoption	<--	Firm strategy	0.068	**	H2a supported
CE adoption	<---	Lack of Technical skills	-0.038	**	H2b supported
CE adoption	<---	Financial capacity	0.230	**	H2c supported
CE adoption	<---	Age	0.010	0.493	-
CE adoption	<---	Sector	-0.066	**	-
CE adoption	<---	Consumer type	0.041	**	-
CE adoption	<---	Size	0.145	**	-
CE adoption	<---	Environmental performance	-0.048	**	-
CE adoption	<---	Economic performance	0.285	**	-
CE adoption	<---	Social performance	-0.092	**	-
Firm performance	<---	CE adoption	0.052	**	H1 supported
Firm performance	<---	Age	0.097	**	-
Firm performance	<---	Size	-0.087	**	-
Firm performance	<---	Consumer type	0.032	*	-
Firm performance	<---	Sector	-0.084	**	-
Firm performance	<---	Environmental performance	0.073	**	-
Firm performance	<---	Economic performance	0.274	**	-
Firm performance	<---	Social performance	0.024	0.496	-
Firm performance	<---	CE * Economic performance	-0.075	*	H3a rejected
Firm performance	<---	CE * Social performance	0.013	0.723	H3b rejected
Firm performance	<---	CE * Environmental perform.	0.043	**	H3c supported

** p < 0.01 (2-tailed)

*   p < 0.05 (2-tailed)

Table 12 demonstrates that the empirical model supports most of the five hypotheses. The regression weight of the Hypothesis 1 is 0.052 (p-value<0.01), while Hypotheses 2a, 2b and 2c present 0.068, -0.038 and 0.230 respectively (all with -value <0.01). The Hypothesis 3a test showed a negative effect (-0.075 with p-value < 0.05) that was not expected, thus it was rejected. The Hypothesis'3b' test presented a regression weight of 0.013, but it does not present statistical significance to this model (p-value = 0.723). Hypothesis 3c, in its turn, was supported with a regression weight of 0.043 (p-value < 0.01). The control variab‘e ''ge' also does not present statistical significance when associated wi‘h 'CE adopt’on', even though it influenc‘s 'Firm performa’ce'. All other relationships presented statistical significance to inferences analysis.

3.5.3. Robustness test

In order to understand whether a different approach in classifying the variable "CE adoption" would result in different results in the model, we ran a robustness test with a new classification. In this new classification, "Adopters" are split into two new categories: (4) adopters of 1 type of activity and (5) adopters of 2 types of activities or more.

The tested model was similar to the result found in the original model: there was no difference in the tested hypotheses.

3.6. Discussion

The results are related to other studies and theoretical literature. The Hypothesis 1 was empirically confirmed in Zamfir et al. (2017) as well, which was one of the few researches that explored the relationship between CE and firm performance. The study of Zamfir et al. (2017) showed that the replanning of water usage, the use of renewable energy, the minimization of the use of materials and the minimization of waste represent choices beneficial for the environment and create improved economic performances.

Moric et al. (2020) showed in their research the influence of the stage of CE implementation on the firm performance, and found that adopters have a higher productivity than prospective adopters, which are, meanwhile, more productive than planners. Our study could add to their research by demonstrating that the firm performance is moderated by the influence of the country's environmental performance (Hypothesis 3c). The efficient use of resources reduces the dependence of the European economy on imports of raw materials (EMF, 2015; Rizos et al., 2016b). With a lower dependency of foreign raw material, the costs of production and management could reduce, leading to an increase on the productivity results for the firms. In addition, Kirchherr et al. (2018) infer that if raw material prices were higher, circular products would be more affordable, which could stimulate the interest of consumers, and increase the firm results.

On the other hand, a county's high economic performance negatively influences the firm performance. According to EMF (2015), the implementation of CE activities could increase the GDP and competitiveness. We can infer with our results (Hypothesis 3a) that high GDP countries have a more intense competitive environment of the firms, which may result in small profit margins for their products and services. The investments necessary to implement the CE activities may pressure the implementor firm's costs, impacting its productivity. The results of the country's social level (Hypothesis 3b) do not present statistical significance to infer its impact on the productivity. Maybe a different proxy, such as consumer culture and lifestyle, could bring different results. Padilla-Rivera et al. (2021) proposed that consumer health and safety were the most relevant social CE indicators based on the literature review and on ranking according to CE experts' value judgments. Adding to this fact, Kirchherr et al. (2018) found that some of the main CE barriers were the lack of consumer interest and the lack of awareness. This means that countries with healthier and safer consumers have a higher environmental conscience.

Another contribution to the research is the result of Hypothesis 2a.: firms with higher R&D investments, which indicates a strategic orientation of differentiation, tend to adopt CE activities more often than other firms, reinforcing the assumption that implementation of circularity involves reorganizing the strategy and industrial process, and that firms with a differentiation strategy have more capacities to these changes. The technical skills are higher in firms with CE activities adoption, as stated in Hypothesis 2b: the higher the lack of technical skills, the lower is the adoption of CE. It indicates that the organization needs to invest in technical skills to implement circularity activities. Neubaum et al. (2004) found that CE adoption is influenced negatively by resources' scarcity and by a concern with survival. This was confirmed in our results for Hypothesis 2c: firms with financial capacity implement CE more often than other firms. This could be explained due to SMEs often facing difficulties in obtaining guarantees to attract the necessary funding from traditional banks (Dervojeda et al., 2014; Hyz, 2011; Rizos et al., 2016b). Besides that, the study of Ghisetti & Montresor (2020) shows that self-financing is more important to implement CE activities than debt financing. In its turn, public financing is in the middle as a fundamental source, reinforcing the importance of a direct support from the government for CE promotion.

Analyzing the influence of control variables, we found similar results compared to other studies: age does not present statistical significance on the CE adoption. This result was also found by Hoogendoorn et al. (2015), which stated that age did not influence environmental practices. Sector, size, and consumer type influence the CE adoption, which was also demonstrated in Zamfir et al. (2017).

Figure 13 and Figure 14 presents the moderation effect. These results show a further step towards research in CE, mainly when we evaluate the interaction between the levels of implementation (macro and micro). The economic and environmental development observed at the macro level can (positively or negatively) influence the micro level's results (firm performance).

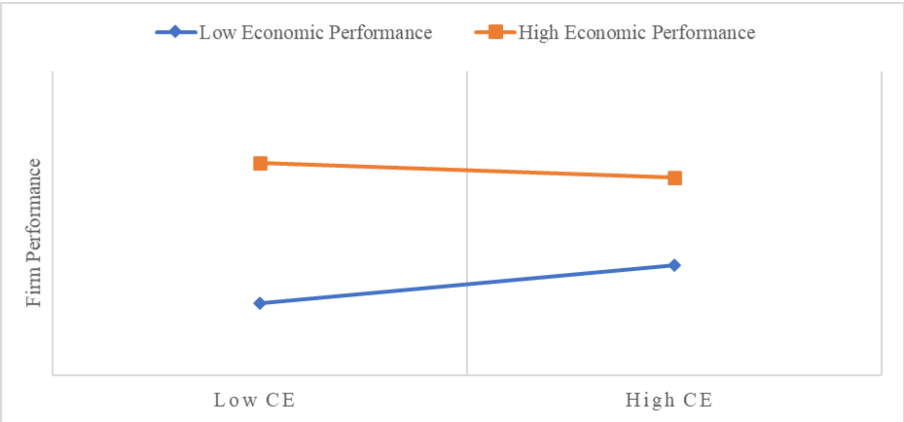


Figure 13: Economic Performance moderation effect

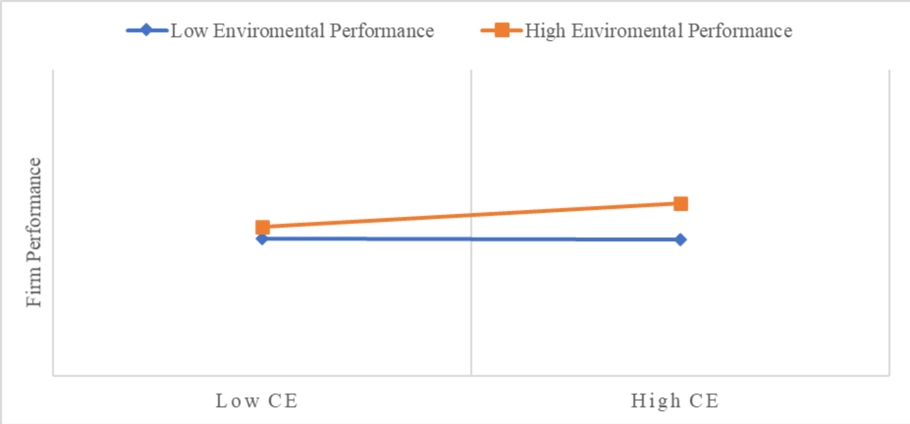


Figure 14: Environmental Performance moderation effect

3.7. Conclusions

Studies on CE exploration have a predominance of qualitative research with a single case; however, like CE is a practice-oriented paradigm, the use of quantitative methodology has become crucial to research articles in this field. This paper could develop CE assessment frameworks and metrics at the country, industry, and firm levels with a quantitative method. This paper examined the relationship between CE adoption and firm performance for SMEs, testing the influence of firm-level or micro-level factors and moderating that relationship with country-level (or macro-level) performance indexes. Applying an empirical model to a sample of 4,550 European SMEs indicated that the country in which they operate could impact the firm performance, influencing companies' decisions to implement CE practices. A management approach for CE development should help understand the conditions for transforming a linear economy into a circular.

By connecting the emerging of CE to the national context, our study highlights the importance of considering the macro-level factors when analyzing the impact of CE adoption on firm performance. The results support the view of some researchers that CE must be proposed with an integrated approach across various implementation levels. The necessity for changing from a linear economic model to a more circular economic solution must go beyond stimulating the increasing CE designing and innovation efforts, in other words, it must go beyond micro-level analysis. It also requires increased investments in this field. Since enterprises are still one of the key players in this transition process, they must be more competent at meeting their needs by supporting relevant investment, infrastructure, technology, and skills plans, especially the small and medium enterprises (European Commission., 2014). We emphasize that our results reveal that the firm location directly influences the results of companies that commit to adopting circularity activities. Once the country's environmental performance could positively contribute to the firm performance, the contribution of its economic performance could be negative when the firm adopts more CE activities. Since CE may perform differently depending on location, copy-pasting solutions will not be effective. Each firm and region should plan based on its own challenges.

Public policies of direct investment, especially in countries with higher economic performance rates where firms operate at a higher level of competitiveness, can improve firm performance indicators and make CE adoption more attractive. Financial support to CE activities may be offered directly by the public sector or via other institutions (e.g., business associations and business development agencies), by different forms, such as grants, tax incentives, loans, or investment guarantees. In addition, countries that already operate with a more present environmental legislation, with better environmental results, also help the firm performance by stimulating a reduction in the cost of raw materials, which makes the adoption of CE more attractive by the economic benefit generated. Therefore some of the main reasons why European SMEs are proactively adopting CE are the savings on material costs, creation competitive advantages, and opening of new markets.

The study has some limitations. For instance, the empirical model used did not contain all possible exogenous variables since it is difficult to represent all the diversity of the indicators that influence the relationships. The use of secondary data also made this study a challenge, as the constructs' development depended on the available data, demanding adaptations. Future research could use the empirical model presented in this study and implement other variables or use new constructs to understand the integration between levels of implementation of CE, utilizing other secondary data or surveys. In this study, we could not account for the influence of the social dimension in the results of firms. This should be addressed in future studies. Some authors have already proposed some indicators that could be more suitable for measuring circularity indexes that are not yet present in the reports from the European Commission, such as the consumer health and safety index.

4
Paper 3 – Within and Outside Industrial Symbiosis Networks: A Study of SMEs Performance

4.1. Abstract

The meso level in the organizational perspective of Circular Economy (CE) refers to the level of corporate synergies and collaborations developed between businesses. Industrial symbiosis (IS) can be implemented at the meso-level to improve resource planning, waste management, and the implementation of circular economy principles. In the absence of IS, intermediaries can help identify cross-sectoral business opportunities for utilizing resources, influencing or disrupting the existing socio-technical *status quo*. This paper investigates the role of intermediaries in engaging European small and medium enterprises (SMEs) in Circular Economy (CE) practices, and the role of the existence of Industrial Symbiosis Networks (ISN) on the SMEs performance. The results supported the hypotheses that ISNs can improve CE adoption and that intermediaries can help SMEs overcome CE barriers. In conclusion, the development of intermediaries and the adoption of CE practices can significantly influence the performance of SMEs and contribute to a sustainable future.

Keywords: Industrial Symbiosis, Circular Economy, Firm Performance

4.2. Introduction

Most studies on circular business models mainly adopt the firm perspective, which is a limitation that needs to be overcome, as noted by Fraccascia et al. (2019). Integrating Circular economy (CE) into business models requires a holistic perspective that takes into account several system components and their interconnections (Evans et al., 2017). Organizations are deeply integrated into a multifaceted and efficient connection, encompassing diverse entities such as stakeholders, government bodies, social actors, facilitators, and firms. Failure to consider these critical elements curtails the comprehension of the origin of value generation and value acquisition for companies that adopt CE. This is the focus of the analysis at the meso level in CE. The meso level in the organizational perspective of Circular Economy (CE) refers to the level of corporate synergies and collaborations developed between businesses. This includes eco-clusters, eco-partnerships, eco-industrial parks, green supply chains, and reverse logistics for the exchange of waste materials, byproducts, and energy (Lanaras-Mamounis et al., 2022). At the meso level, businesses aim to create networks and partnerships that promote the principles of CE and facilitate the circular flow of resources within and between organizations. This level emphasizes the importance of collaboration and cooperation among businesses to achieve sustainable and circular practices (De Lima & Seuring, 2023). Industrial symbiosis (IS) can be implemented at the meso level to improve resource planning, waste management, and the implementation of circular economy principles. The classic concept of industrial symbiosis, defined by Chertow (2007, p.11), involves “physical exchanges of materials, energy, water, and by-products among diversified clusters of firms”. In this concept, the geographic proximity of industries can facilitate the exchange of physical resources and utilities (Shi, 2020). Moreover, being in the same location allows industries to share infrastructures and services more efficiently (Kusch-Brandt, 2020). However, the concept of industrial symbiosis has evolved to encompass more than just physical exchanges. The digital-age interpretation of industrial symbiosis conceptualizes it as the exchange of knowledge to foster eco-innovation through networks of actors (Lombardi & Laybourn, 2012). These exchanges or synergies can occur in different perspectives, such as intra-company, inter-companies, eco-industrial parks, or urban IS (Azevedo et al., 2021). Thus, the potential for industrial symbiosis extends beyond geographic boundaries.

Special attention must be devoted to guaranteeing the complete involvement of Small and Medium Enterprises (SMEs) in the prospects of collaboration and networks. This is due to the findings of Patricio et al (2018), who revealed that the participation of SMEs is associated with the desire of external stakeholders to promote the advancement of such endeavors. These external stakeholders, known as intermediaries, play a crucial role in promoting the CE, especially in contexts where IS is not yet established (Melles, 2023; Moglia et al., 2023; Tseng &

Shang, 2021). They can facilitate the transition to CE by reducing transaction costs, overcoming inertia, streamlining and standardizing processes, and facilitating systemic learning (Moglia et al., 2023). Also, they can connect different players, such as startups, existing businesses, and policy makers, and help them navigate the complexities of transitioning to new business models aligned with CE principles learning (Moglia et al., 2023). In the absence of IS, intermediaries can help identify cross-sectoral business opportunities for utilizing resources, influencing or disrupting the existing socio-technical *status quo* (Melles, 2023).

SMEs are suppliers of components to larger companies or tender for public calls (Taranic et al., 2016) and make up the vast majority of the businesses within the European Union (EU) (Patricio et al., 2018). The European Union recognizes the importance of intermediaries, especially for SMEs, and has implemented incentives to promote their activities (European Commission et al., 2018; Henriques et al., 2022). These incentives are designed to mitigate risks and promote facilitated IS implementation, achieving a replicator effect (Henriques et al., 2022). European cooperation allows the sharing of good practices and new initiatives between States and actors (companies, local authorities, civil society, associations, etc.). By acting as a catalyst for information and creating channels for its transmission between different regions of Europe, the networks built around the circular economy facilitate the sharing of these good practices. (INEC and ORÉE, 2020). Several intermediaries existing structures in the European Union were observed: these could be associations, groups of several existing structures, semi-public entities or online platforms dealing with the subject of circular economy.

The transition to CE requires deep structural change of the entire production-consumption systems. This systemic transition will inevitably be hampered by poor knowledge and resource transfer between various levels of society (Barrie & Kanda, 2020). Therefore, intermediaries play a significant role in the adoption of CE practices by SMEs: they facilitate knowledge exchange, collaboration, and resource transfer, which are crucial for the transition to a CE (Ahmadov et al., 2023; Gennari, 2023). Also, since IS is recognized as a key strategy to support the transition towards the CE, it is important to understand their role to SMEs. Therefore, this article proposes to understand the role of Industrial Symbiosis Networks (ISNs) on SMEs adoption of Circular Economy practices and their effect on performance gains of European SMEs. It also compares the influence of intermediaries in such firms in and out of ISNs.

4.3. Literature review

4.3.1. Industrial symbiosis and CE practices

An industrial symbiosis system is a network of relationships and exchanges (Walls, & Paquin, 2015; Chertow, 2007; Fichtner et al., 2005) that serves as a platform for exploring new opportunities and exploiting existing ones (Alfaro & Miller, 2014). Scholars have often argued that a diversity of actors is necessary to develop IS and ensure that opportunities for exchanges exist (Chertow, 2000) by having an array of resource inputs and outputs, technologies, and processes (Jensen et al, 2012), as well as a diversity of values, worldviews, interests, and preferences (Korhonen, 2005), and a broader potential knowledge base to foster innovation and learning among firms (Boons & Berends, 2001 ; Korhonen, 2001 ; Lombardi & Laybourn, 2012).

According to the 3–2 heuristic logic proposed by Chertow (2007), an industrial symbiosis network (ISN) is defined as a network in which there are at least three different entities exchanging at least two different types of waste. The entities may belong to a single large organization such as an industrial group, may be separate industrial plants of a single company or, in general, may correspond to independent firms. This is consistent with the conceptualization of IS relationship given by Chertow et al. (2000) and Lombardi and Laybourn (2012).

The literature commonly classifies IS networks activity into three main groups: 1) self-organized activity, emerging as the result of direct interaction among industrial actors; 2) facilitated networks, those that have a third party intermediary who coordinates the activity (L. Baas, 2011) and 3) planned networks, which result from a central plan or vision, generally for a specific industrial area, which includes shared infrastructures and services and coordination/promotion of IS exchanges (Domenech, 2019). An ISN can be designed by adopting a top-down approach, such as an eco-industrial park model, that emerge from the bottom as the result of a process undertaken by several firms spontaneously (Chertow & Ehrenfeld,

2012) or it can be the result of a facilitation process driven by a public or private third-party organization (Boons et al., 2011) Within this concept, there are several arrangements for ISN materialization, such as eco-industrial parks (EIP), which is the type of arrangement most associated to ISN in the literature (Huang et al., 2020), virtual IS networks, and industrial ecosystems.

ISN can influence the adoption of circular practices within firms (De Gobbi, 2022; Oughton et al., 2022; Salomone et al., 2020). These circular practices refer to the strategies and actions that companies take to implement CE. These practices aim to keep products and materials in circulation for as long as possible, reducing the need for new resources and minimizing waste. It can be achieved through various methods such as maintenance, reuse, refurbishment, remanufacturing, recycling, and composting (Ellen Macarthur Foundation, 2023). As an example, companies might design products to be easily repaired or recycled, or they might set up systems for recovering and reusing resources from their products (Atasu et al., 2021; Bysong et al., 2023). In addition, circular practices can also involve promoting a sharing economy, where resources are shared among multiple users, further reducing the need for new resources (Bysong et al., 2023). ISN can promote synergies between companies from different sectors, capitalizing on the benefits of implementing CE principles (Atasu et al., 2021)

The SMEs that are interested in developing a CE strategy can benefit from the experiences of existing strategies into ISN. Some sectors, such as steel, construction, and photovoltaic, may have more opportunities for industrial symbiosis than others, due to the nature and quantity of their by-products and waste streams (Akhtar et al., 2022; Branca et al., 2021). For instance, the steel industry in Europe has prioritized the recovery and recycling of by-products, which is in line with the principles of CE Branca et al., (2020). Similarly, the Dutch construction industry aims to implement a CE in the context of using recycled concrete aggregates (Yu et al., 2021). Another example is the photovoltaic (PV) industry, which identifies waste streams as potential raw materials and encourages collaborative interactions among organizations (Mathur et al., 2020). The interaction between actors in mutually beneficial transactions, from both an economic and environmental perspective, can stimulate the mobilization of intangible assets such as intellectual and social capital, ultimately fostering a collaborative and circular culture (Tolstykh et al., 2023). In sectors with established symbiosis, there is a natural tendency towards the implementation of circular practices. This is due to the inherent nature of symbiosis, which promotes cross-sector and cross-cycle collaborations, creating markets for secondary raw materials (European Commission, 2019). The existing networks and relationships within these sectors can often provide the necessary support and guidance for companies to implement circular practices. While it's possible for firms outside IS networks to adopt CE practices, they may face more challenges due to the lack of information, guidance, and support that IS networks provide (Azevedo et al., 2021; Maranesi & De Giovanni, 2020). ISNs often facilitate the sharing of resources, knowledge, and innovations among firms, which can significantly ease the transition to a circular economy. Without this network support, firms may struggle to identify opportunities for resource optimization, face difficulties in implementing new processes, and lack the necessary expertise to overcome technical challenge. Thus, we hypothesize that

Hypothesis 1: SMEs inside a local sector ISN adopt more CE practices than SMEs outside a local sector ISN.

4.3.2. CE and performance

A circular economy is a model of production and consumption that involves sharing, leasing, reusing, repairing, refurbishing, and recycling existing materials and products for as long as possible. This approach minimizes the use of the world's resources, reduces waste, and cuts carbon emissions. Products are kept in use for as long as possible, through repairing, recycling, and redesign. At the end of a product's life, the materials used to make it are kept in the economy and reused wherever possible (Masterson & Shine, 2022). Transitioning to a circular economy can have numerous benefits, including creating jobs across industrial sectors, saving on material costs for fast-moving consumer goods, and growing the economy (Schindler, 2021). Creating a circular business model can be challenging, but success depends on choosing a strategy that aligns with the company's capabilities and resources (Atasu et al., 2021). Once these circular practices are adopted, they can have a significant impact on firm performance (Del Giudice et al., 2021a; S. A. R. Khan, Umar, et al., 2022; Mazzucchelli et al., 2022a; Moric, Jovanović, et al., 2020; Pan et al., 2023). Chen & Dagestani (2023) have found that CE practices have a substantial positive impact on the performance of small companies. These practices can enhance firm performance, with the positive impact being further amplified by innovation and digital transformation strategies (Mora-Contreras et al., 2023)

The adoption of circular practices by SMEs can significantly influence their financial performance. By implementing strategies that minimize waste and maximize the use of resources, SMEs can reduce operational costs. This is achieved through efficient use of materials, energy, and water, which not only cuts costs but also reduces the firm's environmental footprint (de Jong & Wagensveld, 2023). Moreover, circular practices open up new avenues for revenue generation. By creating new products from waste or offering services that extend the lifecycle of a product, SMEs can tap into new markets and customer segments. For instance, offering a product-as-a-service is a popular circular strategy that provides continuous revenue streams (OECD, 2023b). In addition to cost savings and increased revenues, circular practices can enhance a firm's reputation. Consumers today are more conscious about the environmental impact of the products they use. Therefore, firms that demonstrate a commitment to sustainable practices are likely to attract these environmentally conscious consumers, thereby improving their market standing and brand value (Kwarteng et al., 2022). Lastly, circular practices can help mitigate various risks associated with regulatory compliance, market volatility, and environmental factors. By adhering to environmental standards and diversifying their supply chains, SMEs can build resilience against market shocks and regulatory changes (Manea et al., 2021). Mattos et al. (2022) applied a tool to evaluate financial impacts in the context of transitioning to a circular economy. The framework was applied in a real case, revealing employment generation, environmental cost reduction, and CO2 emissions reduction.

Notice that while ISN can facilitate the adoption of circular practices, the increase in the firm performance is primarily driven by the implementation of these circular practices, not by the ISN itself. ISN is a pathway towards the adoption of circular practices, but the practices themselves are what drive performance improvements. Therefore, it is expected that SMEs that already adopt CE practices will have an improvement in performance regardless of the means by which they aim to implement them. Thus, we hypothesize that:

Hypothesis 2: The adoption of CE practices influences positively the performance of SMEs independently of their participation in a local sector ISN.

4.3.3. The role of intermediaries

The concept of intermediaries was primarily used in the field of innovation management, dating back to the 1990s (Bessant & Rush, 1995). Its related variants are *middle actors, hybrid organizations, boundary spanners, change agents* and *brokers*. Intermediaries are assigned multiple roles in different processes, including stimulating innovation, supporting eco-innovation (Kanda et al., 2018), and facilitating transitions (Kivimaa et al., 2019). By connecting new entrants and incumbents, as well as their associated activities, skills, and resources, intermediaries can have a catalyzing effect on sustainability transitions. They can generate momentum for change, foster new collaborations centered around niche innovations, ideas, and markets, and disrupt prevailing socio-technical regimes (Kivimaa, 2014).

Some types of intermediaries include municipalities, business association, or brokers, as well as nongovernmental organizations (NGOs), steering committees or advisory boards, regional programs, and so on. These actors emphasize interorganizational cooperation and communication flows (Vernay et al., 2013) rather than physical flows. Europe has some examples of intermediaries in industrial symbiosis, such the *International Synergies*, a private company that provides IS consultancy and software solutions to various sectors and regions. It has developed the NISP® (National Industrial Symbiosis Programme) model, which has been applied in more than 30 countries. It also operates the SYNERGie® software platform, which enables online identification and tracking of industrial symbiosis opportunities (Azevedo et al., 2021a). Another example is the *CircLean Network*, an European network of businesses and other stakeholders that aims to promote and support industrial symbiosis as a driver for CE. It provides tools and guidelines for measuring and reporting the benefits of industrial symbiosis, as well as a platform for sharing best practices and experiences. It also organizes events and workshops to foster collaboration and learning among members (INTERREG, 2020). It also has the *Symbiosis Center Denmark*, a non-profit organization that supports the development and dissemination of industrial symbiosis in Denmark and abroad; it offers services such as mapping of resource flows, matchmaking of potential partners, project management, and training; it also manages the Kalundborg Symbiosis, one of the oldest and most well-known industrial symbiosis networks in the world (Capucha et al., 2023).

Intermediaries in sectors without well-established ISNs are vital for the adoption of CE practices. With intermediaries in a network: (1) companies are more likely to consider exchange in the first place (Paquin & Howard-Grenville, 2009); (2) the collaboration process is shortened, saving time and costs that would otherwise be incurred through hiring (Doménech & Davies, 2011); and (3) opportunistic and free-riding behavior is reduced (L. W. Baas & Huisingh, 2008; Lombardi et al., 2012). The facilitation provided by intermediaries could foster an ideal environment for the integration of circular strategies within smaller business entities. While all businesses can benefit from the support of intermediaries in their CE transition, SMEs in particular may require more intervention due to their unique challenges (Ahmadov et al., 2023; Gennari, 2023).

As the lack of information about potential partners hinder the adoption of green or CE practices (O. Khan et al., 2021), the presence of intermediaries could be especially beneficial for SMEs in sectors without established local ISN. They offer valuable resources and information that facilitate capacity building and innovation within them, for example, organizing events that bring together stakeholders from various industries to exchange knowledge and explore collaboration opportunities. (Shou et al., 2013). Intermediaries serve as strategic partners by providing market knowledge, recognition, and cost reduction, thereby aiding in the expansion of SMEs (Efrat & Øyna, 2021). Networking activities with intermediaries can influence SMEs' willingness to establish networks (Deschamps et al., 2013). These intermediaries can act as catalysts, facilitating the shift from traditional linear models to more sustainable, circular ones. With expertise in sustainable strategies, intermediaries educate businesses about the benefits of ISNs and CE practices. They stimulate new business relationships by facilitating cooperation among industry players, serving as a bridge between businesses, identifying potential synergies where one company's waste can be another's resource This also can lead to innovative collaborations and partnerships that drive the CE transition. They can help businesses reimagine their models to align with CE principles and they help navigate the complexities of this transition and drive the adoption of sustainable practices across various sectors. Thus, we hypothesize that:

Hypothesis 3: The presence of intermediaries positively influences the adoption of circular practices in SMEs out of local sector ISNs.

The model presented in
Figure 15 illustrate the proposed hypotheses. The influence of intermediates at the meso level on the direct impact of CE adoption is more significant on 'No ISN' compared to 'ISN' at the meso level. Additionally, the relationship between meso level and firm performance is indirectly mediated by CE Adoption. In sectors where a local ISN is present, the level of CE adoption tends to be higher. The control variables encompass micro-level factors such as age, consumer type, and size, as well as macro-level factors including country Economic Performance, Social Performance, and Environmental Performance. These variables have been established as significant in previous research (Moric, Jovanovic, et al., 2020; Rosa & Paula, 2023).

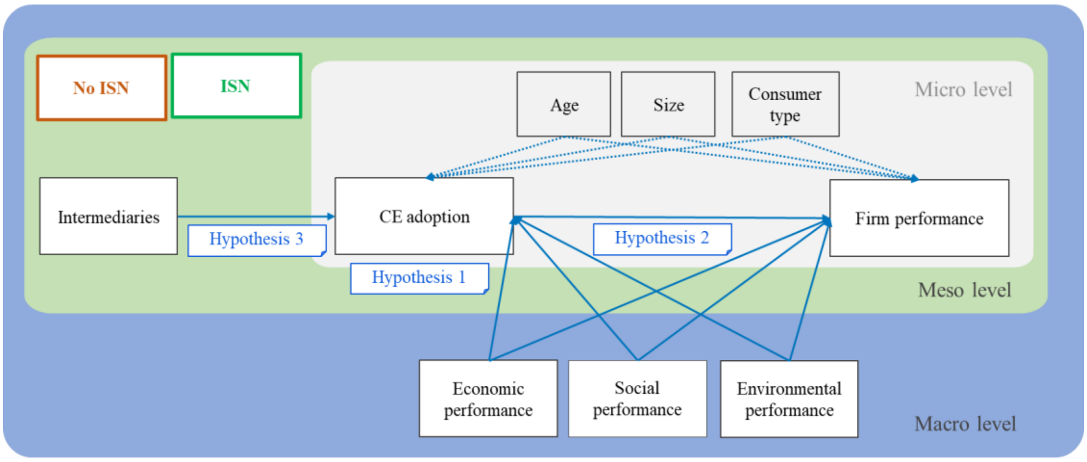


Figure 15: Empirical model

4.4. Method

4.4.1. Data collection and sample

This study employed secondary data sources from various public and private institutions, such as census, surveys, and reports. However, a database had to be implemented with additional information, due to the lack of a complete one that satisfied the research criteria.

Our empirical analysis utilizes data from the Flash Eurobarometer 441 (European SMEs and the Circular Economy), a survey conducted in 2016 across the 28 EU countries. The survey consisted of 10,618 interviews (European Commission, 2016) and served as a means to estimate the micro-level variables. In order to ensure the accuracy of our analysis, we excluded firms that lacked pertinent information, resulting in a final sample size of 4,550 observations. For the measurement of macro-level or country-level variables, additional data from the 2016 EUROSTAT database was employed (European Commission, 2016). The Circular Material Use Rate (CMU) was utilized to estimate environmental performance: CMU is defined as the ratio of the circular use of materials to the overall material use. It measures the share of material recovered and fed back into the economy, thus saving extraction of primary raw materials. While economic performance was measured through the use of “Final consumption expenditure” (FCE): Final Consumption Expenditure of households and non-profit institutions serving households (NPISHs) is a significant component of a country’s GDP. The social performance aspect was derived from the data “Persons employed in circular economy sectors” in 2016 for the countries included in this study.

There are mainly three different types of databases connected to Industrial Symbiosis implementation or facilitation, and more broadly speaking to waste management practices, that are available in literature: (i) databases containing information related to waste available or resources required in a defined geographical area; (ii) databases containing information related to waste management products and services available in a defined geographical area; (iii) databases containing information regarding existing synergies and Industrial Symbiosis case studies.

The analysis required finding surveys and databases that provide information on the symbiosis situation in Europe (meso-level). In the existing literature, there is few data that identify the synergies and the intermediaries for industrial symbiosis in Europe. Some reports and surveys are able to partially capture this data. We found a combination of secondary data sources: i) Domenech et al. (2019) ii) Massard G. et al. (2014); iii) ECSPP (2023); iv) INEC & ORÉE (2020) and v) Interreg Europe, (2023).

Domenech et al (2019) made an analysis based on a combination of desk research, gathering of primary data from case studies, a survey to IS network facilitators (n=22) and in-depth interviews and focus groups (3) with IS practitioners, policy officers and industry representatives (n=25). The analysis identified clusters of IS activity across all Europe. The results provided a descriptive mapping of IS in Europe and identified key characteristics of IS networks. These characteristics include: *Network country, name, size, type and scope; Number of synergies; Economic, Social and Environmental benefits and also the references of these research.*

The study of Massard (2014) developed an international survey by using a set of eco-criteria, and one of the objectives was to present a detailed overview of spatially located eco-innovation experiences for a large selection of European and non-European countries trying to develop integrated systems and establish cooperation linkages among different partners in a defined area. The report details the case study descriptors and provides information describing each case study: for each of the 27 countries, the national framework regarding spatially located eco-innovation is described and detailed. The description includes: *Eco Park country, name, region, type, size and status; Eco-criteria; Project leaders*; *Origin*; *Objectives*; Success factors; *Perspectives* and also the *references of these cases.*

Another study is a publication that resulted of the cooperation between INEC and ORÉE: “Major Circular Economy Networks in Europe”. The study systematically identifies and details the major players in the circular economy in Europe with the aim of strengthening cohesion between key players in the sector. The details include: *Player name; country*; *year of establishment; Statute; Targets; Mission; Means of actions; Main studies; Main horizontal topics* and *Sectors.*

Two databases were used, beside the reports: ECSPP (2023) and Interreg Europe (2023). The European Chemical Site Promotion Platform (ECSPP) is a forum that promotes investment in Europe's integrated, innovative, and competitive chemical industrial complexes. The ECSPP's database of chemical parks is a comprehensive resource that provides details about chemical parks, clusters, and parks across Europe. This includes information about the area, free space, city, and country of each park. Interreg is one of the key instruments of the European Union (EU) supporting cooperation across borders through project funding. The Interreg database of programs and projects is a resource that provides access to information about all Interreg programs, a database of cross-border, transnational, and interregional cooperation programs.

These sources differed in scope, methodology, and format, so it was essential to catalog and standardize the data in a consistent way. This process involved cleaning data, transforming, merging, and aggregating the data according to the research objectives and criteria. The micro and macro level database is available for all EU just for 2016. This means that we had to exclude the symbiosis that was established after 2016, to improve the coherence of our analysis. We merged the data by identifying some common information in each source. Table 13 present the merged data sources. The columns present the information extracted from each data source, for example: the actors involved in the network were identified in Domenech et al (2019) in their study as "network name"; in INEC & ORÉE (2010), they were identified as "Player name". For the missing information, we conducted additional research on the web page of the actors, reports about the specific actor, and other relevant sources (identified as "Researched in other sources" in Table 13**Erro! Fonte de referência não encontrada.**. We also used the Interreg Europe (2023) to identify relevant projects on two topics: Clustering and economic cooperation; and Institutional cooperation and cooperation networks. The search criteria included projects from two periods: 2000-2006 and 2007-2013. Only projects that started before 2016 were selected for the analysis.

The final database, after cleaning, merge and aggregate data, presents 186 cases of ISNs. In the unified database, we able to identify: 1) actors involved; 2) type of actors; 3) actor objective; 4) countries, 5) year of establishment; 6) if the actor has SME focus and 7) directly affected sector (NACE category).

Table 13: Merging data

Source	Actors involved	Type of actor	Actor objective	Countries	Year	SME focus	Direct sectors (NACE)
Domenech et al. (2019)	Network name	Researched in other sources	Researched in other sources	Country	Researched in other sources	Researched in other sources	Reference
INEC & ORÉE (2020)	Player name	Description	Description	Country	Year of establishment	Researched in other sources	Sectors
Massard G. et al. (2014)	Eco Park name	Origin	Type of park	Country	Status/ Researched by author	Researched in other sources	Objectives / Reference
ECSPP (2023)	Name	About	About	Country	Researched in other sources	Researched in other sources	Segments
Interreg Europe (2023)	Name	Researched in other sources	Description	Description	Start date	Description	Description

4.4.2. Measurement scales

After obtaining a unified dataset, the next step is to develop the measurement that will capture the symbiose. Measuring symbiosis as a continuous variable, which indicates the degree or intensity of the exchanges of materials, energy and information among different industries, is challenging, mainly due to the complexity of gathering information about the outcomes of symbiosis (Azevedo et al., 2021; Kosmol & Esswein, 2018; Vostinar et al., 2021; Wadström et al., 2021). In this study, we will consider Industrial Symbiosis Network as a categorical variable, which indicates whether there are exchanges among different industries or not, and we will use a dummy variable to represent it. We define the existence of at least one symbiosis agent (eco park, player, smart city, etc.) in that sector of a given country as a proxy for symbiosis**.** Therefore, to analyze the impact of symbiosis, we will use a dummy variable that is equal to 1 if there is ISN and 0 if there is not, for each sector of different countries. The dummy variable will allow us to compare the groups with and without symbiosis, being controlled by other variables (Azevedo et al., 2021; Fraccascia & Giannoccaro, 2020). We decided to use symbiosis by sector/country instead of by region, as the data availability and quality for the regional level is very limited (Akhtar et al., 2022; Azevedo et al., 2021; Vahidzadeh et al., 2021).

Table 14: Definition of variables

Level	Variables	Definition
Micro	Firm performance	Logarithm of total annual sales per employee
	CE adopting	Level of CE adopting: (1) Non-adopters (2) Planners (3) Prospective adopters (4) Adopters
	Age	The firm was established: (1) After 1 January 2015 (2) Between 1 January 2010 and 1 January 2015 (3) Before 1 January 2010.
	Consumer type	(1) B2C (2) B2B (3) Both
	Size	1 to 9 employees 10 to 49 employees 50 to 250 employees
Meso	Intermediaries	(1) At least one intermediary (sector/country) (0) No intermediaries (sector/country)
	Industrial Symbiosis Network	(1) At least one symbiosis agent (sector/country) (0) No symbiosis agent (sector/country)
Macro	Environmental performance	Circular material use rate
	Economic performance	Final consumption expenditure of households and non-profit institutions serving households (% of GDP)
	Social performance	Persons employed in circular economy sectors (% of total employment)

Table 14 presents the variables that are used in the study to measure the impact of circular economy (CE) adoption on firm performance at different levels of analysis. The “Level” column indicates the level of aggregation of the variables, which can be micro, meso, or macro. The micro level refers to the individual firm level, where the dependent variable is the firm performance, measured by the logarithm of total annual sales per employee, according to Moric et al. (2020). The variable CE adopting, which was measured by the level of CE adoption of the firm, can be non-adopters, planners, prospective adopters, or adopters, following the logic used by Moric et al. (2020). The control variables at this level are the age, the consumer type, and the size of the firm. Age indicates the time frame in which the firm was established; size represents the number of employees of the firm; consumer type indicates whether a firm sells to firms (B2B), directly to customers (B2C), or both, following Rosa and Paula (2023).

At the meso level, the variables are the intermediaries measured by the presence or absence of at least one intermediary and the variable ISN was measured by the presence or absence of at least one symbiosis agent in the sector/country. The intermediaries are the actors that facilitate the CE adoption by providing information, guidance, or support to the firms. The symbiosis agents are the actors that enable the exchanges of materials, energy, and information among different industries.

The macro level refers to the country level, where the independent variables are the environmental, economic, and social performance, measured by the circular material use rate (CMU), the final consumption expenditure of households and non-profit institutions serving households as a percentage of GDP (NPISHs), and the persons employed in circular economy sectors as a percentage of total employment, respectively. CMU was used as an environmental variable in the Oliveira Rosa & de Oliveira Paula (2023) study with positive effect of moderation. The Final consumption expenditure can provide insights into the economic health of a country. For instance, a high percentage might indicate a strong domestic demand, which can drive economic growth. High levels of consumption can indicate a strong economy, as it suggests that people have enough income to spend (OECD, 2023a). And persons employed in circular economy sectors reflects the contribution of the circular economy to job creation and human development. It can show how transitioning to a circular economy can lead to “green jobs” or jobs that contribute to preserving or restoring the environment (Balch, 2011).

4.4.3. Statistical Methods

We used a multigroup moderation analysis, which is a statistical technique used to examine differences in relationships between variables across different groups. The technique involves comparing the strength and significance of relationships between variables across different groups to determine if there are any significant differences. Multigroup moderation analysis can provide valuable insights into how variables interact and influence outcomes differently across several groups (Srisathan et al., 2023). We used three different tests in the multigroup analysis: ANOVA (for H1), and path analysis method and bootstrap (for H2 and H3). ANOVA tests the hypothesis that the means of two or more populations are equal, generalizing the t-test to more than two groups. If no real difference exists between the tested groups, which is called the null hypothesis, the result of the ANOVA’s F-ratio statistic will be close to 1. Bootstrap is a statistical method for estimating the sampling distribution of an estimator by resampling with replacement from the original sample. Bootstrap in AMOS can be used to evaluate model fit and individual parameter estimates (Nevitt & Hancock, 2001). The path analysis method, an extension of the regression model, was employed to test the model and hypotheses (Garson, 2013). Path analysis is a methodology used to disentangle direct and indirect causal effects. It involves decomposing correlation coefficients and estimating path coefficients to examine the effects of variables on each other (Zhou et al., 2023). The observed correlation matrix of the variables was compared to the regression weights predicted by the model, and a goodness-of-fit statistic was computed. Subsequently, the most optimal model was selected to facilitate theory development (Garson, 2013). Additionally, path analysis can be used to test for mediation and moderation, capturing the dependent nature of relationships and reducing the reliance on individual regressions (Silva et al., 2021).

4.5. Results

4.5.1. Sample characterization

Table 15 describes our EU SMEs' sample related to the number of employees, firm age, consumer type. Most firms have less than 10 employees (61.6%) and started their operations before 2010 (84.8%). Regarding the consumer type, we found that 42% of firms are B2B. The majority of the SMEs (55.8%) are adopters, followed by prospective adopters (20.2%), non-adopters (18.5%), and planners (5.5%). More than half of the SMEs (65.3%) have at least one intermediary in their sector, while the rest (34.7%) have none. A slight majority of the SMEs (56.3%) have at least one symbiosis agent in their sector, while the remaining (43.7%) have none.

Table 15: Sample characterization (n=4550)

Variables	Definition	Frequency
CE adopting	(1) Non-adopters	18.5%
	(2) Planners	5.5%
	(3) Prospective adopters	20.2%
	(4) Adopters	55.8%

Age	(1) After 1 January 2015 (2) Between 1 January 2010 and 1 January 2015 (3) Before 1 January 2010.	1.3% 13.8% 84.8%
Consumer type	(1) B2C (2) B2B (3) Both	18.5% 42.0% 39.6%
Size	1 to 9 employees 10 to 49 employees 50 to 250 employees	61.6% 24.3% 14.1%
Intermediaries	(1) At least one intermediary (sector/country) (0) No intermediaries (sector/country)	65.3% 34.7%
Industrial Symbiosis Network	(1) At least one symbiosis agent (sector/country) (0) No symbiosis agent (sector/country)	56.3% 43.7%

Table 16 shows the Pearson's correlations among all the metric variables of the model and a chi-square test for the correlations of categorical variables. The chi-square test results indicate that there is statistically significant relationship between the existence of intermediaries and the existence of industrial symbiosis (chi-square with one degree of freedom = 1112.1, p = 0.000). The results indicate that CE adoption and firm performance are positively and significantly correlated (0.173, p < 0.01). They also have positive and significant correlations with ISN and intermediaries, suggesting that these variables are associated with the adoption of circular economy and the financial performance of the firms. On the other hand, the macro variables (economic performance, social performance and environmental performance) have mixed correlations with CE adopting and firm performance, with some being negative and significant and others being positive and significant. These correlations imply that the macro variables may have different effects on the circular economy and the firm performance, depending on the context and the measurement. To check the multicollinearity of the independent variables, we compute the variance inflation factor (VIF), which measures how much the variance of a regression coefficient is inflated due to the presence of collinearity. A common rule of thumb is that a VIF value above 10 indicates a serious multicollinearity problem (Hair Jr et al., 2018). Our results show that all the independent variables have low VIF values, ranging from 1.008 to 1.450, which means that there is no multicollinearity issue in our data.

Table 16: Pearson's Correlation matrix

		1	2	3	4	5	6	7	8	9	10	VIF
1	Size	1	.129**	.030*	.109**	.399**	.035*	.032*	.020	-.008	-.016	1.033
2	Age		1	.002	.039**	.190**	-.011	.004	.010	.004	.006	1.018
3	Consumer type			1	.060**	.066**	-.031*	-.005	.024	-.041**	-.006	1.008
4	CE adopting				1	.173**	-.085**	-.130**	.051**	.128**	.128**	1.048
5	Firm performance					1	-.120**	-.086**	.142**	.023	.111**	
6	Economic performance						1	.408**	-.230**	-.062**	-.181**	1.266
7	Social performance							1	-.176**	-.353**	-.390**	1.450
8	Environmental performance								1	.196**	.184**	1.101
9	Industrial Symbiosis									1	.494**	1.429
10	Intermediaries										1	1.440

** p < 0.01 (2-tailed)

* p < 0.05 (2-tailed)

4.5.2. Empirical model results

Figure 16 and Figure 17 show the structural equation model and the path coefficients for the hypotheses.

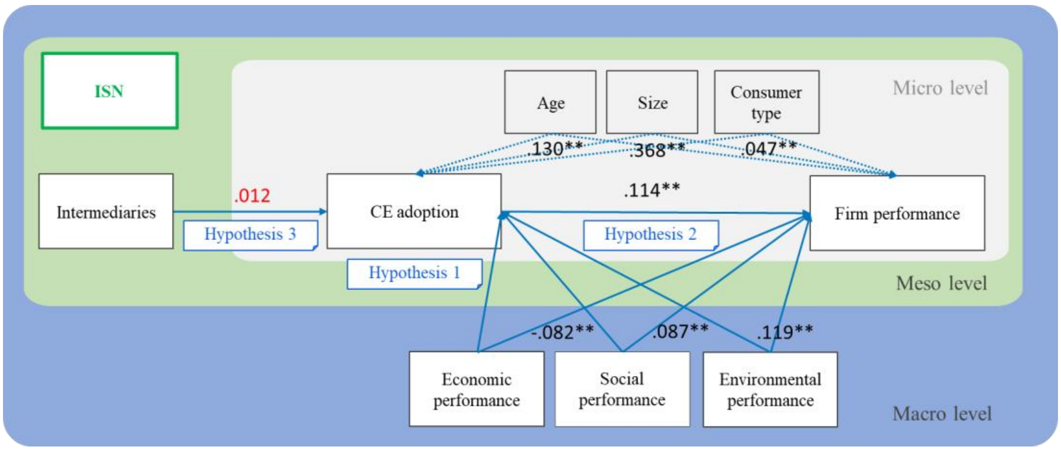


Figure 16: Empirical model results for ISN group

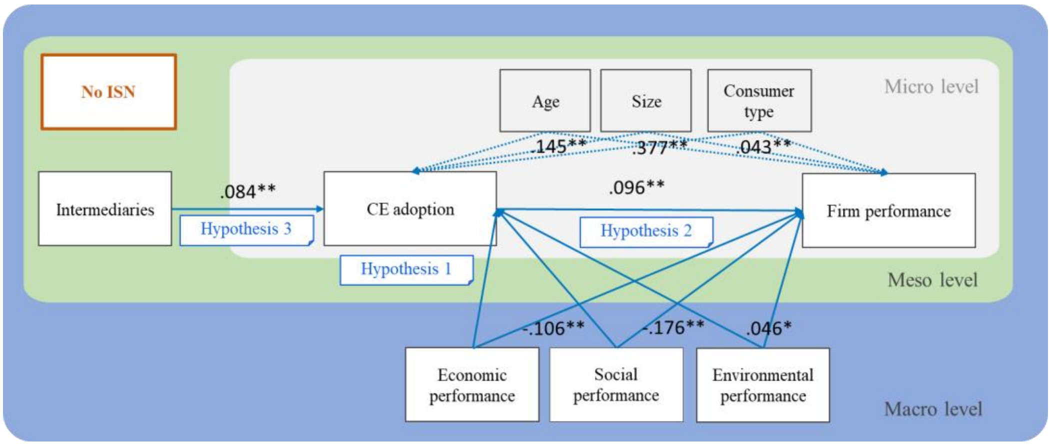


Figure 17: Empirical model results for No ISN group

Table 17 reports the results of the hypotheses testing and the model fit indexes. The model has a good fit to the data, as indicated by the low value of the root mean square error of approximation (RMSEA = 0.029, < 0.08) and the high value of the comparative fit index (CFI = 0.998, > 0.95), which are both within the recommended thresholds. The model explains 22% of the variance in the dependent variable 'Firm performance', which is above the minimum level of 10% suggested by Falk and Miller (1992). When we compare the model with the control variables only, the explained variance drops to 19.3%, which supports the relevance of the proposed model. The path coefficients show the direction and the significance of the causal relationships among the variables. The details of the hypotheses testing are discussed in the next section.

For the multigroup analysis, the model is tested with different levels of constraints on the parameters, such as the structural weights, intercepts, means, covariances, and residuals. The model fit was assessed by using the chi-square statistic (CMIN), the degrees of freedom (DF), and the p-value (P) of each constrained model, and comparing them with the unconstrained model, which is assumed to be the correct one. The results show that the model fit deteriorates as more constraints are imposed, as indicated by the increase in CMIN, the decrease in DF, and the decrease in P. The fit indexes also decrease as the constraints increase, moving away from 1. This implies that there are significant differences between the two groups and the adoption of circular practices and the firm performance are affected by different factors and have different outcomes depending on the presence or absence of symbiotic agents in the sector. The specific differences are discussed in the following paragraphs.

Table 17: Hypothesis test result

			Industrial symbiosis group		No industrial symbiosis group		
			Std Regression Weight	**P**	**Std Regression Weight**	**P**	**Hypothesis test**
CE adopting	<---	Age	.026	.184	.021	.340	-
CE adopting	<---	Consumer type	.060	***	.059	***	-
CE adopting	<---	Size	.101	***	.122	***	-
CE adopting	<---	Intermediaries	.012	.528	.084	***	H3 supported
CE adopting	<---	Economic performance	-.049	**	-.046	*	-
CE adopting	<---	Social performance	-.044	**	-.049	*	-
CE adopting	<---	Environmental performance	-.015	.444	.039	*	-
Firm performance	<---	CE adopting	.114	***	.096	***	H2 supported
Firm performance	<---	Age	.130	***	.145	***	-
Firm performance	<---	Consumer type	.047	***	.043	**	-
Firm performance	<---	Size	.368	***	.377	***	-
Firm performance	<---	Economic performance	-.082	***	-.106	***	-
Firm performance	<---	Social performance	.087	***	-.176	***	-
Firm performance	<---	Environmental performance	.119	***	.046	**	-

*** $p < 0.01$ (2-tailed)
** $p < 0.05$ (2-tailed)
*$p < 0.1$ (2-tailed)

A one-way ANOVA was conducted to test the Hypothesis 1. The results indicated a statistically significant difference between the groups with ISN and without ISN ($F(1, 4551) = 75.269$, $p < .001$). The descriptive statistics revealed that for the group without ISN (N = 1,989), the mean was 2.96 (SD = 1.183). For the group with ISN (N = 2,564), the mean was 3.26 (SD = 1.119). These results support the

Hypothesis 1: SMEs inside a local sector ISN adopt more CE practices than SMEs outside a local sector ISN.

Despite Table 17 showing that the weight for the relationship between circular practice adoption and SMEs performance is higher for the ISN group (.114) than for the no ISN group (.096), and both are significant at the 0.01 level, the results of the bootstrap test shows that the confidence intervals for the effect of CE adoption on firm performance overlap for the two groups (with ISN: [0.063, 0.115], without ISN: [0.040, 0.086]). This overlap suggests that the difference in the effects between the two groups is not statistically significant at the chosen confidence level. In other words, while the point estimates of the effects are different (the effect is larger in the group with ISN), the statistical uncertainty associated with these estimates (as represented by the confidence intervals) is large enough that we cannot rule out the possibility that the true effects in the two groups are the same. Thus, the test supported Hypothesis 2: The adoption of CE practices influences positively the performance of SMEs independently of their participation in a local sector IS.

The results also indicate that the presence of symbiotic intermediaries positively influences the adoption of circular practices in SMEs, and this effect is only significant for the no ISN group, and not for the industrial symbiosis network group (p=.528), thus Hypothesis 3 was supported as well. We can conclude that the presence of intermediaries positively influence the adoption of circular practices in SMEs in sectors without local ISN.

Table 17 shows that the micro level control variables (consumer type and size) have positive and significant effects on CE adopting for both groups, indicating that B2B firms and larger firms are more likely to adopt CE practices. Moreover, age, consumer type and size have positive and significant effects on firm performance for both groups, indicating that older firms, B2B firms, larger firms have better firm performance.

Finally, the results reveal, for the macro level control variables, that the economic performance has a negative effect on the firm performance, indicating that SMEs in countries with higher economic performance achieve less firm performance on both groups. Social performance has a negative effect on the firm performance in the group with no ISN, and a positive effect in the group with ISN. Environmental performance has a positive effect on both groups, implying that SMEs in countries with higher environmental performance influence their firm performance. All these effects are significant at the 0.05 level or lower.

4.6. Discussion

We tested three hypotheses related to the role of intermediaries and industrial symbiosis networks in the adoption of circular practices by SMEs and their impact on firm performance. Hypothesis 1 was supported by the results: the adoption of circular practices is influenced by the existence of ISN. SMEs may wait for others to make a move before acting due to several reasons: for instance, SMEs may lack resources, making them reluctant to join attention-intensive partnerships, even if the potential return can be substantial. In sectors with local ISN, SMEs may have more opportunities for partnerships and collaborations, which can make it easier for them to make a move. Indeed, sectors with a local ISN provide a conducive environment for SMEs to engage in partnerships and collaborations (Azevedo et al., 2021a; Florencio de Souza et al., 2020). These networks facilitate the sharing of resources, such as materials, energy, and information, which can be particularly beneficial for SMEs looking to transition to CE (Yazan et al., 2022). In a CE, the focus is on sustainability and the efficient use of resources by minimizing waste and maximizing the reuse and recycling of materials (Yazan et al., 2022). ISN can support SMEs in this transition by providing access to a network of companies that can exchange by-products and share services, leading to cost savings and innovation opportunities (Symbiosis Center Denmark, 2020). This collaborative approach not only helps SMEs to overcome the challenges associated with resource management but it also aligns with the broader goals of environmental sustainability and economic resilience (Salomone et al., 2020).

Hypothesis 2 also was supported: the adoption of CE practices influences positively the performance of SMEs independently of their participation in an ISN. Notice that H1 supported that ISN can facilitate the adoption of circular practices, however H2 shows that the increase in the firm performance is primarily driven by the adoption of these circular practices, not ISN itself. ISN is a pathway towards the adoption of circular practices, but the practices themselves are what drive performance improvements – which infers that the performance of a firm depends on various and other factors beside the presence of ISN. Therefore, the success of industrial symbiosis is not just about the existence of the network, but also about how these factors are managed and optimized. This is where CE practices come in: CE is about internal company transformation towards sustainability, whereas ISN is about creating external partnerships to achieve mutual sustainability goals (Kusch-Brandt, 2020; Maranesi & De Giovanni, 2020). While the ISN goal is to create a network where the waste of one company becomes the input for another, thus optimizing resource use and reducing environmental impact within a specific industrial cluster or region (Yazdanpanah et al., 2017), CE practices encompass the internal strategies, including designing products for longevity, recycling, upcycling, and adopting business models like product-as-a-service(Walker et al., 2022). Without the broader framework of CE, ISN may not fully embrace the principles of designing out waste, keeping products and materials in use, and regenerating natural systems.

Hypothesis 3 is supported, as the results indicated that the presence of intermediaries positively influences the adoption of circular practices in SME only when there is no existence of ISN. The CE adoption by SMEs is not straightforward, as they face several barriers and challenges, such as lack of financial resources, technical skills, market access and regulatory support (OECD, 2023). Therefore, intermediaries play a crucial role in promoting and facilitating the adoption, as they can provide several services, such as mapping potential synergies, brokering transactions, monitoring impacts, and advocating for policy changes (Saraceni et al., 2023). However, for SMEs already participating in established symbiosis networks, the role of intermediaries may be less significant, as these enterprises likely possess the necessary expertise and relationships to effectively utilize industrial symbiosis (Patala et al., 2020). Thus, Intermediaries can be useful for SMEs that do not have access or knowledge of the opportunities of industrial symbiosis, but they may be less relevant for SMEs that are already part of established symbiosis networks. For successful collaboration in a circular economy, intermediaries are required in business, government, and civil society to promote networking and collaboration, thus driving the shift towards sustainable circular transitions (Melles, 2023).

According to the data, the economic performance of the country can affect the performance of the firms that adopt circular practices inversely, that is, the higher the economic performance of the country, the lower the performance of the firm, regardless of whether there is ISN or not. This may occur because in countries with high economic performance the competition is more intense and the production costs are higher, which can reduce the profit margins and the investment capacity of the firms. Moreover, in developed countries, industrial symbiosis may be motivated by the desire to create competitive advantage, enhance innovation, and improve corporate image, rather than reducing the costs and operational risks (Sonel et al., 2022). Therefore, the positive effect of ISN on the performance of the firms may be lower in countries with high economic performance, especially in sectors without local ISN, where the opportunities for collaboration are scarcer and the barriers are higher.

We also found that the social performance of the country can affect the performance of the firms that adopt circular practices directly, that is, the higher the social performance of the country, the higher the performance of the firm, mainly in sectors with ISN. This may occur because in countries with high social performance, the demand for sustainable products and services is higher and the consumers are more willing to pay for them. In addition, in countries with high social performance, the symbiotic networks may be more planned and intentional, with clear and aligned objectives among the participants, which can facilitate the coordination, the trust and the collective learning. On the other hand, in countries with high social performance, the firms that adopt circular practices without participating in symbiotic networks may have a lower performance, as they may face difficulties to find suitable partners, manage the resource flows and monitor the outcomes. Furthermore, the circular economy without network may have different social effects, such as the loss of jobs, the exclusion of vulnerable groups and the concentration of power (Ghisellini et al., 2016).

Finally, the environmental performance of the country can affect the performance of the firms that adopt circular practices directly, that is, the higher the environmental performance of the country, the higher the performance of the firm, regardless of whether there is ISN or not. This may occur because in countries with high environmental performance the legislation is more stringent, and the incentives are more favorable for the firms that reduce their environmental impact. In countries with high environmental performance, the firms that adopt circular practices can benefit from a higher efficiency in the use of resources, a lower dependence on external sources and a higher resilience to climate change. The positive effect of the circular economy on the performance of the firms may be higher in sectors with local ISN, as the symbiotic networks can increase the possibilities of recycling, reusing and recovering materials and energy.

4.7. Conclusion

This paper aimed to investigate the influence of intermediaries, sectoral characteristics, and country performance on the adoption of circular practices and the performance of SMEs.

The results showed that hypotheses 1, 2 and 3 were supported by the data. The analysis revealed that ISN can offer some benefits to improve SMEs to adopt CE practices. Besides, SMEs require intermediaries to overcome the barriers and challenges to adopt CE practices. However, as symbiosis networks are established, the need for intermediaries for the adoption of CE practices by SMEs no longer influences the results. The performance of SME is not determined by the existence of ISN, but by the adoption of circular practices. Given the complexity of the network, there is a pressing need for more comprehensive studies to thoroughly evaluate the overall performance of ISNs. This will help to deepen our understanding and potentially enhance the effectiveness of ISNs.

Overall, these findings highlight the complex interplay of factors influencing the adoption of circular practices by SMEs and underscore the need for a nuanced understanding of these dynamics to effectively promote the transition to a circular economy. Understanding the multi-level perspective is essential for SMEs to successfully transition to a CE, as it considers factors at the micro, meso, and macro levels. The research into the effects of CE adoption on a firm performance reveals that SMEs must integrate CE practices to maintain competitiveness, even when they are part of an ISN. Such networks can facilitate the adoption of CE practices by providing easier access to collaboration and knowledge, thereby helping to overcome common obstacles. The practical implication for SMEs is that, to improve performance, they ought to prioritize the implementation of CE practices, regardless of their participation in an ISN. Being in such a network, however, can streamline the implementation process and, consequently, enhance performance. The intermediaries also play a crucial role in the transition of SMEs to a CE. The European Union (EU) can focus on developing these actors, especially in sectors and countries that do not have established ISN yet, to elevate the level of CE adoption by SMEs. In conclusion, the development of intermediaries and the adoption of CE practices can significantly influence the performance of SMEs and contribute to a sustainable future.

The paper has some limitations that should be acknowledged. First, it only considered the direct sectors of the SMEs, and not the indirect ones that could also be affected by the circular practices. Second, many of the projects, programs, and incentives for the circular economy were implemented after 2016, which could limit the availability of the data. Third, the data for the ISN on regional level was not sufficient to test the hypotheses, which could affect the generalization of the findings. In the taxonomy of IS indicators created by Fraccascia and Giannoccaro (2020), one of the categories is the geographic dimension. The level of geographic area corresponds to a region or a country, where several IS relationships and ISNs are implemented. However, it is important to understand this level of analyses because many SME networks exist that operate ‘off-line’ in their regions of reference and connections between the several offline networks hardly exist, so that learning benefits remain within existing networks and are not easily spread across networks in other regions and countries (Greeneconet, 2016). Velenturf (2017) corroborates the previous statement in her research, when she concludes that about 73% of these connections are located within a 75 mile radius.

Some recommendations for future research are: i) to test whether intermediaries with a focus on SMEs would have a different effect on the adoption of circular practices, as it was not possible to evaluate it with the current data; ii) to explore the country subregions level of analysis, which could provide more insights into the local dynamics of the circular economy; and iii) to use longitudinal data to capture the changes and trends in the circular economy over time.

5
Conclusion

This study aimed to investigate the influence of the micro, meso and macro level in the relationship between CE adoption and SMEs performance, following a multi-level approach. To achieve this objective, the study was carried out in three secondary objectives: first objective was to identify trend topics in the literature regarding the adoption of circular economy on firm performance and the measures used in quantitative studies; the second objective was to develop and to test an empirical model to analyze the CE adoption on the SMEs performance moderated by country performance (micro and macro level); finally, the third objective was to develop and to test other empirical model to analyze the role of intermediaries in engaging SMEs in Circular Economy (CE) practices, and the role of the existence of Industrial Symbiosis (IS) networks (micro, meso and macro level).

The first chapter aimed to achieve the first objective. We followed a systematic literature review approach. The main contribution of this literature review is to provide a comprehensive and critical overview of the current state of the art on CE and firm performance. The results showed that there are several topics related to Circular Economy and Firm Performance. The majority of studies on CE experienced an increase in publication activity since 2016. Notably, publications in the fields of business and economics have earned more relevance starting from 2020. These studies span a wide range of time, with publications dating back to 1897, and many of them have received numerous citations in high-impact journals. The geographical distribution of these studies shows that the majority of publications are concentrated in Europe and China. Among the 20 topics analyzed, some of the most recent ones include: Firm sustainable development goals, Circular Consumption, Circular Economy Drivers, Circular Economy Barriers, Circular Business Model. We also examined the methodological approaches, data sources, and limitations of some quantitative studies. The results of this study provide a comprehensive overview of the current state of the art in the quantitative research on CE and firm performance and suggest directions for future research in this field. We verified the variables used, the type of data, the method of analysis, the type of industry, the size of the company, the size of the sample and the topic to which the article belongs to. The variables identified can be used as a guide for future research on CE and firm performance. Researchers can use these variables to design more comprehensive studies focused on specific aspects of CE and firm performance. Practitioners can use the variables to identify areas in which they can improve their performance and adopt more sustainable practices. Overall, the chapter provides a valuable resource for researchers and practitioners interested in studying the relationship between CE and firm performance.

Based on the findings of Chapter 1, it is evident that the recent topics of study — such as Firm Sustainable Development Goals, Circular Consumption, Drivers of the Circular Economy, Barriers to the Circular Economy, and Circular Business Models — are all interconnected in the organizational level of investigation. This is in line with the aim of this study, which is to integrate the concept of the CE into the business perspective. Furthermore, we have identified several methods to measure the CE and the firm performance, which have been utilized in Chapter 2.

In the second chapter, we identify that it was important to understand how CE adoption can affect SME performance and how the micro and macro factors can facilitate or hinder this process. The results are related to other studies and theoretical literature showing the positive effect of CE practices on firm performance. Another contribution is that firms with higher R&D investments, which indicates a strategic orientation for differentiation, tend to adopt CE activities more often than other firms, reinforcing the assumption that implementation of circularity involves reorganizing the strategy and industrial process. Firms with a differentiation strategy have more capacities to these changes. The higher the lack of technical skills, the lower is the adoption of CE. It indicates that the organization needs to invest in technical skills to implement circularity activities. Additionally, firms with financial capacity implement CE more often than other firms, reinforcing the importance of a direct support from the government for CE promotion. We also emphasize that our results reveal that the firm location directly influences the results of companies that commit to adopting circularity activities. Once the country's environmental performance could positively contribute to the firm performance, the contribution of its economic performance could be negative when the firm adopts more CE activities. Since CE may perform differently depending on location, copy-pasting solutions will not be effective. Each firm and region should plan based on its own challenges.

In chapter 2 we analyzed the micro and macro level and find that they have influence in the relation between CE adoption and firm performance. However, to follow a more complete multi-level approach, we need to include in the study the meso-level analysis, which was the objective of Chapter 3.

In the third chapter we find that the effects of CE adoption on a firm performance reveal that SMEs must integrate CE practices to maintain competitiveness, even when they are part of an ISN. Such networks can facilitate the adoption of CE practices by providing easier access to collaboration and knowledge, thereby helping to overcome common obstacles. The practical implication for SMEs is that to improve performance, they should prioritize the implementation of CE practices regardless of their participation in an ISN. Being in such a network, however, can streamline the implementation process and, consequently, enhance performance. In conclusion, the development of intermediaries and the adoption of CE practices can significantly influence the performance of SMEs and contribute to a sustainable future.

After the analysis in the three chapters, we conclude that understanding the multi-level perspective is essential for SMEs to successfully transition to CE, as it considers factors at the micro, meso, and macro levels. Therefore, to answer the question "how do the levels relate?", it is necessary to adopt a systemic and multidisciplinary approach, which recognizes the complexity and interdependence of the phenomena involved. It is essential to consider the mediating and moderating factors that shape this relationship. To measure the levels effects, we used the following indicators for each level: i) micro: firm strategy, technical skills, financial capacity, age, consumer type and size; ii) meso: symbiosis agents and intermediaries; iii) macro: country economic, social and environmental performance.

Thus, the question is: What factor mediates and what factors moderates the circular economy practice and SMEs performance? A moderate variable is a type of variable that affects the relationship between a dependent variable and an independent variable. It can change the strength or direction of the relationship depending on its value. A mediating variable is a variable that explains how or why an independent variable affects a dependent variable. It is part of the causal pathway between the two variables, and it tells you the mechanism or process of the effect.

Table 18: The influence of multi-level factors

Level	Factors	Influence on CE adoption	CE Adoption as Mediator to Firm Performance	Moderating role in CE Adoption → Firm Performance	Influence on Firm Performance
Micro	firm strategy	positive	yes	no	positive
	Lack of technical skills	negative	yes	no	positive
	financial capacity	positive	yes	no	positive
	age	positive	no	no	positive
	consumer type	positive	no	no	positive
	size	positive	no	no	positive
Meso	Intermediaries	positive	yes	no	positive
	Industrial Symbiosis Network	positive	no	moderator	positive
Macro	Economic performance	negative	no	moderator	negative
	Social performance	positive	no	no	positive
	Environmental performance	positive	no	moderator	positive

Table 18 provided a structured overview of the various factors at the micro, meso, and macro levels that influence the adoption of circular economy (CE) practices and their subsequent impact on firm performance. The analysis of this table reveals several key insights into the dynamics of CE adoption and their role within the organizational context.

At the micro level, factors such as firm strategy, technical skills, and financial capacity have a direct influence on CE adoption, indicating that these elements are integral to the immediate implementation of CE practices. The direct relationship suggests that improvements or changes in these areas can lead to a more straightforward adoption of CE. Notably, all three factors are associated with a positive influence on firm performance when CE practices are adopted, implying that they are not only facilitators of CE but also contributors to enhanced business outcomes. In contrast, age, consumer type, and size are factors that indirectly influence CE adoption. These factors do not have a direct reflex on the adoption process but they may affect it through other mediating variables or conditions.

Despite their indirect influence, they are associated with a positive impact on firm performance.

At the meso level, intermediaries play a crucial role in directly influencing CE adoption, serving as connectors or facilitators between the firm and the larger network. Their direct influence is indicative of the importance of relationships and networks in the diffusion of CE practices. The Industrial Symbiosis Network, however, serves as a moderator rather than a direct influencer, suggesting that its presence can enhance or change the relationship between CE adoption and firm performance. The positive impact on firm performance highlights the value of collaborative and symbiotic relationships within the industry.

At the macro level, economic performance is identified as a moderating factor with an indirect influence on CE adoption and a negative impact on firm performance. This suggests that broader economic conditions can alter the way CE adoption affects firm performance, potentially creating challenges or barriers. Social performance, while also indirectly influencing CE adoption, does not have a significant moderating role. Environmental performance, similar to economic performance, acts as a moderator with an indirect influence on CE adoption and a positive impact on firm performance, emphasizing the importance of environmental considerations in shaping the outcomes of CE initiatives.

In conclusion, the table illustrates the complicated nature of CE adoption and its varying effects on firm performance across different levels. The direct influencers at the micro level are critical for immediate action, while the indirect influencers and moderators at the meso and macro levels shape the broader context within which CE practices are adopted and generate value for the firm. Understanding these dynamics is essential for developing effective strategies to promote CE adoption and leverage its benefits for sustainable business growth.

This study presents that micro, meso and macro indicators can directly influence CE adoption by providing information, and incentives for companies to improve their circularity. Moreover, the study suggests that these indicators can also influence the firm performance mediated by CE adoption, meaning that there is a positive relationship between CE adoption and firm performance, and that this relationship is influenced by the indicators used to measure and monitor CE adoption. Companies that adapt to the demands and expectations of their external environment and that establish positive relationships with other companies can obtain competitive advantages and contribute to the development of the country.

The insights gleaned from this study have significant implications for the academy, practitioners and policymakers. The theoretical contribution of this study primarily lies in several key areas: the topics over the years on Circular Economy (CE), where we have traced an interesting historical line for researchers to understand the development of the theme over time, its main nuances in bibliographic terms, and above all, we have comprehended the principal measures used in quantitative studies that can aid the progress of further research on CE and performance, and the eventual proposition of a consolidation in the literature of a universal measure for circular practices in companies. Another theoretical contribution is that the results support the view of some researchers that CE must be proposed with an integrated approach across various implementation levels, demonstrating that factors at each level influence the study of CE. It shows that studying CE without recognizing the levels may yield less satisfactory results.

The implication for practitioners is that SMEs must prioritize skill development and R&D investments to effectively implement circular business models. These efforts can be bolstered by the support of symbiotic intermediaries, which play an essential role in SMEs' transition to a CE. Practitioners outside of an ISN who require more technical skills and R&D capacity should seek out intermediaries — be they private, public, or NGO entities — to facilitate this process. Programs that support such initiatives can often be found through platforms like Interreg, a key instrument of the European Union that fosters cooperation across regions and countries. Additionally, SMEs should explore government programs that promote CE and that provide financial support for necessary investments. To enhance performance, SMEs must focus on implementing CE practices, whether or not they are part of an ISN. However, participation in such networks can expedite the implementation process and, as a result, improve performance outcomes.

For policymakers, the implications are multifaceted. At both national and regional levels, there is a need to cultivate an environment conducive to the widespread adoption of CE practices among SMEs. This involves leveraging the influence of intermediaries to facilitate this transition. The European Union (EU) should prioritize the development of these actors, particularly in sectors and countries lacking established ISNs, to enhance the level of CE adoption by SMEs. Public policies of direct investment, especially in countries with higher economic performance rates where firms operate at a higher level of competitiveness, can improve firms performance indicators and make CE adoption more attractive. Financial support for CE activities can be provided directly by the public sector or through other institutions, such as business associations and business development agencies. This support can take plenty of forms, including grants, tax incentives, loans, or investment guarantees. Moreover, policymakers should invest in stringent environmental legislation to promote superior environmental outcomes: this can aid firm performance by reducing raw material costs, thereby making CE adoption more economically beneficial. Consequently, some of the primary reasons European SMEs are proactively adopting CE include the reduction in material costs, the creation of competitive advantages, and the opening of new markets.

The study has some limitations in terms of data and methods. When utilizing secondary databases, we face a range of limitations: the inflexible data model makes it difficult to adapt to changing research needs. Issues of quality and reliability arise, with potential inaccuracies and inconsistencies within the data. Moreover, the information is outdated, not reflecting the latest developments or current conditions. We also have limited control over the data collection process, which can impact the suitability of the data for the research questions. Systematic literature reviews also come with inherent methodological limitations. The selection criteria of inclusion and exclusion for studies influences the results. There is a risk of publication bias, with the potential omission of unpublished studies or those published in languages other than English. Reviewer bias can also influence the selection and interpretation of studies, despite efforts to minimize such biases. Empirical methods present their own set of limitations. For instance, the empirical models used did not contain all possible exogenous variables since it is difficult to represent all the diversity of the indicators that influence the relationships. It may oversimplify complex situations, missing subtleties or nuances. Recognizing these limitations is essential for researchers to ensure the validity and reliability of their findings.

As for any comprehensive study, there are avenues for future research that stem from the findings and implications of this study. For example, future research endeavors could focus on conducting longitudinal studies to track the long-term performance outcomes of SMEs that have adopted CE practices, shedding light on the sustained impact of circular business models. Moreover, comparative analyses across different European regions could elucidate the nuanced moderating effects of macro-level performance indexes on the adoption and performance outcomes of CE practices within SMEs. The findings of a study can be highly relevant for replication on emerging countries, such the Brazilian context, especially considering the potential for sustainable development and economic growth. European SMEs have been at the forefront of adopting CE practices. Emerging countries SMEs can learn from their European counterparts' successes and challenges, implementing best practices that have proven to enhance firm performance. The European experience shows the importance of collaboration among businesses, governments, and academy. Brazilian SMEs can engage in similar networks to accelerate the transition to CE. In conclusion, this study has contributed to a nuanced understanding of the intricate relationship between CE adoption and SME performance, highlighting the mediating and moderating factors that shape this dynamic interplay. By recognizing the multifaceted nature of this relationship, SMEs and policymakers can leverage these insights to drive sustainable and resilient economic growth in the European context or the replication to other countries. We hope that our study will inspire further research and action on circular economy and firm performance and contribute to the transition towards a more sustainable and resilient economy. The circular economy is a promising approach to address the challenges of resource depletion, environmental degradation, and economic inequality, and SMEs can play a crucial role in its implementation and diffusion. By adopting circular economy practices, SMEs can enhance their competitiveness, reduce their environmental footprint, and contribute to the achievement of the Sustainable Development Goals.

6
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7 Appendix

7.1. Appendix A: Variables research

Table 19: Variables

author	firm performance variables	CE variables	Other variables	measure	analysis method	Country	Industry	Firm size	sample	Main topic
(Zhu et al., 2010)	CE Performance: Environmental performance, Economic performance	CE practices: Internal environmental management, Eco-design, Investment recovery	environmental oriented supply chain cooperation	Likert	MANOVA	China	chemical, automotive, mechanical, electronic	mixed	334	Firm sustainable development goals

(Bartolacci et al., 2018)	ROA to measure financial performance	SWC Solid Waste Collection(both per capita and expressed as a percentage) as a proxy for good environmental practices.	-	Secondary data	Regression analysis	Italy	waste management	mixed	45	Firm sustainable development goals
(Botezat et al., 2018)	CE targeted performance: Environmental Performance, Economic Performance	CE practices: Eco-design, Internal environmental management, Investment recovery	green-oriented supply chain cooperation: Green Purchasing, Customer Cooperation	survey	factor analysis	Romania	mixed	mixed	98	Circular Economy Drivers
(Subramanian et al., 2019)	Performance (Profit and TTM stands for "time-to-market")	CE-NPD (CE construct of customer experience in new product development)	Traditional Chinese philosophies	survey	PLS-SEM	China	manufacturing	mixed	200	Firm sustainable development goals
(Chiappetta Jabbour et al., 2020)	Economic Performance (EC) Environmental Performance (EN) Social Performance (SO)	Principles of Circular Economy (PCE)	Stakeholder Pressure (SP) Barriers (BR) Motivators (MT)	Likert	SEM	Brazil	electronics, food and construction	mixed	100	Firm sustainable development goals

(O. Khan et al., 2020)	Performance: Objective – environmental, Subjective – competitiveness, Objective – financial, Subjective – corporate reputation	Circular dynamic environment: Market turbulence, Technology turbulence, Competitive intensity/ Circular economy implementation level: Design and production stage, Consumption and collection stage, Recycling and resourcing stage	Dynamic capabilities: Sensing, Seizing, Reconfiguring/	survey	PLS-SEM	Italy	mixed	mixed	220	Firm sustainable development goals
(Del Giudice et al., 2021b)	firm performance for circular economy supply chain	circular economy supply chain management design, circular economy supply chain relationship management, circular economy HR management	big-data-driven supply chain	Likert	multiple regression analysis	Italy	mixed	mixed	378	Green Supply Chain Management
(Moric, Jovanović, et al., 2020)	productivity of the firm, measured by the logarithm of	Adopters: companies that have adopted at least one type of		Secondary data	Regression analysis	Europe	mixed	SMEs	4237	Circular Economy Drivers

	total annual sales per employee	activity related to the circular economy. - Prospective Adopters: companies that are in the process of implementing at least one type of activity related to the circular economy. - Planners: companies that have not implemented any type of practice related to the circular economy, but plan to do so. - Non-Adopters: companies that have not adopted and do not plan to implement any activity related to the circular economy.								
(S. A. R. Khan et al., 2021)	Firm performance	Circular procurement/ Recycling and remanufacturing/ Circular design/	Blockchain technology	survey	PLS-SEM	Malaysia	mixed	mixed	239	Firm sustainable development goals

(Blasi et al., 2021)	ROA (Return on Assets)	Web Communication Focused on Circular Economy	Dummy_EBITDA, Leverage, Size	Secondary data	nonparametric quantile regression	Italy	manufacturing	SME	168	Circular economy indicators
(Kristoffersen, Mikalef, Blomsma, et al., 2021)	Firm performance	Circular economy (CE)implementation	Business Analytics Capability (BAC) Resource Orchestration Capability (ROC)	survey	PLS-SEM	Noruega, Polônia, Reino Unido, Espanha, Alemanha, Itália, França, Holanda, Dinamarca, Finlândia e Suécia.	manufatura, provedores de serviços, consultoria, energia, utilidades e recursos, varejo e bens de consumo, tecnologia da informação e outro	mixed	125	Firm sustainable development goals
(Saha et al., 2021)	Sustainability performance (economic performance environmental performance, social performance)	CE fields of action (take, make, distribute, use, recover)	External and internal issues (challenges, opportunities), Success factors	Likert/ focus group	regression analysis	Bangladesh, India, and Vietnam	textile and clothing (TC) industry.	mixed	114	Firm sustainable development goals

(Kamble & Gunasekaran, 2023)	Sustainable performance (SP): Economic sustainability (ES), Social Sustainability (SS), Environmental Sustainability (EVS)	CE practices: Management systems (MS), Eco-design (ED), Investment recovery (IR)	I4 technologies	survey	SEM	India	manufacturing	mixed	238	Firm sustainable development goals
(Rodríguez-González et al., 2022)	Financial Performance (FP)	Circular Economy Practices (CE)	Sustainable Supply Chain Management (SSCM)	Likert/ Secondary data	PLS-SEM	Mexico	automotive	mixed	460	Green Supply Chain Management
(Mazzucchelli et al., 2022b)	financial performance	Circular economy: 3R practices: waste treatment, reduction, recycle within firm	brand reputation	survey	SEM	Italy	mixed	mixed	150	Firm sustainable development goals
(de Sousa Jabbour et al., 2022)	Firm performance: Economic Performance (ECP), Environmental Performance (ENP), Social	Level of circular economy adoption	Level of Industry 4.0 adoption	Likert	SEM	Brazil	mixed	mixed	132	Firm sustainable development goals

	Performance (SCP), Operational Performance (ORP)									
(Chowdhury et al., 2022)	sustainable performance	CE practices	leadership, innovation, culture, skills and competences	Likert	SEM	Vietnam	Agriculture Forestry and Fishing 10 Mining and Quarrying 5 Manufacturing 26 Electricity Gas Steam and Air Conditioning 9 Water Supply Sewerage Waste	SMEs	205	Firm sustainable development goals
(Dong et al., 2022)	Business performance (BP)	Circular economy: Recycle (RCC), Reduce (RDC), Reuse (RUC)	Environmental performance (EP)		PLS-SEM	China	energy	mixed	295	Firm sustainable development goals
(Dey et al., 2022)	Economic performance (Revenue,	Circular Economy Fields of action (Design,		Survey	SEM	Greece, France, Spain, UK	mixed	SMEs	401	Circular Economy Drivers

	Business growth, Contribution to local economy) / Environmental performance (Energy efficiency, Resource efficiency, Waste reduction) / Social performance (Employee wellbeing, Health and safety, Social wellbeing)	Procurement, Production, Distribution, Usage, consumption, Reverse Logistics)								
(Rodríguez-Espíndola et al., 2022)	Social Performance, environmental Performance, economic performance	CE principals	Customer, Government support, uncertainty, Tech, sustainable-oriented innovation	Likert	SEM	Mexico	mixed	SMEs	60	Firm sustainable development goals
(J. Liu et al., 2022)	Organizational Performance (ORP): Economic (ECO), Operational (OPP)	Circular Economy Practices (CEP): Green procurement (GP), Green transportation (GT)	Covid-19: Personal perceived risk (PPR), Govt Policies (P)/ Technological	survey	SEM	China	manufacturing	mixed	277	Circular Economy Drivers

			Innovation (T.I.): Information sharing ability (ISA), Coordination and integration ability (CIA)							
(Bag et al., 2022)	Firm performance (FP)	Circular economy capability (CEC)	Institutional pressures (IP) Eco-innovation (EI) Green supply chain management (GSCM)/ big data Driven Supply Chains (BDSC)	survey	SEM	South Africa	manufacturing	SME	240	Firm sustainable development goals
(Alcalde-Calonge et al., 2022)	Performance (TBL approach)	circularity level: 10R	entrepreneurial orientation/ external and internal social capital/ dynamic capabilities/ Environmental factor: Social, Cultural, technological,	review	case study	-	bioeconomy	-	-	Firm sustainable development goals

			regulatory, economic, financial							
(Nishitani et al., 2022)	Economic performance: Productivity, Improvement, Profit growth/ Environmental performance: Energy consumption, Water withdrawal, CO2 emissions, Waste produced	CE indicator: Material flow oriented accounting			Regression analysis	Japan	mixed	mixed	225	Firm sustainable development goals
(O. Khan et al., 2023)	Performance (PER)	behavior towards CE	Attitude (ATT)/ Subjective Norms (SN)/ Perceived Behavioral Control (PBC)/ Intention (INT)/ Behavior (BEH)/ Barriers (BAR)/ Dynamic Capabilities (DC)		PLS-SEM	Cyprus, France, Italy, Spain	tourism	mixed	256	Firm sustainable development goals

(Edwin Cheng et al., 2022)	SSC Performance: Economic, Environmental, Social	CE Practices: Eco-design, Management systems, investment recovery	Big Data Analytics capabilities: BDA Infrastructure, BDA Personnel expertise, BDA Management Capabilities/ Sustainable supply chain (SSC) Flexibility: Green products flexibility, environmental practices flexibility, environmental technology flexibility, Resource consumption flexibility, Green supplier flexibility	survey	PLS-SEM	India	manufacturing	mixed	320	Firm sustainable development goals
(Rehman Khan et al., 2022)	Organizational performance (ORM)	Circular Economy practices: Recycling & remanufacturing (RR), Green manufacturing (GM), Green design (GD)	Blockchain technology (BCT)/ Environmental performance (ENP)/ Economic performance (ECO)	survey	PLS-SEM	Chinese and Pakistanis	manufacturing	mixed	290	Firm sustainable development goals

(Pinheiro et al., 2022)	Environmental performance/ Market performance	Circular product design	Stakeholder pressure Industry 4.0	Likert	PLS-SEM	Brazil	equipamentos elétricos e eletrônicos (EEE).	mixed	142	Firm sustainable development goals
(Y. Liu et al., 2023)	Environmental Performance (EP) e Financial Performance (FP)	CE culture, Circular product design, Circular Manufacturing	Cleaner Production (CP), Industry 4.0 Production Technologies (IPT), integrate Management Systems	Likert	CB-SEM	China	mixed	mixed	360	Firm sustainable development goals
(Yin et al., 2023)	Economic performance: improvement of sales, revenue and an improvement of market share) Ecological performance: energy conservation, waste reduction and pollution reduction)	CE practices: eco-design ,Cleaner production, Consumers' responsibility, waste management		meta-analysis	CMA	mixed	mixed	mixed	-	Firm sustainable development goals

(Fernando et al., 2023)	Financial performance	A CERL-product return/ A CERL-product recovery	Sustainable Resource Commitment	survey	PLS-SEM	Malaysia	mixed	mixed	113	Firm sustainable development goals
(Ghaithan et al., 2023)	Sustainability performance: economic, social, environmental	CE: Regenerate Criterion, Share Criterion, Optimize Criterion, Loop Criterion, Virtualize Criterion, Exchange Criterion	Industry 4.0 Technologies: IoT—Internet of Things (IOT), Big Data Analytics (BDA), Additive Manufacturing (AM), Cloud Computing (CC), Robotic Systems (RS), Augmented Reality (AR)/ Lean Manufacturing: Supplier Development (SD), Just in Time (JIT), Customer Involvement (CI), Continuous Flow (CF), Statistical Process Control	survey	PLS-SEM	Latin America	manufacturing	mixed	486	Circular Economy Barriers

			(SPC), Employee Involvement (EI)							
(D'Angelo et al., 2023)	Turnover increase (% of turnover)	Number of circular economy activities undertaken: (i) re-planning water usage to minimize use and maximize reuse; (ii) using renewable energy; (iii) re-planning energy usage to minimize consumption; (iv)minimizing waste by recycling or reusing waste or selling it to another company, and (v) redesigning products and services to minimize the use of materials or using recycled materials.		Secondary data	Regression analysis	Europe	mixed	SMEs	1000	Firm sustainable development goals
(Triguero et al., 2023)	economic and environmental performance	CE practices: life cycle analysis (LCA), product upgradability,		Survey	ordered logit regressions (OLOGIT) a	Spain	manufacturing	mixed	300	Firm sustainable

		Design for disassembly (DfD), Design for remanufacturing and reuse (DfR), Design for recycling (DfRc)								development goals
(Alamelu et al., 2023)	- Economic Performance (EP) - Social Performance (SP) - Environmental Performance (ENP) - Value-Based Performance (VBP)	Circular Economy (CE)	Supply Chain Management (SCM) Sustainable Circular Supply Chain Management (SCSCM)	Survey	PLS-SEM	India	manufacturing	SMEs	486	Green Supply Chain Management
(Sarfraz et al., 2019.)	Financial performance: WACC - weighted cost of capital, defined as weighted mean of cost of equity and cost of debt, based on firm's	Circular economy: Resource use, Waste recycled, Management systems, Emissions	Organizational and management ability: Governance, Management, Innovation, Strategy	Secondary data	OLS regression model	G7 countries	mixed	mixed	1786	Circular Economy Drivers

	financing structure; ROA									
(Riggs et al., 2023)	Sustainable Performance (SP): Economic performance, Social performance, Environmental performance	Circular Economy Practices (CEP): Governance initiatives, Economic initiatives, Cleaner production, Product development, Management support, Knowledge	Supply Chain management Capabilities (SCMC): Information exchange, Coordination, Integration, Responsiveness / Big Data Analytics Capabilities (BDAC)	Survey	PLS-SEM	Spain	mixed	mixed	210	Firm sustainable development goals
(S. A. R. Khan, Piprani, et al., 2022)	Environmental performance (ENP)/ Economic performance (ECO)	Circular procurement (CP)/ Circular design (CD)	Technological innovation (TI)	survey	PLS-SEM	China	mixed	SMEs	290	Circular Economy Barriers
(De Lima & Seuring, 2023)	Financial performance and continuity	Circular economy implementation	Organizational risks and uncertainties/ Supply chain risks and uncertainties/ External risks and	survey	Delphi	mixed	-	-	-	Green Supply Chain Management

			uncertainties/ Strategies to reduce risk and uncertainty/ Strategies to cope with risk and uncertainty							

7.2.
Appendix B: Intermediaries and ISN's

Table 20: Intermediaries and ISN's

actors involved	type of actor in the network	actor objective	countries	reference
Lifestyle & Design Cluster	Intermediaries	N/A	Denmark	INEC & ORÉE (2020)
SITRA	Intermediaries	N/A	Finland	INEC & ORÉE (2020)
National Institute of Circular Economy (INEC)	Intermediaries	institute	France	INEC & ORÉE (2020)
ORÉE	Intermediaries	multi-stakeholder organization	France	INEC & ORÉE (2020) & Domenech et al (2019)
Circle Economy	Intermediaries	social enterprise	Holland	INEC & ORÉE (2020)
Rediscovery Centre	Intermediaries	movement	Ireland	INEC & ORÉE (2020)
AISEC	Intermediaries	association	Italy	INEC & ORÉE (2020)
Circular Economy (ZIEDINE EKONOMIA)	Intermediaries	N/A	Lithuania	INEC & ORÉE (2020)
SuperDrecksKëscht	Intermediaries	brand	Luxembourg	INEC & ORÉE (2020)
LIPOR	Intermediaries	N/A	Portugal	INEC & ORÉE (2020)
IRCEM	Intermediaries	institute	Romania	INEC & ORÉE (2020)
Zero Waste Scotland	Intermediaries	regional program	Scotland	INEC & ORÉE (2020)
Institute of Circular Economy (INCIEN)	Intermediaries	institute	Slovakia/ Czech Republic	INEC & ORÉE (2020)
CirEko	Intermediaries	service hub	Sweden	INEC & ORÉE (2020)
Circular Economy Transition	Intermediaries	service hub	Switzerland	INEC & ORÉE (2020)
Green Alliance	Intermediaries	service hub	United Kingdom	INEC & ORÉE (2020)
London Waste and Recycling Board (LWARB)	Intermediaries	regional program	United Kingdom	INEC & ORÉE (2020)
Kalundborg	Player	park - combined	Denmark	Domenech et al (2019) & Massard (2014)
Kemi-Tornio	Player	industry cluster	Finland	Domenech et al (2019)
Händelö	Player	park - industrial	Sweden	Domenech et al (2019) & Massard (2014)

Eyde Network	Player	industry cluster	Norway	Domenech et al (2019)
Svartsengi	Player	industry cluster	Iceland	Domenech et al (2019)
NISP-Hungary	Intermediaries	national program	Hungary	Domenech et al (2019)
REPROWIS	Intermediaries	project	HU-SK	Domenech et al (2019)
Styrian recycling network	Player	individual business interests	Austria	Domenech et al (2019)
GreenTech Clus ter	Player	industrial cluster	Austria	Domenech et al (2019)
Essenscia Bruss els	Intermediaries	institute	Belgium	Domenech et al (2019)
NISP ECOREG	Intermediaries	project	Romania	Domenech et al (2019)
Bratislavsky Kraj / ERDF	Intermediaries	national program	Slovakia	Domenech et al (2019)
werecycle.be	Intermediaries	service hub	Belgium	Domenech et al (2019)
PNSI - Programme national de synergies interentreprises	Intermediaries	program	France	Domenech et al (2019)
Silver Project	Intermediaries	program	Netherlands	Domenech et al (2019)
Rotterdam Harbour INES project	Player	park - industrial	Netherlands	Domenech et al (2019) & Massard (2014)
FISS - Finnish Industrial Symbiosis system	Intermediaries	program	Finland	Domenech et al (2019)
ENEA Italian Network	Intermediaries	program	Italy	Domenech et al (2019)
Industrial Park of Rieti-Cittaducale	Player	industry cluster	Italy	Domenech et al (2019)
Green Industrial Symbiosis Denmark	Intermediaries	program	Denmark	Domenech et al (2019)
EUR-ISA European Industrial Symbiosis Association	Intermediaries	association	EU	Domenech et al (2019)
Harjavalta	Player	park - industrial	Finland	Domenech et al (2019)
Wildling Butler	Player	organization	United Kingdom	Domenech et al (2019)
ZeroWin	Intermediaries	project	EU	Domenech et al (2019)
SMILE	Intermediaries	Platform	Ireland	Domenech et al (2019)
Knapsack chemical park	Player	park	Germany	Domenech et al (2019)
Bazancourt-Pomacle	Player	industrial cluster	France	Domenech et al (2019)
Symbioseplatfor m	Intermediaries	Platform	Belgium	Domenech et al (2019)
Biopark Terneuz en	Player	cluster	Netherlands	Domenech et al (2019)

Organised Wast e Market (MOR)	Intermediaries	Platform	Portugal	Domenech et al (2019)
ResidiRecurso	Intermediaries	Platform	Spain	Domenech et al (2019)
symbiosis.gr	Intermediaries	project	Greece	Domenech et al (2019)
Manresa	Intermediaries	project	Spain	Domenech et al (2019)
NISP NI	Intermediaries	program	EU	Domenech et al (2019)
NISP Scotland	Intermediaries	program	United Kingdom	Domenech et al (2019)
Rethink Sustainable Solutions	Player	organization	Italy	Domenech et al (2019)
Inex	Intermediaries	platform	FR / BE/ ES	Domenech et al (2019)
Industrial Park of Sweden	Player	industry cluster	Sweden	Domenech et al (2019)
Oresundskraft	Player	organization	Sweden	Domenech et al (2019)
Nordvästra Skånes Renhållning	Player	organization	Sweden	Domenech et al (2019)
Nordvastra Skanes Vaten o ch Avlopp	Player	organization	Sweden	Domenech et al (2019)
Lidkoping IS Network	Player	cluster	Sweden	Domenech et al (2019)
Enkoping IS Network	Player	cluster	Sweden	Domenech et al (2019)
Stenungsund IS Network	Player	cluster	Sweden	Domenech et al (2019)
Avesta IS Network	Player	cluster	Sweden	Domenech et al (2019)
Heidelberg industrial estate of Pfaffengrund	Player	cluster	Germany	Domenech et al (2019)
Rhein Neckar	Player	cluster	Germany	Domenech et al (2019)
Aspern Vienna’s Urban Lakeside	Player	urban	Austria	Massard (2014)
Eco World Styria	Player	industrial	Austria	Massard (2014)
Ecopark Hartberg Steiermark	Player	industrial	Austria	Massard (2014)
Créalys® Scientific Park	Player	industrial	Belgium	Massard (2014)
Ecolys® Park	Player	industrial	Belgium	Massard (2014)
Evolis Business Park	Player	combined	Belgium	Massard (2014)
Galaxia Industrial Park	Player	industrial	Belgium	Massard (2014)
Kaiserbaracke Industrial Park	Player	industrial	Belgium	Massard (2014)
Monceau-Fontaines Park	Player	industrial	Belgium	Massard (2014)
Tenneville Industrial Park	Player	industrial	Belgium	Massard (2014)
Business Park Sofia	Player	industrial	Bulgaria	Massard (2014)

Aarhus Eco-city	Player	urban	Denmark	Massard (2014)
Herning-Ikast Industrial Park	Player	combined	Denmark	Massard (2014)
Kymi Eco-Industrial Park	Player	industrial	Finland	Massard (2014)
MABU (Material Business) Project	Player	industrial	Finland	Massard (2014)
Rantasalmi Eco-industrial park	Player	industrial	Finland	Massard (2014)
Uimaharju Industrial Area	Player	industrial	Finland	Massard (2014)
Chemical Valley Industrial Area	Player	industrial	France	Massard (2014)
Croix-Fort Artisanal Park	Player	industrial	France	Massard (2014)
Deux Synthe Industrial Park	Player	industrial	France	Massard (2014)
Grand Troyes Park	Player	industrial	France	Massard (2014)
Havre Industrial-Harbour Park	Player	industrial	France	Massard (2014)
Lagny-sur-Marne and La Courtilière Industrial Parks	Player	industrial	France	Massard (2014)
Les Sohettes Bio-refinery	Player	industrial	France	Massard (2014)
Lille City	Player	urban	France	Massard (2014)
Nogent Industrial Basin	Player	industrial	France	Massard (2014)
Plaine de l’Ain Industrial Park	Player	industrial	France	Massard (2014)
Port-Jérôme Industrial Park	Player	industrial	France	Massard (2014)
Roche en Brénil Wood Ecopole	Player	industrial	France	Massard (2014)
Technopôle de Métropole Savoie	Player	industrial	France	Massard (2014)
Torvilliers Industrial Park	Player	industrial	France	Massard (2014)
BASF Verbund site Ludwigshafen	Player	industrial	Germany	Massard (2014)
Bayer Industrial Park Brunsbüttel	Player	industrial	Germany	Massard (2014)
Camp CO2-Zero	Player	industrial	Germany	Massard (2014)
Chemical industrial Park Knapsack	Player	industrial	Germany	Massard (2014)
Chemie- und Industriepark Zeitz	Player	industrial	Germany	Massard (2014)
ChemiePark Bitterfeld Wolfen	Player	industrial	Germany	Massard (2014)
Chempark Dormagen	Player	industrial	Germany	Massard (2014)
Chempark Krefeld-Uerdingen	Player	industrial	Germany	Massard (2014)

Chempark Leverkusen	Player	industrial	Germany	Massard (2014)
Dow Value Park	Player	industrial	Germany	Massard (2014)
Gertshofen Industriepark	Player	industrial	Germany	Massard (2014)
Gewerbenetzwerk Pfaffengrund	Player	industrial	Germany	Massard (2014)
Honeywell Seelze	Player	industrial	Germany	Massard (2014)
Industriepark Höchst	Player	industrial	Germany	Massard (2014)
Industriepark Kalle Albert	Player	industrial	Germany	Massard (2014)
Infraleuna, Leuna	Player	industrial	Germany	Massard (2014)
Marl Chemical Park	Player	industrial	Germany	Massard (2014)
Neue Bahnstadt, Opladen	Player	combined	Germany	Massard (2014)
Oberbruch Industry Park	Player	industrial	Germany	Massard (2014)
Pharma- und Chemiepark Wuppertal	Player	industrial	Germany	Massard (2014)
Schwedt Industrial Park	Player	industrial	Germany	Massard (2014)
Zero Emission Park Bottrop	Player	industrial	Germany	Massard (2014)
Zero Emission Park Bremen	Player	industrial	Germany	Massard (2014)
Zero Emission Park Kaiserslautern	Player	industrial	Germany	Massard (2014)
Amaro Industrial Park (Area Industriale di Amaro)	Player	industrial	Italy	Massard (2014)
Cairo Montenotte Industrial Park (Area Industriale di Cairo Montenotte)	Player	industrial	Italy	Massard (2014)
Envipark (Parco Scientifico Tecnologico per l'Ambiente)	Player	industrial	Italy	Massard (2014)
Lucento Industrial Area (Area Industriale Lucento)	Player	combined	Italy	Massard (2014)
Navicelli di Pisa Park (Area Navicelli di Pisa)	Player	industrial	Italy	Massard (2014)
Padova Industrial Park (Zona Industriale di Padova, ZIP)	Player	industrial	Italy	Massard (2014)
Ponte Rizzoli Industrial Park (Area Industriale di Ponte Rizzoli)	Player	industrial	Italy	Massard (2014)

Prato 1st Industrial Macrolotto (1° Marcolotto Industriale di Prato)	Player	industrial	Italy	Massard (2014)
San Daniele s.c.a.r.l Agrifood Park	Player	combined	Italy	Massard (2014)
Ecopark Windhof	Player	combined	Luxembourg	Massard (2014)
Biopark Terneuzen	Player	industrial	Netherlands	Massard (2014)
Chemiepark Delfzijl	Player	industrial	Netherlands	Massard (2014)
Emmtec industry & business park	Player	industrial	Netherlands	Massard (2014)
Moerdijk	Player	industrial	Netherlands	Massard (2014)
Rietvelden – De Vutter (RiVu)	Player	industrial	Netherlands	Massard (2014)
South Groningen business park	Player	industrial	Netherlands	Massard (2014)
Boruta Zgierz Industrial Park	Player	industrial	Poland	Massard (2014)
Business Garden Warsaw	Player	combined	Poland	Massard (2014)
Police Industrial Park	Player	industrial	Poland	Massard (2014)
Pulawy Production Park	Player	industrial	Poland	Massard (2014)
Wroclaw Industrial Park	Player	industrial	Poland	Massard (2014)
Relvão Eco-Industrial Park	Player	industrial	Portugal	Massard (2014)
ResiSt Project	Player	combined	Portugal	Massard (2014)
EKO-PARK d.o.o. Lendava	Player	industrial	Slovenia	Massard (2014)
22@Barcelona	Player	combined	Spain	Massard (2014)
Cicle Pell	Intermediaries	project	Spain	Massard (2014)
Parc de l'Alba	Player	combined	Spain	Massard (2014)
Parque tecnológico de Valencia	Player	industrial	Spain	Massard (2014)
Parque Tecnológico Galicia Tecnópole	Player	industrial	Spain	Massard (2014)
Parque tecnológico y logístico de Vigo	Player	industrial	Spain	Massard (2014)
Polígono As Gándaras	Player	industrial	Spain	Massard (2014)
Polígono industrial de Alfacar	Player	industrial	Spain	Massard (2014)
Polígono Industrial El Congost	Player	industrial	Spain	Massard (2014)
Polígono O Ceao	Player	industrial	Spain	Massard (2014)

Hammarby Sjöstad	Player	urban	Sweden	Massard (2014)
Jämtland County	Player	combined	Sweden	Massard (2014)
Landskrona Industrial Symbiosis	Player	combined	Sweden	Massard (2014)
Malmö Cleantech City	Player	combined	Sweden	Massard (2014)
Norrköping and Linköping	Player	combined	Sweden	Massard (2014)
Södra Cell – Mönsterås Network	Player	combined	Sweden	Massard (2014)
Basel Industrial Area	Player	industrial	Switzerland	Massard (2014)
Bulle industrial park	Player	industrial	Switzerland	Massard (2014)
Chablais eco-industrial region	Player	industrial	Switzerland	Massard (2014)
Cimo – Monthey Chemical Park	Player	industrial	Switzerland	Massard (2014)
Ecosite workgroup	Player	combined	Switzerland	Massard (2014)
Infrapark Baselland	Player	industrial	Switzerland	Massard (2014)
Dyfi Eco Park	Player	combined	United Kingdom	Massard (2014)
Green Park	Player	industrial	United Kingdom	Massard (2014)
Humber Industrial Symbiosis Programme	Player	industrial	United Kingdom	Massard (2014)
Ince park	Player	industrial	United Kingdom	Massard (2014)
London Sustainable Industries Park	Player	industrial	United Kingdom	Massard (2014)
Industrial Symbiosis in Helsingborg	Player	cluster	Sweden	author
Norrköping Industrial Symbiosis Network	Player	cluster	Sweden	author
Biogas2020	Intermediaries	program	SW/ DK/ NO	keep.eu
VLRB	Intermediaries	program	Germany/ Austia	keep.eu
Baltic Chemical Park	Player	industrial	Estonia	ECSPP
BASF Tarragona	Player	industrial	Spain	ECSPP
Chemical park of Huelva	Player	industrial	Spain	ECSPP
Chemiepark Knapsack	Player	industrial	Germany	ECSPP
Grangemouth	Player	industrial	United Kingdom	ECSPP
Leuna Chemical Complex	Player	industrial	Germany	ECSPP
Monksland	Player	industrial	Ireland	ECSPP
Pétfürdö	Player	industrial	Hungary	ECSPP
Port of Le Havre	Player	industrial	France	ECSPP

Strážske Chemko	Player	industrial	Slovakia	ECSPP
Valuepark Terneuzen	Player	industrial	Netherlands	ECSPP
Wolfgang Industrial Park	Player	industrial	Germany	ECSPP

7.3.
Appendix C: Sources and sector of ISN’s and Intermediaries

Table 21: Sources and sector of ISN’s and Inntermediaries

actors involved	SMEs focus	NACE														sector	link source
		A	B	C	D	E	F	G	H	I	J	K	M	N	Q		
Lifestyle & Design Cluster	N/A			1									1				
SITRA	N/A	1					1	1		1			1				
National Institute of Circular Economy (INEC)	N/A	1				1											
ORÉE	N/A			1		1	1										
Circle Economy	N/A	1		1		1	1			1			1		1		
Rediscovery Centre	N/A			1			1	1					1				
AISEC	N/A	1		1		1	1	1		1			1				
Circular Economy (ZIEDINE EKONOMIA)	N/A	1		1		1							1				
SuperDrecksKëscht	N/A	1				1	1	1		1			1				
LIPOR	N/A	1		1	1	1		1		1			1		1		
IRCEM	N/A			1	1	1	1	1		1			1				
Zero Waste Scotland	N/A			1	1	1	1	1		1							
Institute of Circular Economy (INCIEN)	N/A			1		1		1		1			1				
CirEko	N/A												1				

Circular Economy Transition	N/A			1	1	1	1	1		1			1		1		
Green Alliance	N/A	1				1				1							
London Waste and Recycling Board (LWARB)	N/A			1		1	1			1							
Kalundborg	N/A																
Kemi-Tornio	100 SMEs	1	1	1												stainless steel plant, forestry industry plant and chrome mine	
Händelö	N/A																
Eyde Network	No		1	1												Non-Ferrous metals and process industry	
Svartsengi	No			1	1											geothermal power	
NISP-Hungary	N/A	1	1	1	1	1	1	1	1	1	1	1	1	1	1	general	
REPROWIS	Yes	1	1	1	1	1	1	1	1	1	1	1	1	1	1	general	
Styrian recycling network	No			1		1	1									waste management associations, construction and primary industries	
GreenTech Cluster	No			1	1	1										Renewable energy, industrial and green power – hydro, solar and biomass – as well as the recycling sector.	https://www.greentech.at/en/uber-das-valley/
Essenscia Brussels	No			1									1			chemistry, plastics, pharma, biotech and industrial production	https://www.essenscia.be/en/essenscia/
NISP ECOREG	No	1	1	1	1	1	1	1	1	1	1	1	1	1	1	general	https://revecon.ro/articles/2017-1/2017-1-13.pdf
Bratislavsky Kraj / ERDF	No															smart city	https://ec.europa.eu/commission/presscorner/detail/en/MEMO_08_258
werecycle.be	No			1		1										plastic	http://werecycle.be/nl/home.aspx

PNSI - Programme national de synergies interentreprises	No				1			1	1				1	1		Corporate, Energy, Education, Healthcare, Retail, Govt/Military and Transportation	https://librairie.ademe.fr/dechets-economie-circulaire/1747-programme-national-de-synergies-interentreprises.html
Silver Project	No	1	1	1	1	1	1	1	1	1	1	1	1	1	1	general/ sinergy	https://www.innofunding.nl/nl/nieuws/04/06/13/project-silver-verbindt-limburgse-ondernemers/
Rotterdam Harbour INES project	N/A																
FISS - Finnish Industrial Symbiosis system	No	1	1	1	1	1	1	1	1	1	1	1	1	1	1	general/ sinergy	https://teollisetsymbioosit.fi/mika-on-fiss/
ENEA Italian Network	Yes			1	1						1		1				
Industrial Park of Rieti-Cittaducale	No			1				1								Manufacturing and Wholesale and retail trade; repair of motor vehicles and motorcycles	https://dspace.unitus.it/handle/2067/2997
Green Industrial Symbiosis Denmark	N/A																
EUR-ISA European Industrial Symbiosis Association	Yes	1		##	1		1	1									https://www.inno4sd.net/european-industrial-symbiosis-association-eur-isa-185
Harjavalta	N/A																
Wildling Butler	N/A						1									construction	https://find-and-update.company-information.service.gov.uk/company/02857797
ZeroWin	N/A			1			1	1								Electrical and Electronic Equipment (EEE); Automotive sector; Photovoltaic (PV) sector; and Construction and Demolition (C&D).	https://www.southampton.ac.uk/smmi/research/smmispecific/environmentappliedsolutions/zerowin_zerowaste_in_industrial_network.page
SMILE	N/A			1		1	1			1						hotels, charities, furniture, outdoor activity centres, hospital, recycled, waste food, biogas and construction	https://greenhospitality.ie/smile-resource-exchange-launches-national-hotline-supports-businesses-getting-greener/
Knapsack chemical park	N/A			1												chemical	https://chemicalparks.eu/parks/chemiepark-knapsack

Bazancourt- Pomacle	38 SMEs			1												Biorefinery	https://www.springerprofessional.de/en/industrial-symbiosis-at-the-bazancourt-pomacle-biorefinery/4415580
Symbioseplatform	N/A												1				https://www.smartsymbiose.com/#/welkomstpagina/industriele-symbiose/0
Biopark Terneuzen	N/A			1					1							Industrial Port	https://www.pressreleasefinder.com/prdocs/2008/Biopark_Fact_Sheet.pdf https://edepot.wur.nl/161908
Organised Waste Market (MOR)	N/A					1										waste management	https://bdigital.ufp.pt/bitstream/10284/2340/3/32-43.pdf
ResidiRecurso	N/A			1	1	1	1	1		1						Chemical; plastic and rubber; paper and cardboard; metal; organic animal and vegetable; wood and biomass; inorganic and glass; saline, waste water and process water; textiles and leather; sewage sludge	https://twitter.com/residuorecurso https://www.residuorecurso.com/en/inici
symbiosis.gr	Yes			1	1	1		1	1				1	1		aim of improving cross industry resource efficiency through the commercial trading of materials, energy and water and sharing assets, logistics and expertise.	https://www.esymbiosis.gr/site/
Manresa	N/A			1	1		1	1					1			https://www.simbiosy.com/_files/ugd/cd7287_4d90c8e2287f4e35ad48455e7483c25b.pdf	https://www.simbiosy.com/projecte-1
NISP NI	Yes			1	1	1							1	1			https://www.international-synergiesni.com/about
NISP Scotland	Yes			1	1	1							1	1			https://www.nispnetwork.com/
Rethink Sustainable Solutions	N/A			1													https://www.linkedin.com/company/rethink-srl/about/
Inex	N/A				1	1	1									biogas, recycling, construction, solar,	https://sourcing.inex-circular.com/#clients
Industrial Park of Sweden	N/A		1	1												chemical and minerals industries	https://industriellekologi.se/ipos.html

Oresundskraft	N/A				1	1										Electricity, gas, water and sewage services	https://www.oresundskraft.se/
Nordvästra Skånes Renhållning	N/A					1			1							recycling and transport	https://nsr.se/
Nordvastra Skanes Vaten och Avlopp	N/A				1	1										Electricity, gas, water and sewage services	https://www.nsva.se/
Lidkoping IS Network	N/A				1	1										energy and recycling	https://www.industriellekologi.se/symbiosis/lidkoping.html
Enkoping IS Network	N/A	1		1	1	1										biomass; agriculture; water and energy	https://www.industriellekologi.se/symbiosis/enkoping.html
Stenungsund IS Network	N/A			1												chemical	https://www.industriellekologi.se/symbiosis/stenungsund.html
Avesta IS Network	N/A		1	1	1											steel manufacturer and district heating	https://www.industriellekologi.se/symbiosis/avesta.html
Heidelberg industrial estate of Pfaffengrund	N/A			1													
Rhein Neckar	N/A			1									1			biotechnology	Top cluster Rhein-Neckar makes Germany a dynamic site for biotechnology (biorn.org)
Aspern Vienna's Urban Lakeside	N/A			1			1	1					1			Aspern Smart City	
Eco World Styria	N/A			1													
Ecopark Hartberg Steiermark	N/A			1				1									
Créalys® Scientific Park	N/A	1		1							1		1	1		life sciences (bio-industry agri-food, health, diagnostic, pharma, biotechnology, environment), ICT and digital marketing, quality management, and agrifood sectors	
Ecolys® Park	N/A				1		1									sustainable construction and short circuits	
Evolis Business Park	N/A			1			1										https://slideplayer.com/slide/11183368/

Galaxia Industrial Park	N/A										1		1				
Kaiserbaracke Industrial Park	N/A			1													
Monceau-Fontaines Park	N/A																
Tenneville Industrial Park	N/A																https://www.rtbf.be/article/tenneville-inauguration-du-parc-d-activites-economiques-7786979
Business Park Sofia	N/A			1				1								eco-city	https://pitchbook.com/profiles/company/169308-73
Aarhus Eco-city	N/A																https://www.nationalgeographic.com/travel/article/smart-cities-aarhus-denmark
Herning-Ikast Industrial Park	N/A			1												textile industry	https://p2infohouse.org/ref/24/23332.htm
Kymi Eco-Industrial Park	N/A			1													
MABU (Material Business) Project	N/A			1									1	1			
Rantasalmi Eco-industrial park	N/A			1													https://greenerideal.com/news/business/0113-rantasalmi-finlands-first-planned-eco-industrial-park/
Uimaharju Industrial Area	N/A			1													
Chemical Valley Industrial Area	N/A			1													
Croix-Fort Artisanal Park	N/A			1													
Deux Synthe Industrial Park	N/A			1													
Grand Troyes Park	N/A			1													
Havre Industrial-Harbour Park	N/A			1													

Lagny-sur-Marne and La Courtilière Industrial Parks	N/A			1													
Les Sohettes Bio-refinery	N/A			1													
Lille City	N/A																
Nogent Industrial Basin	N/A			1													
Plaine de l’Ain Industrial Park	N/A			1													
Port-Jérôme Industrial Park	N/A			1													
Roche en Brénil Wood Ecopole	N/A			1													
Technopôle de Métropole Savoie	N/A			1													
Torvilliers Industrial Park	N/A			1													
BASF Verbund site Ludwigshafen	N/A			1													
Bayer Industrial Park Brunsbüttel	Yes			1												biological or technical SME's.	
Camp CO2-Zero	N/A			1													https://www.aachener-zeitung.de/lokales/eschweiler/aus-camp-astrid-wird-camp-co2-zero_aid-27070317
Chemical industrial Park Knapsack	N/A			1												chemical industry	
Chemie- und Industriepark Zeitz	N/A			1												chemical industry	
ChemiePark Bitterfeld Wolfen	N/A			1			1	1					1			production, services, construction, retail	
Chempark Dormagen	N/A			1												chemical industry	

Chempark Krefeld-Uerdingen	N/A			1												chemical industry	
Chempark Leverkusen	N/A			1												chemical industry	
Dow Value Park	N/A			1												chemical industry	
Gertshofen Industriepark	N/A			1												chemical industry	
Gewerbenetzwerk Pfaffengrund	N/A			1												chemistry, car manufacturing, pharmaceutical industry, and services	
Honeywell Seelze	N/A			1													
Industriepark Höchst	N/A			1													
Industriepark Kalle Albert	N/A			1													
Infraleuna, Leuna	N/A			1												chemical industry	
Marl Chemical Park	N/A			1												chemical industry	
Neue Bahnstadt, Opladen	N/A			1												chemical fibres	https://www.neue-bahnstadt-opladen.de/
Oberbruch Industry Park	N/A			1													
Pharma- und Chemiepark Wuppertal	Yes			1												producers of pharmaceutical and active ingredients, with a preference for biological or technical SME's	
Schwedt Industrial Park	N/A			1													
Zero Emission Park Bottrop	N/A			1													
Zero Emission Park Bremen	N/A			1													
Zero Emission Park Kaiserslautern	N/A			1													

Amaro Industrial Park (Area Industriale di Amaro)	N/A			1													
Cairo Montenotte Industrial Park (Area Industriale di Cairo Montenotte)	N/A			1													
Envipark (Parco Scientifico Tecnologico per l'Ambiente)	N/A			1													
Lucento Industrial Area (Area Industriale Lucento)	N/A																
Navicelli di Pisa Park (Area Navicelli di Pisa)	N/A			1													
Padova Industrial Park (Zona Industriale di Padova, ZIP)	N/A			1													
Ponte Rizzoli Industrial Park (Area Industriale di Ponte Rizzoli)	N/A			1													
Prato 1st Industrial Macrolotto (1° Marcolotto Industriale di Prato)	N/A			1													
San Daniele s.c.a.r.l Agrifood Park (Parco-Agro- Alimentare di San Daniele s.c.a.r.l.)	N/A																
Ecopark Windhof	N/A																
Biopark Terneuzen	N/A	1		1												sustainable agro-industrial activities.	

Chemiepark Delfzijl	N/A			1													
Emmtec industry & business park	N/A			1				1								manufacturing and maintenance companies, chemistry industry, new materials, commercial services, and utilities	
Moerdijk	N/A			1												sustainable production processes and has several economic sectors, including a Shell refinery, Arcelor Mittal, Tetra Pak, Thyssen Krupp, and DHL	
Rietvelden – De Vutter (RiVu)	N/A			1		1			1							food industry, logistics, and recycling	
South Groningen business park	N/A			1		1			1							food industry, logistics, and recycling	
Boruta Zgierz Industrial Park	N/A			1													
Business Garden Warsaw	N/A																
Police Industrial Park	N/A			1													
Pulawy Production Park	N/A			1													
Wroclaw Industrial Park	N/A			1													
Relvão Eco-Industrial Park	N/A			1													
ResiSt Project	N/A	1		1										1		agricultural, industrial and services activities to housing.	
EKO-PARK d.o.o. Lendava	N/A			1													https://eko-park.si/podjetje-osnovni-podatki/
22@Barcelona	N/A			1	1									1		ICT, media, biomedical, energy, and design	
Cicle Pell	N/A			1												leather industry	
Parc de l’Alba	N/A			1	1											ST-4 polygeneration plant and the residential areas	

Parque tecnológico de Valencia	N/A			1													
Parque Tecnológico Galicia Tecnópole	N/A			1													
Parque tecnológico y logístico de Vigo	N/A			1													
Polígono As Gándaras	N/A			1													
Polígono industrial de Alfacar	Yes			1												foster SMEs development based on sustainable	
Polígono Industrial El Congost	N/A			1													
Polígono O Ceao	N/A			1			1		1				1	1		trade business, manufacturing, transport, construction, and services.	
Hammarby Sjöstad	N/A																
Jämtland County	N/A																
Landskrona Industrial Symbiosis	N/A																
Malmö Cleantech City	N/A																
Norrköping and Linköping	N/A																
Södra Cell – Mönsterås Network	N/A																
Basel Industrial Area	N/A			1													
Bulle industrial park	N/A			1													
Chablais eco-industrial region	N/A			1													
Cimo – Monthey Chemical Park	N/A			1													
Ecosite workgroup	N/A																
Infrapark Baselland	N/A			1													

Dyfi Eco Park	Yes																
Green Park	N/A			1													
Humber Industrial Symbiosis Programme	N/A			1													
Ince park	N/A			1													
London Sustainable Industries Park	N/A			1													
Industrial Symbiosis in Helsingborg	N/A			1	1											energy, waste, biogas, biofertilizer	https://www.industriellekologi.se/symbiosis/helsingborg.html
Norrköping Industrial Symbiosis Network	N/A			1	1											energy	https://www.industriellekologi.se/symbiosis/norrkoping.html
Biogas2020	Yes			1	1											biogas	Project Link
VLRB	Yes			1							1					communication, marketing and communications strategies, online marketing, the development of marketing and PR instruments	Project Link
Baltic Chemical Park	N/A			1												chemical industry	
BASF Tarragona	N/A			1												chemical industry	
Chemical park of Huelva	N/A			1												chemical industry	
Chemiepark Knapsack	N/A			1												chemical industry	
Grangemouth	N/A			1												chemical industry	
Leuna Chemical Complex	N/A			1												chemical industry	
Monksland	N/A			1												chemical industry	
Pétfürdö	N/A			1												chemical industry	
Port of Le Havre	N/A			1												chemical industry	
Strážske Chemko	N/A			1												chemical industry	

Valuepark Terneuzen	N/A			1												chemical industry	
Wolfgang Industrial Park	N/A			1												chemical industry	