Finanziato dall'Unione europea NextGenerationEU

Ministero dell'Università e della Ricerca

Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

Finanziato nell'ambito del Piano Nazionale di Ripresa e Resilienza PNRR. Missione 4, Componente 2, Investimento 1.3 Creazione di "Partenariati estesi alle università, ai centri di ricerca, alle aziende per il finanziamento di progetti di ricerca di base"

GRINS FOUNDATION

DELIVERABLE 5.1.1:

INDICATORS AND MODELS

Document data	
Title	Spoke 5 Work Package 1 D5.1.1 Indicators and Models
Owner	Università degli Studi di Torino Università degli Studi di Bergamo
Contributor/s	Intesa San Paolo, Politecnico di Milano, Prometeia, Università degli Studi di Bergamo, Università degli Studi di Torino
Document version	D5.1.1 – Final version
Last version date	01/07/2024

Executive summary

Work Package 5.1 analyzes the determining factors and the impact of innovations and technologies designed to enable the transition to the circular economy paradigm. The research activity leverages technology landscaping methodologies to develop indicators for analyzing and evaluating innovation strategies related to the circular economy, and to map geographical, sectoral, and technological topologies and their implications. By adopting an ecosystemic approach, the role of various institutional actors in the generation and dissemination of technologies related to the circular economy is modeled. Specific attention is given to interactions among businesses, universities, financial institutions, research centers, innovative startups, and incubators and accelerators. These institutions and their interactions are responsible for a significant portion of the generation and application of knowledge, representing an important area of investigation (D'Este & Perkmann, 2011). In addition, the transition to a circular model requires profound changes that extend beyond individual companies, involving the entire ecosystem where stakeholders and businesses collaborate to achieve economic, social, and environmental goals (Aarikka-Stenroos et al., 2023). Although extensive research highlights the importance of CE and the role of these organizations in knowledge creation and dissemination, there are no indicators that demonstrate their contribution to the circular economy development. To fill this gap, this work aims to develop a set of indicators that encompass the areas of innovation, university and research, firms and financing, and ecosystem relationships.

The first area of interest regards the generation of innovations and concerns the analysis of patents related to CE. This analysis allows for the creation of three indicators that emphasize the importance of tracking the shift toward a more circular economy through innovations. The first indicator is the *Circular Innovation Score*, which provides a quantitative assessment of the patents that contribute to circular economy practices. This allows for an understanding of the overall impact and progress of circular-related inventions. Secondly, the *Exposure of Local Innovation Dynamics to Circular Economy Technologies* examines the influence of CE technologies on local innovation activities, thereby identifying regions where CE technologies are being adopted and integrated into local innovation landscapes. Thirdly, the *Sectoral Exposure to Circular Economy Technologies by Province* evaluates the extent to which different economic sectors within each province are engaged with CE technologies and innovations.

The second area of interest pertains to the higher education and research sector. This sector is of particular interest due to its missions, characteristics, and role in shaping future generations. Universities and research centers serve as repositories and generators of knowledge, exerting a huge impact on the territory through the establishment of stable relationships and synergies with local actors (De Medici et al., 2018; Janzen et al., 2022). In particular, universities can contribute to the CE by considering their triple missions: teaching, research, and outreach. The indicators in this context underscore the importance of these contributions. Firstly, the *University Score of Participation in the Circular Economy* quantifies the involvement of universities in circular economy initiatives. This score highlights the contributions of academic institutions in the promotion and development of circular economy practices. Secondly, the indicator of *Publications in the Circular Economy Domain by Province and Scientific Areas* tracks the number and distribution of academic publications related to the circular economy across different provinces and scientific disciplines. This indicator is of great importance for gaining insight into the geographical and disciplinary distribution of research efforts toward the circular economy. Thirdly, the *Science-Based Technologies in the Circular Economy Domain by Province* assesses the development and implementation of technologies grounded in scientific research within the circular economy, categorized by province. This measure is essential for identifying regions where scientific research is translating into practical solutions for the CE. Collectively, these indicators provide insight into the role of universities and research in fostering circular economy innovations. They facilitate the monitoring of academic and scientific contributions by evaluating university participation, tracking relevant publications, and assessing the regional development of science-based circular technologies.

The third area encompasses the innovation indicators used to analyze the participation and performance of different firms. In this section, seven indicators are constructed to highlight the contributions to the CE transition, considering different typologies of firms. These include measures related to family-owned or innovative firms such as startups, patenting firms, and fintech firms. Firstly, the *Family Involvement in Innovative SMEs that Invest in CE* assesses the role of family-owned businesses in driving circular economy investments and supporting sustainable innovation. Secondly, the *Share of Innovative Startups in Italy by Province and Sector* tracks the distribution and sectoral focus of innovative startups across different provinces. This measure is crucial for understanding the geographic and industrial spread of startup activities related to the circular economy. Thirdly, thee connected indicators help mapping and evaluating the sacling performance of entrepreneurial ecosystem: the *Startup Formation Rate* evaluates the rate at which new startups focusing on circular economy innovations are established; the *Entrepreneurial Quality Index* measures the overall quality of entrepreneurship within a region, considering factors such as innovation, scalability, and impact; and the *Regional Entrepreneurship Cohort Potential Index* assesses the potential of entrepreneurial cohorts within different regions, thereby enabling the identification of areas with considerable potential for entrepreneurial growth and innovation in the circular economy. Fourth, the *Performance of Firms Patenting in Circular Economy* tracks the success and impact of firms that have patented circular economy innovations. Lastly, the *ECF Platform ESG Score* evaluates the environmental, social, and governance performance of firms listed on the ECF platform, allowing for the understanding of the broader impact of these firms on sustainability and ethical practices. Collectively, these indicators provide a detailed overview of the various factors influencing the circular economy from the company's point of view, highlighting its multifaced nature.

The fourth and final area of analysis pertains to the roles, interests, and perspectives of stakeholders in the implementation of CE. These indicators underscore the significance of studying stakeholder interactions, cognitive biases, and inter-firm relationships. They also emphasize the importance of integrating social and cultural aspects for successfully implementing CE (Murray et al., 2017; Shah & Rezai, 2023). The metrics for analyzing ecosystem relationships in the circular economy enable the development of three distinct indicators. Firstly, the *Stakeholder Approach to Facilitate CE* examines how different stakeholders collaborate to support and enhance circular economy initiatives. This indicator underscores the significance of a coordinated and inclusive approach among businesses, governments, and communities to drive CE practices. Secondly, the *Stakeholder Cognitive Biases in CE* explores the cognitive biases that stakeholders may have regarding circular economy practices. Understanding these biases is crucial for addressing misconceptions and fostering a more effective and rational approach to CE adoption and implementation. Thirdly, the *Relationship Among Firms Patenting in Circular Economy* analyzes the interactions and collaborations between firms that have patented circular economy innovations. This measure is essential for understanding the network dynamics and knowledge exchange that can enhance innovation and diffusion of circular technologies. These indicators collectively provide a comprehensive view of the ecosystem relationships that influence the CE implementation. By examining stakeholder collaboration, cognitive biases, and inter-firm relationships, these indicators provide a comprehensive view of the complex interplay of factors that drive the successful implementation and scaling of circular economy practices.

These innovative indicators collectively provide a comprehensive framework for the analysis and understanding of the various aspects of the circular economy. Collecting and interpreting data concerning patents, higher education and research sectors, innovative and family firms, and ecosystem relationships enable a deeper understanding of the dynamics of circular economy practices and facilitate recording all the progress and improvements.

References

Aarikka-Stenroos, L., Kokko, M. and Pohls, E.-L. (2023) “Catalyzing the circular economy of critical resources in a national system: Case study on drivers, barriers, and actors in nutrient recycling,” Journal of cleaner production, 397(136380), p. 136380.

D’Este, P., & Perkmann, M. (2011). Why do academics engage with industry? The entrepreneurial university and individual motivations. The Journal of Technology Transfer, 36(3), 316–339.

De Medici, S., Riganti, P., & Viola, S. (2018). Circular Economy and the Role of Universities in Urban Regeneration: The Case of Ortigia, Syracuse. Sustainability, 10(11), 4305.

Janzen, K., Panitz, R., & Glückler, J. (2022). Education premium and the compound impact of universities on their regional economy. *Research Policy*, *51*(1), 104402.

Murray, A., Skene, K. and Haynes, K. (2017) “The circular economy: An interdisciplinary exploration of the concept and application in a global context,” Journal of business ethics, 140(3), pp. 369–380.

Shah, M. U., & Rezai, R. (2023). Public-sector participation in the circular economy: A stakeholder relationship analysis of economic and social factors of the recycling system. Journal of Cleaner Production, 400(136700), 136700

TABLE OF CONTENTS

1. Circular innovation score

1.1 Introduction

In the face of increasing environmental challenges and resource scarcity, the imperative for a transition towards a circular economy has become increasingly evident. Such a transition has the potential to reduce resource use, decrease dependency on critical materials from other countries, and lower greenhouse gas emissions.

This potential has been clearly recognized by the European Union within the EU Taxonomy for Sustainable Activities, which identifies economic activities promoting the transition towards a circular economy as being aligned with a net zero trajectory and significantly contributing to the environmental goals outlined by the regulation. This recognition underscores the utmost importance of identifying circular practices.

As of now, there is no unique definition of circular economy in the literature. Nobre and Tavares (2021) suggest the following definition that combines some of the past attempts to describe such a multifaceted concept: *"Circular Economy is an economic system that targets zero waste and pollution throughout materials lifecycles, from environment extraction to industrial transformation, and to final consumers, applying to all involved ecosystems. Upon its lifetime end, materials return to either an industrial process or, in case of a treated organic residual, safely back to the environment as in a natural regenerating cycle"*.

This paradigm shift holds profound implications for various sectors, ranging from manufacturing to services, necessitating innovative approaches and technologies to realize their full potential.

Monitoring the state of the transition towards a more circular economy is essential with a view to understanding where it is most urgent to act and where advancements are most necessary. Various metrics exist in the scientific literature: however, some of them only account for specific components of circularity (e.g., recycling). Furthermore, current efforts and initiatives in the field of circularity measures show a huge variety of purposes and audiences.

One of the first proposals aimed at developing a standardized set of circular economy indicators at the company level was supported by the Ellen MacArthur Foundation (2015). The approach is based on metrics concerning input in the production process, utility during use phase, destination after use and efficiency of recycling. Circular economy can also be measured at more aggregate levels: for instance, Eurostat (2023) provides some data of circular indicators at the country level in its monitoring framework, related to production and consumption, waste management, secondary raw materials, competitiveness and innovation, global sustainability and resilience. ESPON (2019) provides a territorial overview of circular economy by estimating regional performance over a set of relevant indicators (changes in domestic material consumption, waste generation per capita, turnover of circular economy business models).

An alternative approach to measure the transition towards a circular economy focuses on the development and the diffusion of circular innovations. Within this context, patents emerge as a crucial lens through which to examine and forecast the trajectory of circular economy developments. Patents not only represent technological innovations but also serve as indicators of future market trends and areas of investment. Analyzing patent activity provides insights into the direction of research and development efforts, identifies emerging technologies, and highlights potential areas for collaboration and investment in the transition towards a circular economy.

Despite the growing recognition of the importance of patents in shaping the circular economy landscape, the existing literature suffers from a critical gap: the absence of a standardized classification system for circular economy patents. Without a clear taxonomy, researchers, policymakers and industry stakeholders face challenges in accurately assessing the scope, impact and evolution of circular economy innovations. Indeed, existing patent classification systems often fall short of capturing the multidimensional nature of circular economy technologies, resulting in fragmented and incomplete analyses (Venugopalan and Rai, 2015).

We aim at addressing this gap by introducing a novel taxonomy for classifying circular economy patents. This taxonomy not only simplifies the identification of circular technologies but also facilitates more accurate and insightful assessments of the state of the circular economy innovation. The presented classification identifies both patents related to waste management technologies and those containing circular-economy-related keywords in their abstracts or titles.

Once a taxonomy for circular patents is developed, an analysis of the sectoral and geographical distribution of circular patents in Italy is performed. We then extend the analysis to the network of patent citations, identifying the number of patents citing and cited by circular patents. This allows to identify crucial interconnections for enabling technologies as well as potential adopters of circular technologies.

The resulting indicators represent a first step towards a deeper understanding of the circular economy innovation landscape and the identification of pivotal technological drivers and adopters, which would allow us to assess the broader economic ramifications of the circular economy transition. Such insights will inform strategic decision-making for policymakers, industry stakeholders and researchers committed to advancing sustainable development and innovation agendas, fostering collaboration towards a more sustainable future.

1.2 Literature Review

Despite the critical importance of measuring the transition towards a circular economy and the significant role of innovation in facilitating this shift, there currently exists no standardized classification for circular patents.

To date, circular patents have primarily been identified by looking at codes from the Cooperative Patent Classification (CPC) and International Patent Classification (IPC) (Valero-Gil and Scarpellini, 2024; Portillo-Tarragona, Scarpellini and Marín-Vinuesa, 2022; Hysa et al., 2020; Marino and Pariso, 2020) – and especially technology classes related to waste treatment and recycling technologies. However, this approach is inadequate for capturing the full spectrum of the circular economy.

An alternative approach for the identification of circular patents consists of text analysis techniques to extract insights from titles and abstracts. Text analysis represents a scalable and efficient method for identifying relevant patents and uncovering trends and patterns within patent datasets. One of the strategies concerns the use of keywords (e.g., Gerdsri and Teekasap, 2022; Venugopalan and Rai, 2015), such as the terms used in the 9R framework (refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, recover). However, this methodology can be inaccurate in identifying all the relevant patents: spelling mistakes in patent descriptions may exclude innovators from the sample and the use of the 9R words in the everyday language can bring to the inclusion of non-CE patents in the sample. To overcome this problem, the keywords approach can be combined with the use of CPC/IPC classifications (Popp et al., 2011, Dechezleprêtre et al., 2011). This methodology restricts the search to patents of selected economic sectors, reducing the probability of selecting false positives, but may still fail to capture the entire universe of circular patents.

1.3 Methodology

We employ patent data from PATSTAT (2023 Spring edition), which provides a comprehensive set of patent information, including bibliographic data, standard patent classifications, and applicant information. We focus on filings made by Italian firms at the European Patent Office between 1997 and 2021, consisting of 70,634 patents filed by 15,004 firms.

We trained the algorithm by first identifying patents related to waste management technologies based both on the CPC and IPC technology classifications, as these technologies are widely recognized in the literature as being circular. This initial set consists of 590 patents (less than 1% of total considered patents).

To create a new taxonomy of circular patents, we employ a keyword-search algorithm. This algorithm involves the identification of keywords related to the circular economy, which are then used to refine the initial set of patents.

Keywords are identified through the following steps. First, we identify circular terms associated with the 9R paradigm. We, then, analyze the abstracts and titles of patents related to waste management to identify the most frequent circular economy terms. This process involves natural language processing techniques to extract relevant terms and assess their frequency. Additionally, we make use of the International Energy Agency database of green technologies to identify circular terms present in established repositories of sustainable technologies. The keywords identified via the previous steps are then manually validated to ensure their relevance to the circular economy context, thus eliminating irrelevant terms.

Using the identified keywords, we refine the initial set of patents related to waste management, selecting those that demonstrate a clear association with circular economy principles and practices. This refinement process involves matching patent titles and abstracts containing groups of identified keywords, allowing us to create a more targeted set of circular patents for analysis: patents whose title and abstract contain at least three terms from the adopted set of keywords are considered as potentially circular. Such patents are then manually checked to eliminate false positives. The manual validation phase further allows us to verify that the set of keywords does not generate too many false positives, thus, corroborating the validity of the keyword set and the threshold of three keywords used to tag potentially circular titles and abstracts.

The final set of circular patents consists of approximately 1,400 patents, corresponding to about 2% of the total number of patents filed by Italian firms in the considered timeframe. We, then, explore the evolution of circular patents' applications over time and their sectoral and geographical distribution. Moreover, we analyze the backward and forward citations of each circular patent.

The proposed metrics are presented in Table 1.

Table 1: Variables, metrics and sources.

Variable	Metric	Source
CE patents	Circular patents by economic sector (NACE 2-digits) of the patenting firm, year of patenting (1997-2021), and province (NUTS 3 level) – if more than 3-5 firms. Absolute number and proportion over the total number of filed patents.	Patstat, Orbis
CE-enabling patents	Number of patents cited by CE patents and their distribution by technological class (CPC/IPC) and province (NUTS 3 level).	Patstat

CE-adopting patents	Number of patents citing CE patents and their distribution by technological class (CPC/IPC) and province (NUTS 3 level).	Patstat

References

Dechezleprêtre, A., Glachant, M., Haščič, I., Johnstone, N., & Ménière, Y. (2011). Invention and transfer of climate change-mitigation technologies: A global analysis. Review of Environmental Economics and Policy, 5(1), 109–130.

Ellen MacArthur Foundation (2015). Material Circularity Indicator (MCI). https://www.ellenmacarthurfoundation.org/material-circularity-indicator

ESPON (2019). CIRCTER – Circular Economy and Territorial Consequences, Final Report (Main Report). https://www.espon.eu/circular-economy

Eurostat (2023). Improved circular economy monitoring framework now live. https://ec.europa.eu/eurostat/web/products-eurostat-news/w/wdn-20230515-1

Gerdsri, N., & Teekasap, P. (2022). Identifying Potential Areas for Circular Economy Development from the Perspective of Developing Economies: Using Patent and Bibliometric Analyses. International Journal of Automation Technology, 16(6), 838-844.

Hysa, E., Kruja, A., Rehman, N. U., & Laurenti, R. (2020). Circular economy innovation and environmental sustainability impact on economic growth: An integrated model for sustainable development. Sustainability, 12(12), 4831.

Marino, A., & Pariso, P. (2020). Comparing European countries' performances in the transition towards the Circular Economy. Science of the Total Environment, 729, 138142.

Nobre, G. C., & Tavares, E. (2021). The quest for a circular economy final definition: A scientific perspective. Journal of Cleaner Production, 314, 127973.

Popp, D., Haščič, I., & Medhi, N. (2011). Technology and the diffusion of renewable energy. Energy Economics, 33(4), 648–662.

Portillo-Tarragona, P., Scarpellini, S., & Marín-Vinuesa, L. M. (2022). 'Circular patents' and dynamic capabilities: new insights for patenting in a circular economy. Technology Analysis & Strategic Management, 36(7), 1571–1586.

Venugopalan, S., & Rai, V. (2015). Topic based classification and pattern identification in patents. Technological Forecasting and Social Change, 94, 236–250.

2. Patent-based indicators of exposure to CE, based on Large Language Models

2.1 Introduction

To realize its full potential, the CE calls for a systemic change in companies, industries, and the economy through radical shifts in societal values, norms, and behaviors (Chizaryfard, Trucco, & Nuur, 2021; Murray et al., 2017). In this scenario, industrial and regional systems are expected to encompass radical and systemic innovation to search for new and creative solutions, such as cleaner technologies, innovative business models, infrastructures, and institutional capacity (Chizaryfard et al., 2021). Thus, the urgent need for a successful transition from a linear to a circular organization of production and economy calls for a comprehensive understanding of the relationship between innovation and CE implementation (De Jesus & Mendonça, 2018).

However, despite the crucial role of innovation in designing and implementing CE transition strategies, the literature focusing on this nexus is still underdeveloped (Jakobsen et al., 2021). Former quantitative research has analyzed the innovation for the CE transition within the conceptual and methodological framework of the eco-innovation literature (Barbieri et al., 2016). On the one hand, existing studies provide insights into the evolution of single technologies applied in specific CE-related domains. For example, Barrag´an-Ocan˜a, Silva-Borjas, and Olmos-Pen˜a (2021) sought to identify the technological trajectory of wastewater reuse technologies by exploiting patent data. At the same time, few studies dealt with the firm-level drivers of CE innovation adoption, focusing on the role of demand-side factors and environmental regulation (Cainelli, D'Amato, & Mazzanti, 2020; de Jesus et al., 2018; De Jesus & Mendonça, 2018).

Within this context, the geography of innovation literature has largely neglected the study of innovation dynamics related to the CE transition. This is quite an important gap, as the heterogeneity of places in terms of skills and capabilities likely affects the development of CE-related trajectories (Fusillo, Quatraro, & Santhià, 2024), and uneven spatial evolutionary patterns can be a source of inequalities within and across regions.

The proposed indicators help filingl this gap by looking at Italian regions' innovation patterns in the CE domain. In doing so, we adopt a recombinant knowledge perspective (Weitzman, 1998) and implement an analysis of the drivers behind the generation of new technologies recombining CE-related knowledge.

2.2 Literature review

2.3 Methodology

2.3.1 Identifying CE patents: state of the art

In order to investigate the knowledge recombination dynamics of CE technologies, extant literature uses patent data. Patents are commonly employed as proxies for inventions to assess technological progress since they provide granular information on the location, time, and specific technological classification of the invention. Notwithstanding the well-known drawbacks in using patent data (Griliches, 1998), primarily due to the existence of alternative protecting tools and to the different patenting rates or the impossibility to protect all inventions with patents, this remains one of the most effective ways to explore the broad set of invention activities and the recombinant pattern of CE knowledge (Jaffe & Trajtenberg, 2002; Strumsky, Lobo, & Van der Leeuw, 2012).

Data related to patents are sourced from the Organisation for Economic Cooperation and Development (OECD) REGPAT database, March 2020. We focus on patent applications at the European Patent Office (EPO) published between 1980 and 2015. We use the inventor's address, provided at the NUTS2 regional level, to detect the patents' geographic origin. [1] We also exploit the OECD Citation Database, March 2020, to retrieve all the citations in the EPO and PCT patent documents. In the case of co-invented patents with inventors residing in different regions, patent applications are proportionally allocated to all the co-inventing regions following a fractional counting procedure.

These studies rely on the widely accepted classification developed by the European Commission (EC) to identify patents related to the CE. Included in the set of CE indicators to monitor progress towards a circular economy on the thematic area of competitiveness and innovation, the EC provides a list of CPC (Cooperative Patent Classification) technological classes associated to CE.[2] The list encompasses all technological fields in the subclass Y02W: "Climate change mitigation technologies related to wastewater treatment or waste management".

Machine learning techniques, and Large Language Models in particular, can help improving our capacity to assign inventions to the CE domain, as we explain in what follows.

2.3.2 Marking a step forward using machine learning

Lately, natural language processing (NLP) and machine learning (ML) tools have gained considerable prominence in various fields, including economics and innovation research, by enhancing the processing and comprehension textual. The methodology presented in this section employs some of these tools to address the identification and classification of circular economy (CE). The GPT-3.5-turbo-16k model developed by OpenAI (OpenAI, 2024) is used to classify a sample of patents abstracts, which then serve as inputs for fine-tuning the BERT for Patents model provided by Google (Srebrovic and Yonamine, 2020) for broadering the classification tasks. Lastly, the zero-shot BERTopic model (Grootendorst, 2024) is used to further categorize CE patents into specific subclasses.

The methodology is divided into two main steps:

1. Binary classification of patents, which is in its turn conducted in two phases:
    - Phase 1: Semantic similarity and the GPT-3.5-turbo-16k model are used to classify a subsample of patents as either "YES" (circular) or "NO" (not circular).

[1] Patent applications beyond 2015 are excluded because of the known drop in recorded applications due to the time required to complete the patent application process.

[2] https://ec.europa.eu/eurostat/web/circular-economy/indicators/monitoring-framework

- Phase 2: The dataset resulting from the classification in Phase 1 is then employed to fine-tune the BERT for Patents model (Srebrovic and Yonamine, 2020) to extend the classification to the full dataset of patent abstracts.

2. Identification of CE subclasses, utilizing the the zero-shot BERTopic model (Grootendorst, 2024) on the classified CE patents.

2.3.3 Binary classification

Traditionally, the identification of CE patents has relied on keyword retrieval approaches or on the CPC classification, and particularly on class Y02W, which covers technologies related to climate change and wastewater management. However, these approaches have significant limitations. Keyword searches can lack interpretative depth, failing to assess the specific significance of keywords within the patent context, while the Y02W class only captures a subset of circular innovations, specifically those related to waste, and it may easily include false positives related to the waste management but not to the circular economy.
To address these problems, we developed a two-step described in the following. First, we classify a representative sample of patents utilizing the GPT-3.5-turbo-16k model (OpenAI, 2024). Secondly, we extend this classification to the full subset of patents through the training and mapping of the BERT for Patents model (Srebrovic and Yonamine, 2020). The following paragraphs illustrate both these steps in detail.

Phase 1. Classification of a subsample of patents through semantic similarity and LLM

To address the limitations of traditional methods for identifying CE patents, we make use of a LLM. LLMs are a special class of pretrained language models (PLMs) obtained by scaling model size, pretraining corpus, and computation. They demonstrate “emerging abilities” that allow them to achieve remarkable performances without any task-specific training (Brown et al., 2020, Wei et al., 2022). This capability has made LLMs particularly valuable in scenarios where labeled data is scarce (Gilardi et al., 2023, Alizadeh et al., 2023), so when pretrained language models like BERT or GPT-2 cannot be fine-tuned to downstream tasks (Devlin et al., 2019, Radford, 2019).

The classification process is structured through three main components: the document retrieval, the prompt, and the model inference. As for the document retrieval part, we conducted a literature review to identify 36 documents focused on the circular economy. These documents, which include academic papers and policy guidelines, are used to extract relevant features from patent abstracts. These texts are then utilized in the code pipeline to ensure that the classification criteria are comprehensive and well-grounded in established CE concepts.

Regarding the prompt, we define it iteratively by leveraging the 'chain-of-thought' prompting approach. This approach facilitates the model's decomposition of complex problems into manageable steps, enabling more effective allocation of computational resources and providing insights into the model's decision-making process. We start with a simple natural language instruction for the GPT-3.5-turbo-16k model, asking it to classify whether the content of a patent pertains to the circular economy, with no other instructions provided. We iteratively run this prompt on a sample of patents, modifying and integrating it according to the results obtained. At the end of this process, we obtain a few-shot prompt, characterized by specific instructions and related examples on how the task has to be performed. In particular, we impose the model to classify as circular all those abstract concerning the following topics: recycling, reuse, recovery, and refurbishment; renewable, reusable, non-toxic resources and energy; environmental regeneration and restoration; maximization of products life and efficiency; maintenance, repair, and upgrade of resources; use of waste streams as secondary resources; waste recovery for reuse and recycling; improvement of resource efficiency; optimization of material consumption; product design for extended lifetime and future reuse; digital platforms and technologies for tracking and optimizing resource reuse; biological cycles like composting and anaerobic digestion returning materials to the ecosystem; resource recycling and efficient use.

Using the refined prompt, the GPT-3.5-turbo-16k model processes the patent abstracts (OpenAI, 2024). The model leverages its pretrained knowledge and the specific examples provided in the prompt to provide as output a binary classification ("YES" or "NO") for each abstract, indicating whether the patent is related to the circular economy.

Phase 2. Fine-tuning of the BERT for Patents model for the identification of CE patents task

In the second step, we employ the BERT for Patents model (Srebrovic and Yonamine, 2020) to extend the classification over the full dataset of patent abstracts. BERT for Patents is a model provided by Google and available on Hugging Face. It is based on BERTLARGE (Devlin et al., 2019) and fine-tuned on more than 100 million patents (Srebrovic and Yonamine, 2020). In this phase, patent abstracts are tokenized and chunked using the BERT tokenizer. The tokenization process includes handling overflow and creating attention masks to ensure proper sequence representation for the model. The dataset is then split into training and validation sets. A custom Trainer class is implemented to compute weighted loss during training. Hyperparameter tuning is conducted using Optuna to optimize the model's performance. The training process is further enhanced with callbacks like ReduceLROnPlateau and EarlyStoppingCallback to prevent overfitting and adjust learning rates dynamically. Once trained and validated, the model is used to classify the full dataset of patents.

2.3.4 Identification of CE subclasses

As for the second step of the methodology, we focus on the identification of CE subclasses, in order to delve deeper into the different CE themes. relies on the zero-shot BERTopic model (Grootendorst, 2022). Zero-shot topic modeling is a technique that allows to find topics defined in advance in large amounts of documents (Grootendorst, 2024). In this step, the ultimate goal is to assign each patent to the framework proposed by the Ellen MacArthur Foundation, that identifies three main pillars concerning the circular economy: the first one concerns the prioritization of regenerative resources, the second is related to stretching the products lifetime, and the thirds regards the use of waste as a resource (Figure 1) (Ellen MacArthur Foundation, 2013). Moreover, each of these three pillars is in its turn associated with associated with other reference frameworks, such as the 10R Framework, its simplified version the 5R Framework, and the Flow Framework devised by Bocken et al. (2016).

The zero-shot BERTopic method allows not only find those specific topics, as the three pillars in this case, but also to create new topics for those patents abstracts that do not fit with your predefined topics. This allows for extensive flexibility that is particularly advantageous when dealing with a topic as cross-cutting as the circular economy (Grootendorst, 2024). For this second part of the methodology, the output is a multiclass classification related to how different abstracts fit within circular economy issues, not only those already defined by the theoretical framework but also opening up to up-down results.

The methodology presented in this section offers a comprehensive approach to identifying and classifying patents related to the circular economy (CE) by leveraging advanced natural language processing (NLP) and machine learning (ML) tools. By integrating the GPT-3.5-turbo-16k model, the BERT for Patents model, and the zero-shot BERTopic model, we have developed a robust framework capable of addressing the limitations of traditional keyword-based and CPC classification methods.

CIRCLE ECONOMY'S CORE ELEMENTS	STRATEGIES FOR RESOURCE CYCLING[13]	10R FRAMEWORK	5R FRAMEWORK
Prioritise Regenerative Resources	Regenerate flows		
	Narrow flows	Refuse	
		Reduce	Reduce
		Rethink	
Stretch the Lifetime	Slow flows	Reuse	Reuse
		Repair	Repair
		Refurbish	Refurbish
		Remanufacture	
Use Waste as a Resource	Close flows	Repurpose	
		Recycle	Recycle
		Recover	

Figure 1. CE framework proposed by the Ellen MacArthur Foundation.

2.3.5 The indicators

2.3.5.1 Exposure of local inovation dynamics to CE technologies

The indicator of local exposure to Circular Economy (CE) technologies is meant to capture the extent to which the technologies for which the local area has a Revealed Technological Advantage (RTA) show a high incidence of the exploitation of CE-related technologies. Precisely, the exposure of a local area to CE technologies is higher if the local area is specialised (has an RTA) in technologies for which the technological advancement significantly relies on CE technologies.

The construction of the local exposure indicator consists of two steps. The first step combines two main quantities, i.e., the RTA of the local areas in each technology and the incidence of the use of CE-related technologies. Formally, let *r* be the local area, *i* the technology – i.e., the technology classes to which patent documents are assigned at the 4-digits level of the Cooperative Patent Classification (CPC) scheme – and *t* the time. Accordingly, we can define the exposure to CE technologies of local area *r* in technology *i* at time *t*, as follows:

$$CE\ exposure_{rit} = 1[RTA_{rit}] \times \frac{CE\ PatCit_{it}}{Pat_{it}}$$

where $1[RTA_{rit}]$ is an indicator function taking value 1 if the local area has an RTA in technology *i*; $CE\ PatCit_{it}$ is the number of patents worldwide classified in technology *i* that cite (through backward citation) CE-related patents; Pat_{it} is the number of patents worldwide classified in technology *i*. The RTA of a local area in a given technology is calculated exploiting the location quotient function set equal to 1 if the location quotient is greater or equal to 1, and 0 otherwise. Formally, the RTA of local area *r* in technology *i* at time *t* is defined as follows:

$$RTA_{rit} = \frac{\frac{Pat_{rit}}{\sum_t Pat_{rit}}}{\frac{\sum_r Pat_{rit}}{\sum_t \sum_r Pat_{rit}}}$$

The second and last step consists in summing up the area-technology specific exposure at the local area level, as follows:

$$CE\ exposure_{rt} = \sum_i CE\ exposure_{rit}$$

where $CE\ exposure_{rt}$ measure the exposure of local area *r* at time *t* to CE technologies.

2.3.5.2 Sectoral exposure to CE technologies, by province

The indicator of sectoral exposure to Circular Economy (CE) technologies by province is meant to capture the extent to which the industries in which the province's inventive activity concentrates, show a high incidence of CE-related technologies. Precisely, the sectoral exposure of a province to CE technologies is higher the higher the relevance of CE-technologies in industries in which provinces are more active in terms of inventive activity.

The construction of the sectoral exposure indicator consists of two steps. Firstly, patents are assigned to industries following the Algorithmic Links with Probabilities (ALP) approach as proposed in Lybbert and Zolas (2014), assigning a probability weight for each technology class-industry correspondence. Following this procedure, each patent is assigned to one or more industrial sectors, weighted proportionally to the relevance of the technologies – at the 4-digits level of the Cooperative Patent Classification (CPC) scheme – into which the patents is classified with respect to the corresponding industry.

The second and last step combines two main quantities, i.e., the weight of industries in the patents portfolio of the province and the incidence of CE technologies in the sector. Formally, let *r* be the province, *i* the industry and *t* the time. The sectoral exposure to CE technologies of province *r* in industry *i* at time *t*, is defined as follows:

$$CE\ exposure_{rit} = Ind\ W_{rit} \times \frac{CE\ Pat_{it}}{Pat_{it}}$$

where $Ind\ W_{rit}$ is the weight (share) of patents of province *r* in industry *i*; $CE\ Pat_{it}$ is the number of CE-related patents worldwide classified in industry *i*; Pat_{it} is the number of patents worldwide classified in industry *i*.

References

Bocken, Nancy M. P., Ingrid de Pauw, Conny Bakker, and Bram van der Grinten. "Product Design and Business Model Strategies for a Circular Economy." Journal of Industrial and Production Engineering 33, no. 5 (2016): 308–320. https://doi.org/10.1080/21681015.2016.1172124.

Brown, Tom B., Benjamin Mann, Nick Ryder, Melanie Subbiah, Jared Kaplan, Prafulla Dhariwal, Arvind Neelakantan, Pranav Shyam, Girish Sastry, Amanda Askell, Sandhini Agarwal, Ariel Herbert-Voss, Gretchen Krueger, Tom Henighan, Rewon Child, Aditya Ramesh, Daniel M. Ziegler, Jeffrey Wu, Clemens Winter, Christopher Hesse, Mark Chen, Eric Sigler, Mateusz Litwin, Scott Gray, Benjamin Chess, Jack Clark, Christopher Berner, Sam McCandlish, Alec Radford, Ilya Sutskever, and Dario Amodei. "Language Models are Few-Shot Learners." arXiv (2020). https://arxiv.org/abs/2005.14165.

Devlin, Jacob, Ming-Wei Chang, Kenton Lee, and Kristina Toutanova. "BERT: Pre-training of Deep Bidirectional Transformers for Language Understanding." North American Chapter of the Association for Computational Linguistics (2019).

Ellen MacArthur Foundation. "Towards the Circular Economy: Economic and Business Rationale for an Accelerated Transition." (2013). https://tinyurl.com/hzfrxvb.

Gilardi, Fabrizio, Meysam Alizadeh, and Maël Kubli. "ChatGPT Outperforms Crowd Workers for Text-Annotation Tasks." Proceedings of the National Academy of Sciences 120, no. 30 (July 2023). https://doi.org/10.1073/pnas.2305016120.

Grootendorst, Maarten. "BERTopic: Neural Topic Modeling with a Class-based TF-IDF Procedure." arXiv preprint arXiv:2203.05794 (2022).

Grootendorst, Maarten. "Zero-shot Topic Modeling." BERTopic. Last modified 2024. https://maartengr.github.io/BERTopic/getting_started/zeroshot/zeroshot.html.

Lybbert, T. J., & Zolas, N. J. (2014). Getting patents and economic data to speak to each other: An 'algorithmic links with probabilities' approach for joint analyses of patenting and economic activity. Research Policy, 43(3), 530-542.

OpenAI. "GPT-3.5 Turbo." OpenAI Platform. Accessed June 12, 2024. https://platform.openai.com/docs/models/gpt-3-5-turbo.

Radford, Alec, Jeff Wu, Rewon Child, David Luan, Dario Amodei, and Ilya Sutskever. "Language Models are Unsupervised Multitask Learners." (2019).

Srebrovic, Rob, Yonamine, Jay. "BERT for Patents." White Paper (2020) https://services.google.com/fh/files/blogs/bert_for_patents_white_paper.pdf.

Wei, Jason, Xuezhi Wang, Dale Schuurmans, Maarten Bosma, Ed Huai-hsin Chi, F. Xia, Quoc Le, and Denny Zhou. "Chain of Thought Prompting Elicits Reasoning in Large Language Models." arXiv abs/2201.11903 (2022).

4. University score of participation to Circular economy

4.1 Introduction

Higher education institutions (HEIs) have the potential to play a pivotal role in the transition to a circular economy (CE), given their missions, characteristics, and role in shaping the future generations of citizens and leaders. However, the implementation of CE in HEIs is still an emerging topic and there is a scarcity of information regarding the practical application of CE strategies to them (Mendoza et al., 2019a). In addition, few studies have analyzed the implementation and the evaluation of circularity principles adopted and no methodologies or tools have been developed to measure the level of CE implementation in HEIs (Mendoza et al., 2019b; Valls-Val et al., 2023). Our indicator aims to address this gap. In particular, universities can contribute to the CE by considering their triple missions: teaching, research, and outreach. In light of the previous considerations, the objective of our indicator is to assess the circularity propensity of universities with regard to their teaching and research activities. This indicator will consider various elements, including courses, publications, citations, and research centers. In addition, data will be collected from online databases and websites in order to ensure objectivity.

4.2 Literature Review

The formulation of a metric to assess the engagement of HEIs in the transition towards a circular economy presents a multifaceted challenge, given the absence of a predefined model. Deda et al., (2022), Serrano-Bedia & Perez-Perez, (2022) and the Ellen MacArthur Foundation, (2013), posit that HEIs can contribute to the transition towards a circular economy in five distinct categories: by incorporating CE principles into their teaching, by guiding student-led innovation, by encouraging research on CE, by shaping and influencing local change, and by managing their campuses in a sustainable manner. The first and third categories are of particular importance to our purpose, as they align with the teaching and research missions of universities.

With regard to the first category, one of the most significant contributions of HEIs is the generation of human capital, which is of vital importance in educating individuals who are aware of the necessity for a transition toward a circular economy (Chiappetta Jabbour et al., 2020). In this context, universities play a crucial role in developing business leaders and policymakers with the appropriate skills and sensitivity regarding CE principles (Kılkış & Kılkış, 2017). In order to achieve this objective within the context of the teaching mission, the initial step is to establish and design courses that will successfully train future professionals with the requisite skills in terms of CE. Concurrently, the advancement of research in the field of CE is of critical importance for the dissemination of knowledge but despite that, research topic receives fewer citations in literature (Vergani, 2024). Nevertheless, it is crucial to stimulate research in this area to provide the indispensable insights and knowledge necessary to facilitate industrial and policy adaptations favorable to CE (Serrano-Bedia & Perez-Perez, 2022). Notably, the identification of suitable metrics remains a subject of ongoing discourse. In this regard, (Valls-Val et al., 2023) proposed some metrics that can be useful to evaluate the participation of universities to circular economy.

4.3 Methodology

In this study, we have developed a scoring system that encompasses both Italian public and private universities. Schools of higher education were excluded from consideration due to the unavailability of data concerning CE courses. The table below provides a summary of all variables considered, along with their respective metrics and sources. In detail, the data regarding courses is extracted from the MUR database and pertains to the period between 2000 and 2023. The metrics for publication and citations are a cumulative measure of all papers that belong to the CE topic and their respective citations. In order to ensure the greatest possible inclusivity, we have chosen to include not only the keyword "circular economy," but also other topics that are relevant to the field. This is of particular importance, given that CE represents an umbrella concept encompassing a multitude of different topics and definitions (Homrich et al., 2018). Finally, we count the number of research centres that operate in accordance with CE principles.

The methodology employed to construct the score entails the generation of rankings for each criterion, followed by the calculation of their average. Subsequently, a new scoring scale, ranging from 0 to 100, is generated.

Table 2: CE variable, metrics, and sources.

Variable	Metric	Source
CE courses	Number of degree courses that present in the title one of the terms associated with circular economy.	MUR database
CE publication	Total number of publication of universities that present one of these keywords in the title, abstract or paper keywords: *circular economy, cradle-to-cradle, industrial metabolism, industrial ecology, industrial symbiosis*	SCOPUS
CE citations	Number of citations of CE publication. This measure represents a proxy of research quality.	SCOPUS
CE research centres	Number of research centres established by universities that have a circular principle in their mission or activities.	Universities Websites

References

Chiappetta Jabbour, C. J., De Camargo Fiorini, P., Wong, C. W. Y., Jugend, D., Lopes De Sousa Jabbour, A. B., Roman Pais Seles, B. M., Paula Pinheiro, M. A., & Ribeiro Da Silva, H. M. (2020). First-mover firms in the transition towards the sharing economy in metallic natural resource-intensive industries: Implications for the circular economy and emerging industry 4.0 technologies. *Resources Policy*, *66*, 101596. https://doi.org/10.1016/j.resourpol.2020.101596

Deda, D., Barros, M. V., Rigueiro, C., & Ribau Teixeira, M. (2022). From Linear to Circular Ideas: An Educational Contest. *Sustainability*, *14*(18), 11207. https://doi.org/10.3390/su141811207

Ellen MacArthur Foundation. (2013). *Towards the circular economy Vol. 1: An economic and business rationale for an accelerated transition*. https://www.ellenmacarthurfoundation.org/towards-the-circular-economy-vol-1-an-economic-and-business-rationale-for-an

Homrich, A. S., Galvão, G., Abadia, L. G., & Carvalho, M. M. (2018). The circular economy umbrella: Trends and gaps on integrating pathways. *Journal of Cleaner Production*, *175*, 525–543. https://doi.org/10.1016/j.jclepro.2017.11.064

Kılkış, Ş., & Kılkış, B. (2017). Integrated circular economy and education model to address aspects of an energy-water-food nexus in a dairy facility and local contexts. *Journal of Cleaner Production*, *167*, 1084–1098. https://doi.org/10.1016/j.jclepro.2017.03.178

Mendoza, J. M. F., Gallego-Schmid, A., & Azapagic, A. (2019a). A methodological framework for the implementation of circular economy thinking in higher education institutions: Towards sustainable campus management. *Journal of Cleaner Production*, *226*, 831–844. https://doi.org/10.1016/j.jclepro.2019.04.060

Mendoza, J. M. F., Gallego-Schmid, A., & Azapagic, A. (2019b). Building a business case for implementation of a circular economy in higher education institutions. *Journal of Cleaner Production*, *220*, 553–567. https://doi.org/10.1016/j.jclepro.2019.02.045

Serrano-Bedia, A.-M., & Perez-Perez, M. (2022). Transition towards a circular economy: A review of the role of higher education as a key supporting stakeholder in Web of Science. *Sustainable Production and Consumption*, *31*, 82–96. https://doi.org/10.1016/j.spc.2022.02.001

Valls-Val, K., Ibáñez-Forés, V., Lo-Iacono-Ferreira, V. G., Capuz-Rizo, S. F., & Bovea, M. D. (2023). Adequacy of existing circular economy assessment tools for higher education institutions. *Sustainable Production and Consumption*, *39*, 399–413. https://doi.org/10.1016/j.spc.2023.05.011

Vergani, F. (2024). Higher education institutions as a microcosm of the circular economy. *Journal of Cleaner Production*, *435*, 140592. https://doi.org/10.1016/j.jclepro.2024.140592

5. Science and technology in the CE domain, by province and scientific areas

5.1 Introduction

Recent literature has shown increasing interest in the interplay between local scientific and technological capabilities. In this framework, Pugliese et al. (2019) have proposed a three-layered model articulating the network of interactions among science, technology and production by using data on scientific publications, patents and industrial production.

Consistently, Catalán et al. (2022) and Balland and Boschma (2022) have put forth analyses aiming at investigating the influence of scientific capabilities on technological trajectories, leveraging the concept of research space and using scientific publications to implement it (Guevara et al., 2016). The former contribution focuses on country-level dynamics and develops a measure of cross-science-technology relatedness to assess the extent to which scientific capabilities shape the patterns of countries' technological diversification. They find that this measure has a significant impact, though the effect of technological relatedness remains stronger (Catalán et al., 2022). The second study carries out a region-level analysis of the interplay between local scientific capabilities and technological diversification, exploiting scientific publications to map the science space onto the technology space, finding a robust empirical association between a strong local scientific base in a given domain and the ability of a region to develop new technologies in that specific domain (Balland and Boschma, 2022).

In line with this growing literature, this chapter illustrates the methodology to implement indicators of scientific specialization of regions in the CE domain, drawing upon publications data

5.2 Methodology

5.2.1 Data preparation

5.2.1.1 Data sources

To retrieve scientific publications data, we make use of OpenAlex database (Priem et al., 2022). OpenAlex (OA) is an open access bibliographic database launched in 2022, it covers more than 200 million scientific publications (journal articles, book chapters, conference proceedings etc.), it is fully open access and regularly updated.

Scientific publications in OA are grouped in "topics" using an automated system that takes into account the available information, including title, abstract, source (journal) name, and citations. There are 4,516 topics, each publication is associate up to 3 topics. The highest-scoring topic is that publication's "primary topic". Topics are grouped into 252 subfields, which are grouped into 26 fields, which are grouped into 4 top-level domains.

To retrieve information of patent-to-paper citations we use the "Reliance on Science" (RoS) dataset (Marx & Fuegi, 2020, 2022). RoS provides front-page and in-text citations from worldwide patents to scientific articles indexed by OA.

5.2.1.2 Identification of CE papers

To identify papers in the Circular Economy (CE) domain, we rely on the topics identified by OA. Out of the 4,516 available topics, 8 are relevant to CE research (the list is provided in the appendix). We then classify all publications grouped under either one of these 8 topics into a new subfield that we call "Circular Economy". Therefore, in our analysis, we will refer to a total of 253 subfields: the 252 subfields identified by OA, plus the newly created Circular Economy subfield.

5.2.1.3 Linking scientific domains to technologies

To link scientific domains to technologies, we follow a methodology similar to the one used in Poege et al. (2019). We create a correspondence between OA subfields and patent technology classes, based on scientific non-patent literature (SNPL) citations in patents provided by RoS. Technological domains are identified by CPC technology classes that are mentioned on patents. Scientific domains are identified by the subfield of the primary topic reported on scientific publications cited by patents. We then derive a relatedness measure for each pair of technology domain (CPC patent class) and scientific domain (paper subfield) from the fractional patent counts for technology/science domains combinations.

5.2.2 Definition of scientific knowledge space

Several methodologies have been proposed to map science into a scientific knowledge space. We follow the methodology proposed by Guevara et al. (2016), which relies on career trajectories of researchers. We calculate the scientific knowledge space to determine the relatedness between all pairs of scientific subfields. The scientific knowledge space is not based on citations, but connects two subfields when researchers are likely to have published in both of them (see the appendix for the details). Guevara et al. (2016) argue that the scientific knowledge space constructed with this methodology is more accurate with respect to those based science maps.

5.3 List of indicators

We compute the indicators at the level of the 110 Italian provinces and 253 scientific subfields.

5.3.1 Specialization in CE scientific subfield

To define de specialization in CE scientific subfield, we use the Revealed Scientific Advantage (RSA) indicator (Balassa, 1965) in which we compare the presence of a province (p), in a research subfield (f), with the presence that we expect from that province, based on its effective number of papers. If the effective number of papers produced by a province in the CE field is larger than the effective number of papers we expected from a province with that many total papers in that field, then we say that provice p is specialized in the CE field. Formally we define it as follows:

$$RSA_{p,CE} = \frac{Pubs_{p,CE}/\sum_i Pubs_{p,f}}{\sum_p Pubs_{p,CE}/\sum_p \sum_f Pubs_{p,f}}$$

We then use $RSA_{p,CE}$ to define four discrete states that we use to characterize the diversification and evolution of the CE research output of provinces:

$RSA_{p,CE} = 0$		Inactive (no papers in the CE subfield)
$RSA_{p,CE} > 0$ (Active)	$0 < RSA_{p,CE} < 0.5$	Nascent (few papers in the CE subfield)
	$0.5 \leq RSA_{p,CE} < 1$	Intermediate (less papers than expected in the CE subfield)
	$RSA_{p,CE} \geq 1$	Developed (more papers than expected in the CE subfield)

5.3.2 Proximity to CE science

To assess the potential of a province to develop CE science, we use a relatedness indicator that captures the idea that a province is more likely to develop scientific domains that are related to the existing science base in the province (Hidalgo et al., 2007). The density of scientific fields around CE in province *p* is derived from the sum of relatedness $\phi_{f,f'}$ of CE to all other scientific fields f' in which the province has a $RSA_{p,f'} \geq 1$ (We define $\boldsymbol{U}_{p,f}$ as a matrix that is equal to one when $RSA_{p,f'} \geq 1$ and 0 otherwise), divided by the sum of relatedness of CE to all other subfields f' in the reference region (Italy):

$$\omega_{p,CE} = \frac{\sum_{f'} \boldsymbol{U}_{p,f'} \phi_{CE,f'}}{\sum_{f'} \phi_{CE,f'}}$$

This also allows us to predict a transition of a province in CE field between a pair of states defined in section 2.1. (e.g., from inactive to active) by sorting provinces by density ($\omega_{p,CE}$). The prediction is that the provinces with higher density will transition to a higher state of development before those with lower density.

5.3.3 Overlap between scientific and technology domains

In order to determine whether a province with a strong scientific base in the CE subfield also has a strong technological base in the same field, we rely on the link between scientific and technological domains (see section 1.4.). We use this information to determine whether there is match (or mismatch) between the scientific and technological bases in a province (Balland & Boschma, 2022 follow a similar approach in the case of European regions).

We measure the CE knowledge base of a province by the number of scientific publications by local researchers in subfields relevant to CE patents. We measure the CE technological base by the number of CE patents by local inventors.

We then classify provinces into the following four categories:

- *Leaders*: belong to the top 25 % (in terms of ranking) for both the number of CE patents per capita and the number of CE-related publications per capita.
- *Experts*: belong to the top 25 % for the number of CE-related publications but not for the number of CE patents per capita.
- *Innovators*: belong to the top 25 % regarding the number of CE patents but not the number of CE-related publications per capita.

– *Followers*: do not belong to any of the previous categories.

References

Balassa, B. (1965). Trade Liberalisation and "Revealed" Comparative Advantage. *The Manchester School*, *33*(2), 99-123. https://doi.org/10.1111/j.1467-9957.1965.tb00050.x

Balland, P.-A., & Boschma, R. (2022). Do scientific capabilities in specific domains matter for technological diversification in European regions? *Research Policy*, *51*(10), 104594. https://doi.org/10.1016/j.respol.2022.104594

Guevara, M. R., Hartmann, D., Aristarán, M., Mendoza, M., & Hidalgo, C. A. (2016). The research space : Using career paths to predict the evolution of the research output of individuals, institutions, and nations. *Scientometrics*, *109*(3), 1695-1709. https://doi.org/10.1007/s11192-016-2125-9

Hidalgo, C. A., Klinger, B., Barabási, A.-L., & Hausmann, R. (2007). The Product Space Conditions the Development of Nations. *Science*, *317*(5837), 482-487. https://doi.org/10.1126/science.1144581

Marx, M., & Fuegi, A. (2020). Reliance on science : Worldwide front-page patent citations to scientific articles. *Strategic Management Journal*, *41*(9), 1572-1594. https://doi.org/10.1002/smj.3145

Marx, M., & Fuegi, A. (2022). Reliance on science by inventors : Hybrid extraction of in-text patent-to-article citations. *Journal of Economics & Management Strategy*, *31*(2), 369-392. https://doi.org/10.1111/jems.12455

Poege, F., Harhoff, D., Gaessler, F., & Baruffaldi, S. (2019). Science quality and the value of inventions. *Science Advances*, *5*(12), eaay7323. https://doi.org/10.1126/sciadv.aay7323

Priem, J., Piwowar, H., & Orr, R. (2022). *OpenAlex : A fully-open index of scholarly works, authors, venues, institutions, and concepts* (Version 2). arXiv. https://doi.org/10.48550/ARXIV.2205.01833

7. Family involvement in innovative SMEs that invest in the circular economy transition

7.1 Introduction

Family involvement in innovative Small and Medium Enterprises (SMEs) that invest in the circular economy transition is an indicator that explains the complexity of family involvement in SMEs that drives investments in circular economy transition. The indicator applies the family influence construct, identifying family ownership, governance or management structure and firm identification in Italian SMEs. The objective of the indicator is to identify the mediating effect of family involvement in SMEs' circular economy investment.

7.2 Literature

SMEs like every business are made of different characteristics (Blackburn et al., 2013). These include the size, economic sector, ownership and governance structure. The ownership structure is composed of shareholders, stakeholders and family ownership (Demsetz & Villalonga, 2001). Family involvement in the context of innovative SMEs embarking on the circular economy transition presents an intriguing avenue for exploration. Italy, in particular, showcases a unique scenario of family involvement in business operations, deeply rooted in cultural traditions. Within SMEs, decisions are often profoundly influenced by family dynamics. Family-owned SMEs often prioritize values such as stewardship, legacy, and community impact (Laguir et al., 2016). This alignment can drive sustainable practices and circular economy investments. Innovative SMEs play a pivotal role in facilitating the transition towards a circular economy through their capacity for innovation. However, the interplay of family involvement within these enterprises introduces additional layers of complexity and opportunity. Understanding the nuances of family participation in innovative SMEs venturing into the circular economy transition necessitates a comprehensive exploration. To comprehend this intricate dynamic, we propose a model elucidating the role of family involvement in driving investments towards the circular economy transition within SMEs.

7.3 Methodology

Developing a model to assess family involvement in innovative SMEs investing in the circular economy transition requires a comprehensive methodology. Below is a proposed approach:

1. Identification of innovative SME involved in circular economy practices:

2. Analysis of family involvement: Using variables from family business literature such as family ownership, presence of family members in the board of directors, presence of a family member as CEO, firm name identified by family name, etc.

3. Use of the family involvement variable as a mediating variable to assess SME investment in a circular economy.

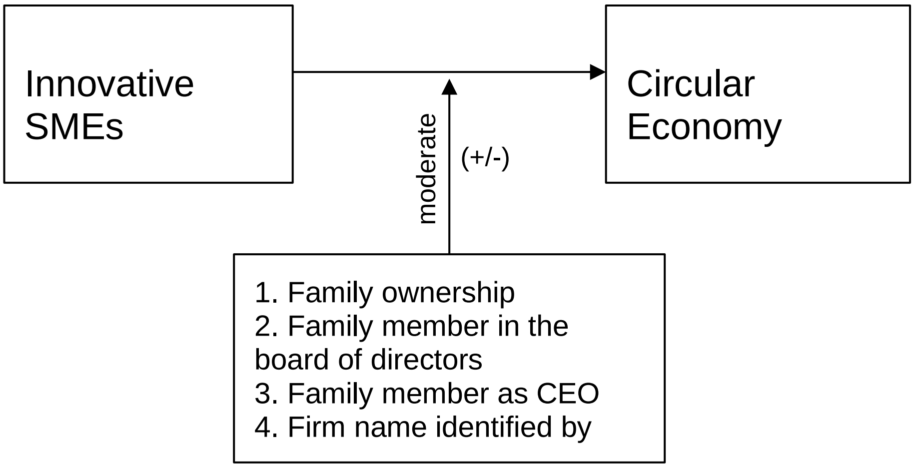

Fig. 1. Innovative SMEs and circular economy, moderated by family involvement

7.4 Conclusion

In conclusion, the family involvement in innovative SMEs in circularity investment will provide a model to better understand the moderation effect of family involvement on SMEs in the circular economy landscape.

References

Blackburn, R. A., Hart, M., & Wainwright, T. (2013). Small business performance: business, strategy and owner-manager characteristics. Journal of small business and enterprise development, 20(1), 8-27.

Laguir, I., Laguir, L., & Elbaz, J. (2016). Are family small-and medium-sized enterprises more socially responsible than nonfamily small-and medium-sized enterprises?. Corporate Social Responsibility and Environmental Management, 23(6), 386-398.

Demsetz, H., & Villalonga, B. (2001). Ownership structure and corporate performance. Journal of corporate finance, 7(3), 209-233.

8. Share of Innovative startups in Italy, by province and sector

8.1 Introduction

8.2 Literature review

8.3 Methodology

References

9. Mapping and evaluating the scaling performance of entrepreneurial ecosystems

9.1 Introduction

Innovative startups are a small fraction of the overall firm population that disproportionally contribute to employment, innovation and growth (Shane 2009). Not surprisingly, the debate on how to support the development of vibrant entrepreneurial ecosystems (EEs) has gained enormous popularity within research, policy, and practitioners over the last decade (Wurth et al. 2021). Nevertheless, assessing the state of EEs requires not simply counting the quantity but also the quality of startups in a geographical area. Also, little is known concerning the state of EE in the circular economy (CE), despite startups can play a pivotal role in the transition towards more sustainable business models. We therefore aim at measuring and evaluating the state of EEs by using novel approaches that consider the ability of EEs to generate growth-oriented startups in a geographical area, by linking a startup scaling outcome (IPO, M&A, growth) to descriptors that are available at startup's founding date (Andrews et al. 2022). Furthermore, we leverage recent advancements in Artificial Intelligence (AI) to map EEs in CE.

9.2 Literature Review

Over the past two decades, interest from both academic researchers and policymakers in the role of startup companies and in regional economic performance has surged (Feldman 2001; Schrijvers et al. 2024). This growing interest is due to the increasing recognition of the empirical link between startups and regional economic growth (Feldman et al. 2005; Glaeser et al. 2015).

Research on EEs entails a shift in the unit of analysis away from a region's total new venture population or its socio-economy to a more specific type of entrepreneurial activity—productive or growth-oriented entrepreneurship—and the actors and factors affecting this. An EE is defined as a set of interdependent elements, such as informal and formal institutions, networks of entrepreneurs, access to finance, talent, knowledge and support services, coordinated in such a way that they enable growth-oriented entrepreneurship within a particular geographical area (Isenberg 2010).

Despite the popularity of the EE approach in science and policy, there is a scarcity of credible, accurate and comparable metrics of the state of EEs (Leendertse et al. 2022). Evaluating EEs presents indeed significant conceptual and empirical challenges. Key issues include skewness and lagged performance, with a few high-performing startups disproportionately impacting overall economic performance. This makes it essential to measure both the quantity of startups and their growth potential, or "entrepreneurial quality" (Guzman and Stern 2020). Andrews et al. (2020) uses a predictive analytics approach to estimate, for any given startup, the probability of growth of that firm at or near the time of founding (a measure of its quality). Then, leveraging this measure of entrepreneurial "quality" for all firms, they introduce a set of novel entrepreneurship statistics that capture the quantity, quality and performance of any given set of firms, allowing for consistent measures of the state of EE across time and place.

An EE perspective is also useful for better understanding the transition towards a more CE (Kanda et al. 2021). Recent research has started discussing the mechanisms by which circularity can be embedded in EEs through the flow of relevant knowledge and values (Audretsch et al. 2023). Quite notably, it has been argued that startups are in a better position to adopt business models based on CE practices. This is because they do not face sunk costs resulting from legacy investments in old technology, practices and knowledge relevant to a traditional production model in a linear setting (Henry et al. 2020).

9.3 Methodology

We apply a predictive analytics approach to measure the state of an EE in order to develop indicators that consider both the quantity and quality of startups generated in a EE (Andrews et al. 2022; Guzman and Stern 2020). We use data on the population of Italian innovative startups from the official register website managed by Infocamere (the official repository of the Italian Chambers of Commerce, www.infocamere.it) and collect information on their characteristics at foundation, such as business structure, name features, IPR (patents and trademarks) and board composition using a combination of secondary data sources. We then use a predicting analytics approach in a logistic regression framework to relate the likelihood of exit through IPO/M&A or to reach a minimum size threshold in terms of turnover or assets (€5 million) within 5 years of founding to the type of business structure chosen by the startup (corporation, limited liability company), name features (eponymous firm and name length), intellectual property protection mechanism (patents and trademarks), and board composition (female board member, board experience, serial entrepreneur board member, age of board members). Predicted values are used to assess the startup quality (i.e., the potential scaling performance at a given point of time).

Table 3: Indicators, metrics, and sources.

Indicator	**Description**	**Source**
Startup Formation Rate (SFR)	Number of innovative startups at the NUTS3 level.	Infocamere
Entrepreneurial Quality Index (EQI)	Average entrepreneurial quality of startups at the NUTS3 level. Entrepreneurial quality is based on a predictive analytics approach that links the likelihood of exit through IPO/M&A or to reach a minimum size threshold in terms of turnover or assets (€5 Millions) to a set of startup characteristics at foundation (name, trademarks, patents).	Infocamere, ORBIS, Patstat, EUIPO
Regional Entrepreneurship Cohort Potential Index (RECPI)	Overall measure of the state of EE obtained by multiplying SFR with EQI.	Infocamere, ORBIS, Patstat, EUIPO

All indicators are developed by distinguishing startups operating in the CE. Specifically, we exploit an AI-based approach that analyzes the textual descriptions of the value proposition of startups to identify business models that are consistent with the CE paradigm. Textual descriptions are obtained from Infocamere. We then leverages the natural language understanding capabilities of GPT models to classify and analyze text based on contextual criteria that refer to CE.

References

Andrews, R. J., Fazio, C., Guzman, J., Liu, Y., & Stern, S. (2022). Reprint of "The startup cartography project: measuring and mapping entrepreneurial ecosystems". Research Policy, 51(9), 104581.

Audretsch, D. B., & Fiedler, A. (2023). Bringing the knowledge spillover theory of entrepreneurship to circular economies: Knowledge and values in entrepreneurial ecosystems. Article in press.

Feldman, M. P. (2001). The entrepreneurial event revisited: firm formation in a regional context. *Industrial and corporate change*, *10*(4), 861-891.

Feldman, M., Francis, J., & Bercovitz, J. (2005). Creating a cluster while building a firm: Entrepreneurs and the formation of industrial clusters. *Regional studies*, *39*(1), 129-141.

Glaeser, E. L., Kerr, S. P., & Kerr, W. R. (2015). Entrepreneurship and urban growth: An empirical assessment with historical mines. *Review of Economics and Statistics*, *97*(2), 498-520.

Guzman, J., & Stern, S. (2020). The state of American entrepreneurship: New estimates of the quantity and quality of entrepreneurship for 32 US States, 1988–2014. American Economic Journal: Economic Policy, 12(4), 212-243.

Henry, Marvin, Thomas Bauwens, Marko Hekkert, and Julian Kirchherr. "A typology of circular start-ups: An Analysis of 128 circular business models." *Journal of cleaner production* 245 (2020): 118528.

Isenberg D. (2010). How to start an entrepreneurial revolution. Harvard Business Review, 88(6), 40–50.

Kanda, W., Geissdoerfer, M., & Hjelm, O. (2021). From circular business models to circular business ecosystems. *Business Strategy and the Environment*, *30*(6), 2814-2829.

Leendertse, J., Schrijvers, M., & Stam, E. (2022). Measure twice, cut once: Entrepreneurial ecosystem metrics. *Research Policy*, *51*(9), 104336.

Schrijvers, M., Stam, E., & Bosma, N. (2024). Figuring it out: Configurations of high-performing entrepreneurial ecosystems in Europe. *Regional Studies*, *58*(5), 1096-1110.

Shane, S. (2009). Why encouraging more people to become entrepreneurs is bad public policy. *Small business economics*, *33*, 141-149.

Wurth, B., Stam, E., & Spigel, B. (2022). Toward an entrepreneurial ecosystem research program. *Entrepreneurship Theory and Practice*, *46*(3), 729-778.

10. Performance of firms patenting in circular economy

10.1 Introduction and literature review

The relationship between firms' performance and innovation in the specific Circular Economy (CE) context is still in the incipient stage of analysis in the economic literature.

Firstly, there is still an ongoing debate about specific indicators for capturing CE value and the use of patents to this end. However, it is worth noting that circular economy is closely connected to technological innovations, which are more frequently patented than other types of innovations. A circular business model can in fact be achieved by reducing dependence on raw materials and energy through innovations, by focusing on waste minimisation, and by creating circular (closed) loops in which raw materials and other resources are used repeatedly in different phases of production. We can therefore assume that circular innovation can be proxied by patents registered to protect technology innovations related to the CE model adopted by a firm, consistent with previous studies on this topic (Portillo-Tarragona et al., 2022; Fusillo et al., 2021; Modic et al., 2021; Hysa et al., 2020; Prieto-Sandova et al., 2018).

Specifically, we will contribute to the economic debate by analyzing whether the investment in circular patents generates improvements in the business performance of firms, such as sales growth and profitability ratios. Moreover, we will investigate the relationship between innovation and productivity (both labour productivity and total factor productivity (TFP)), which is still a relatively understudied topic from the CE side.

It is important to understand if and to what extent the adoption of strategies related to the environment may limit the efficiency and ability to generate income or may represent, on the other hand, a competitive advantage. The debate is still open on this front too. A first strand of literature (mainly attributable to the contributions of Jaffe et al, 1995 and Jenkins, 1998) tends to underline the increase in fixed costs and variable costs associated with regulatory environmental obligations. Environmental strategies would subtract resources from the firm core business, leading to a decrease in profitability, productivity and a consequent loss of competitiveness. Over time, however, the opposite view started to emerge. According to the "Porter's hypothesis", there exists a strong link between environmental regulation and competitiveness (Porter and Van der Linde, 1995). Environmental regulation can in fact lead companies to adopt strategies, particularly on the innovation side, which can in turn translate into an improvement in business performance. The most direct channel is cost reduction: a decrease in the cost of raw materials (energy included) can generate a positive effect on the cost of capital and labor. Moreover, the adoption of sustainable strategies could lead to an increase in sales and profitability, through the push towards product differentiation, the creation of market niches, the development of specific technologies and the consequent increase in productivity.

Among the recent studies at the micro-level which have highlighted the presence of a positive correlation between green innovation and firm performance, we can cite Mingxia Liu et al., 2024; Sangalli and Trenti, 2014; Albertini, 2013; Aguilera-Caracuel and Ortiz-de-Mandojana, 2013;Al-Tuwaijri, 2004[3]. Our analysis will contribute to this second strand of the literature by focusing specifically on the less explored intersection of circular economy innovation and the performance of manufacturing firms.

[3] Molina-Azorin J.F, 2009 and Iraldo at al., 2022, offer a good review of the literature on green management and financial performance, and on the links between environmental regulation and competitiveness.

10.2 Methodology

The empirical analysis will exploit a rich firm-level dataset of Italian manufacturing companies belonging to the Intesa Sanpaolo Research Department. The dataset matches financial KPIs (Key Performance Indicators) with circular patent demands submitted to the European Patent Office (EPO)[4], and other qualitative variables representing firm strategies, such as trademarks (source WIPO, World Intellectual Property Organization), ISO green and quality certifications subscribed by firms (source Accredia, Ente Italiano di Accreditamento), foreign direct investments (source Reprint, Milan Polytechnic).

Starting from our database, it is possible to analyze whether the most innovative companies in the CE context are more competitive than the non circular counterparts sharing the same sectoral specialization.

We measure competitiveness through various financial KPIs taken from financial statements, such as the **evolution of turnover** and **profitability ratios** (gross profit margin[5], ROI - Return on Investment[6], ROE – Return on Equity[7]). Moreover, the database allows for the estimation of **employment growth**, **labour productivity** (value added per employee) and **total factor productivity** at the firm level (TFP is estimated as the residual of a Cobb Douglas production function by applying the Levinsohn and Petrin approach (2003[8])). Summary indicators will be produced based on a sectoral-territorial approach, depending on the granularity of the matched dataset (CE patents-financial KPIs) and on data availability.

As a second step, we will enrich the analysis by considering the supply relationships of companies that patent in the circular economy (see Section 16).

References

Aguilera-Caracuel, J. and Ortiz-de-Mandojana, N. (2013) Green innovation and financial performance: An institutional approach. Organization & Environment, 26, 4, 365–385. https:// doi. org/ 10. 1177/ 10860 26613 507931.

Al-Tuwaijri, S.A., Christensen, T.E., and Hughes, K.E. (2004) The relations among environmental disclosure, environmental performance, and economic performance: a simultaneous equations approach. Accounting, Organizations and Society, 29, 5–6, 447–471. https://doi. org/ 10. 1016/ S0361 -3682(03) 00032 -1.

Albertini, E. (2013) Does environmental management improve financial performance? A meta-analytical review. Organization & Environment, 26, 4, 431–457. https://doi. org/ 10. 1177/ 10860 26613 510301.

[4] Circular patents will be identified by the working group belonging to the University of Turin (UniTO). Please refer to chapter 3 of the present document.

[5] Gross profit margin is a profitability ratio that measures what percentage of revenue is left after subtracting the cost of goods sold. The cost of goods sold refers to the direct cost of production and does not include operating expenses, interest, or taxes.

[6] Return on Investment (ROI) is the ratio between net income (over a period) and investment (costs resulting from an investment of some resources at a point in time).

[7] Return on equity, more commonly displayed as ROE, is a profitability ratio measured by dividing net profit over shareholders' equity. It indicates how well the business can utilize equity investments to earn profit for investors.

[8] The Levinsohn and Petrin approach employes instrumental variables in order to solve for the simultaneity bias in the estimation of the production function (the one arising from an endogenous labor input).

Fusillo, F., Quatraro, F., and Santhià, C. (2021) The geography of circular economy technologies in Europe: evolutionary patterns and technological convergence. In: Jakobsen, S., Lauvås, T., Quatraro, F., Rasmussen, E., and Steinmo, M. (eds), Research handbook of innovation for a circular economy. Cheltenham: Edward ElgarPublishing Ltd, pp. 277–293.

Griliches Z. (1979) Issues in assessing the contribution of research and development to productivity growth. Bell Journal of Economics. 10(1), 92-116.

Griliches, Z. (1990) Patent statistics as economic indicators: a survey. Journal of Economic Literature 1, 1324-1330. https:// doi. org/ 10. 1016/ S0169- 7218(10) 02009- 5.

Hysa, E., Kruja, A., Rehman, N.U., and Laurenti, R. (2020) Circular economy innovation and environmental sustainability impact on economic growth: an integrated model for sustainable development. Sustainability, 12, 12, 4831. https:// doi. org/ 10. 3390/ su121 24831.

Iraldo F., Testa F., Melis M., Frey M. (2011) A Literature Review on the Links between Environmental Regulation and Competitiveness, Environmental Policy and Governance Vol. 21, n. 3, pp. 210–222.

Jaffe A., Peterson S., Portney P. e Stavins R. (1995), Environmental regulation and the competitiveness of US manufacturing: what does the evidence tell us? Journal of Economic Literature, Vol.33, n.1. ,pp. 132-63.

Jenkins R. (1998) Environmental Regulation and International Competitiveness: a review of the Literature and some European Evidence, The United Nations University – Institute for New Technologies Discussion Paper Series, n.98-01.

Levinsohn, J. and Petrin, A. (2003) Estimating Production Functions Using Inputs to Control for Unobservables. Review of Economic Studies, 2, 317-341. http://dx.doi.org/10.1111/1467-937X.00246.

Mingxia Liu & Liqian Liu & Amei Feng, 2024. "The Impact of Green Innovation on Corporate Performance: An Analysis Based on Substantive and Strategic Green Innovations," Sustainability, MDPI, vol. 16(6), pages 1-19, March. DOI:10.3390/su16062588.

Modic, D., Johnson, A., and Vučkovič, M. (2021) Towards measuring innovation for circular economy using patent data. In: Jakobsen, S. et al. (ed.), Research Handbook of Innovation for a Circular Economy. Northampton, MA: Edward Elgar Publishing Ltd., pp. 1–346. https:// doi.org/ 10. 4337/ 97818 00373099.

Molina-Azorin J.F., Claver-Cortés E., Lopez-Gamero M.D., Tarì J.J. (2009), Green management and financial performance: a literature review, Management Decision, Vol.47 Iss.7, pp1080- 1100.

Porter, M.E. and van der Linde, C. (1995) Toward a New Conception of the Environment Competitiveness Relationship. Journal of Economic Perspectives, 9, 97-118. http://dx.doi.org/10.1257/jep.9.4.97

Portillo-Tarragona, P., Scarpellini, S., and Marín-Vinuesa, L.M. (2022) “Circular patents” and dynamic capabilities: new insights for patenting in a circular economy. Technology Analysis & Strategic Management. https://doi. org/ 10. 1080/ 09537 325. 2022. 2106206.

Prieto-Sandoval, V., Jaca, C. and Ormazabal, M. (2018) Towards a Consensus on the Circular Economy. Journal of Cleaner Production, 179, 605-615. https://doi.org/10.1016/j.jclepro.2017.12.224.

Sangalli I., Trenti S. (2014) Environmental strategies and firm performance in ‘hard times’: is there a causal link? Evidence from a Heckman selection model, Intesa Sanpaolo Working Papers

11. ECF platforms ESG score

11.1 Introduction

Environmental, social, and governance (ESG) issues have significantly transformed the finance industry (e.g., Edmans and Kacperczyk, 2022). Fintech, in particular, is recognized as a powerful tool for advancing sustainable objectives (United Nations, 2019), leading policymakers to develop innovative solutions to enhance ESG integration in the fintech sector. As highlighted in Deloitte's (2022, p.3) report on fintech, sustainability, and ESG: "The ongoing evolution of ESG policies has created opportunities for fintech companies to be early movers in this fast-moving area." Consequently, both consumers and investors have developed high expectations for fintech to lead on ESG issues, with a growing number of investors seeking to achieve both financial and ESG goals (e.g., Block et al., 2021). This trend is especially evident in the increasing orientation of equity crowdfunding (ECF) platforms towards ESG issues (e.g., Cumming et al., 2024). A growing number of ESG platforms has engaged with ESG over the last few years. However, despite this progress, there is still a lack of systematic measures linking ESG with ECF platforms. Our indicator aims to fill this gap by providing an objective and comparable score of the ESG orientation of ECF platforms.

11.2 Literature Review

There is growing interest on the role of ECF platforms as gatekeepers for ESG businesses seeking to list online (e.g., Kleinert et al., 2022). Previous studies have shown that platforms engaging with ESG issues tend to perform better, particularly in attracting investors (e.g., Cumming et al., 2024; Vismara, 2019). Similarly, socially responsible investments have surged in recent years, with a growing number of investors prioritizing ESG goals (e.g., Block et al., 2021). Research consistently indicates that ESG-oriented crowdfunding offerings attract a higher number of investors, especially retail investors who consider both financial returns and broader social objectives (Vismara, 2018). ESG-oriented platforms not only draw more investors but also reach a more diverse investor base, including underrepresented groups such as young investors (Tenner and Hörisch, 2020) and those who typically invest in multiple campaigns (Hornuf et al., 2022). Several factors contribute to this trend. First, the investor pool in ECF is more diverse compared to traditional funding sources (Hervé et al., 2019), with varying investment motives ranging from financial returns to support for ESG initiatives. Second, younger generations, who are more prevalent in ECF and exhibit stronger ESG orientations than older generations, find ESG goals particularly appealing (Mansouri and Momtaz, 2022). Third, the rise of ECF reflects a disillusionment with the perceived fairness of traditional financial markets and the challenges faced by entrepreneurs in securing capital (Block et al., 2018). Given these insights, there is a compelling need to develop an objective and comparable score to measure the ESG orientation of ECF platforms.

11.3 Methodology

We have developed an aggregate scoring system to measure at the regional level the ESG orientation of the Italian ECF platforms. We retrieved the list of ECF platforms from the CONSOB registry and traced them from their launch until 2022. From the platform websites and reports, we retrieved information about the environmental, social, and governance dimensions that ECF platforms include in the selection process of the firms admitted to raise funds on the platform. ESG dimensions are taken from the Morgan Stanley Capital International ESG Intangible Value Assessment (MSCI ESG IVA) and are summarized in the table below. The score ranges from 0 to 12, measuring the sum of the dimensions considered in the selection process. The regional score is computed as the average score of all the ECF platforms operating within the same region.

ESG component	Dimension	Source
Environmental	1) Climate change 2) Natural resources 3) Pollution and waste 4) Environmental opportunities	Platform websites and reports
Social	5) Human capital 6) Product liability 7) Stakeholder opposition 8) Social opportunities	Platform websites and reports
Governance	9) Ownership and governance 10) Board of directors 11) Business ethics 12) Financial stability	Platform websites and reports

References

Block, J. H., Colombo, M. G., Cumming, D. J., & Vismara, S. (2018). New players in entrepreneurial finance and why they are there. *Small Business Economics*, *50*, 239-250.

Block, J. H., Hirschmann, M., & Fisch, C. (2021). Which criteria matter when impact investors screen social enterprises? *Journal of Corporate Finance*, *66*, 101813.

Cumming, D., Meoli, M., Rossi, A., & Vismara, S. (2024). ESG and crowdfunding platforms. *Journal of Business Venturing*, *39*(1), 106362.

Deloitte (2022). Fintech, sustainability, and ESG reporting: is now the time for fintech to become early movers in adopting a formal ESG strategy? file:///C:/Users/Utente/Downloads/us-audit-fintech-sustainability-and-esg-reporting.pdf

Edmans, A., & Kacperczyk, M. (2022). Sustainable finance. *Review of Finance*, *26*(6), 1309-1313.

Hervé, F., Manthé, E., Sannajust, A., & Schwienbacher, A. (2019). Determinants of individual investment decisions in investment-based crowdfunding. *Journal of Business Finance & Accounting*, *46*(5-6), 762-783.

Hornuf, L., Stenzhorn, E., & Vintis, T. (2022). Are sustainability-oriented investors different? Evidence from equity crowdfunding. *The Journal of Technology Transfer*, *47*(6), 1662-1689.

Kleinert, S., Bafera, J., Urbig, D., & Volkmann, C. K. (2022). Access denied: How equity crowdfunding platforms use quality signals to select new ventures. *Entrepreneurship Theory and Practice*, *46*(6), 1626-1657.

Mansouri, S., & Momtaz, P. P. (2022). Financing sustainable entrepreneurship: ESG measurement, valuation, and performance. *Journal of Business Venturing*, *37*(6), 106258.

United Nations (2019). People's money: Harnessing Digitalization in Financing of the Sustainable Development Goals. https://unsdg.un.org/sites/default/files/2020-08/DF-Task-Force-Full-Report-Aug-2020-1.pdf

Vismara, S. (2018). Information cascades among investors in equity crowdfunding. *Entrepreneurship Theory and Practice*, *42*(3), 467-497.

Vismara, S. (2019). Sustainability in equity crowdfunding. *Technological Forecasting and Social Change*, *141*, 98-106.

Tenner, I., & Hörisch, J. (2021). Crowdfunding sustainable entrepreneurship: What are the characteristics of crowdfunding investors? *Journal of Cleaner Production*, *290*, 125667.

12. The stakeholder approach to facilitate the circular economy

12.1 Introduction

Over the past decade, the concept of a circular economy (CE) has gained significant attention for its potential to reshape business models with innovative strategies aimed at advancing economic, social, and environmental sustainability goals (Millar et al., 2019; Murray et al., 2017; Villalba-Eguiluz et al., 2023). However, current CE research has primarily focused on the ecological and technical challenges of transitioning to and succeeding in a CE, often overlooking the social and cultural dimensions (Murray et al., 2017; Korhonen et al., 2018). Understanding stakeholders' roles, interests, and perspectives is crucial for the successful implementation of CE and the co-creation of value with other stakeholders (Awan et al., 2021; Shah & Rezai, 2023; Tapaninaho & Heikkinen, 2022). This has led to a growing emphasis on incorporating social and cultural aspects into CE research, particularly regarding stakeholder engagement (Moggi & Dameri, 2021; Quintelier et al., 2023). Our proposed indicators align with the above-mentioned gap by offering metrics to assess stakeholder approaches to facilitate CE.

12.2 Literature Review

In the realm of stakeholder theory (ST), the Stakeholder Approach (SA) holds significant importance in grasping the involvement of stakeholders in the Circular Economy (CE). SA, as a theoretical framework, places stakeholders at the forefront, integrating business and ethical concerns into innovative purposes. Essential traits of SA include recognizing stakeholders' moral standing (Freeman et al., 2010), fostering trustworthy relationships through ongoing consultation (Greenwood & Van Buren III, 2010), and aligning interests for shared goals through empowerment and engagement practices (Freeman et al., 2020; Greenwood, 2007). Despite its multidimensional nature, the literature lacks a precise definition of SA. To address this, we synthesize interpretations from stakeholder theory and engagement literature, categorizing SA into levels, directions, and components for a more systematic understanding. This includes delineating two main levels of the SA: the firm-stakeholder level and the stakeholder-firm level (Freeman, 2010; Parmar et al., 2010). The firm-stakeholder level describes how firms manage and engage stakeholders, while the stakeholder-firm level outlines how stakeholders impact firms' performances and purposes through multi-stakeholder alliances. Additionally, we consider the directions of the SA that can be unilateral (management-oriented) or bilateral (engagement-oriented). Unilateral approaches focus on managing stakeholders, while bilateral approaches involve ongoing engagement and dialogue with stakeholders to establish reciprocal relationships. Furthermore, the SA includes moral, strategic, and pragmatic components (Donaldson & Preston, 1995; Kujala et al., 2022; Oberholzer & Sachs, 2023). The moral component emphasizes ethical principles such as trust, fairness, and legitimacy. The strategic component views stakeholder practices as instrumental in enhancing firm performance and competitive advantage. Finally, the pragmatic component considers context-dependent meanings and practical consequences of firms' attitudes, strategies, and actions on stakeholders' well-being. The level, direction, and components of SA represent our theoretical framework to build the indicators of stakeholder approaches that enable CE.

12.3 Methodology

To develop indicators for SA approaches facilitating CE, we began with a systematic literature review following Denyer & Tranfield's (2009) five-step protocol. Initially, we collected 3,817 papers using a search query suggested by academic and practitioner experts on Scopus, Web of Science, and EBSCO HOST. After refining the sample to include only papers from Business, Management, and accounting fields, written in English, we narrowed the initial sample down to 306. Subsequently, engaging multiple reviewers, we selected 111 papers for descriptive and content analysis.

The content analysis guided by stakeholder theory and engagement literature (Kujala et al., 2022; Pedrini & Ferrik, 2019; Reed et al., 2009), yielded four stakeholder approaches aimed at facilitating CE: the informative, relational, advocative, and ecosystemic stakeholder approaches. Each approach was delineated in terms of its strategies and actions, forming the foundation for establishing the initial set of indicators to measure these approaches in fostering CE. Subsequently, the validity of the initial indicators was assessed through testing on a sample of 20 CE-implementing companies in Italy, leading to the refinement of the indicators as presented in Table 1. Below, we provide a more elaborate explanation of SA to facilitate CE, including a discussion of indicators for each approach:

- ***The Informative Stakeholder Approach***

The informative stakeholder approach involves one-way management strategies and actions by firms aimed at informing, communicating, training, and educating stakeholders to support the transition to a circular economy (CE) and enhance the effectiveness of CE strategies. Consequently, the KPI related to the "Informative stakeholder approach" encompasses metrics aimed at assessing the company's efforts to raise CE stakeholder awareness about CE (Jakhar et al., 2019) and to create enabling conditions for stakeholder participation in CE activities (Esposito et al., 2023; Modgil et al., 2021; McMahon et al., 2019).

- ***The Relational Stakeholder Approach***

The relational stakeholder approach involves bi-directional engagement strategies and actions between firms and stakeholders, alongside trust-based attitudes, to foster legitimate collaborations and establish long-term partnerships with both internal and external stakeholders. Consequently, the KPI for the "Relational Stakeholder Approach" measures the company's efforts in building and maintaining collaborations and partnerships with both internal and external stakeholders. This KPI specifically tracks efforts to achieve circularity goals through co-created solutions.

- **The Advocative Stakeholder Approach**

The advocative stakeholder approach involves one-way support from stakeholders to firms through initiatives guided by moral principles and institutional policies aligned with the strategic objectives of the circular economy. This support aims to exert pressure on firms' activities and create favorable conditions for enhancing and implementing new policies, products, processes, and supply chain reconfigurations to promote circular economy goals. Consequently, the KPI for the "Advocative Stakeholder Approach" measures the strategies and actions undertaken by stakeholders to pressure companies into aligning with CE principles.

- ***The Ecosystemic Stakeholder Approach***

The ecosystemic stakeholder approach involves shifting the focus from individual companies to the entire system, recognizing the interconnectedness of various stakeholders within an organizational ecosystem. Consequently, the "Ecosystemic Stakeholder Approach" KPIs measure various aspects of collaborative efforts within an ecosystem to facilitate circular economy (CE) practices. These include resource sharing, cross-industry or cross-sector collaborations, and initiatives to promote shared value and knowledge.

Table 1: KPI for measuring the stakeholder approach to facilitate the CE

STAKEHOLDER APPROACH	KPI	DESCRIPTION	REFERENCES
INFORMATIVE STAKEHOLDER APPROACH INDICATORS	**CE Awareness Mapping**	The number of initiatives undertaken to assess the level of CE awareness among stakeholders.	Awan et al., 2021; Govindan & Hasanagic, 2018
	Awareness Campaigns	The number of campaigns through traditional and/or digital media aimed at raising awareness about CE-specific issues, causes, or topics among stakeholders	Pourranjbar & Shokouhyar; Aschemann-Witzel & Stangherlin, 2021; Gandolfo & Lupi, 2021
	CE events	The number of corporate events dedicated to CE organized	Wang et al., 2022; Güsser-Fachbach et al., 2023
	CE educational programs for employees	The number of CE educational programs organized to facilitate employee education on the CE.	Bhattacharjee et al., 2023; Khan et al., 2023; Saha et al., 2021
	CE information in integrated reports	The percentage of information related to CE included in the integrated report compared to the total information provided.	Esposito et al., 2023
	CE information schemes	The number of standards information schemes addressed to raise stakeholders' awareness about the CE.	Gåvertsson et al., 2020; Wrålsen et al., 2021; Pereira & Vence, 2021; Nag et al., 2021
RELATIONAL STAKEHOLDER APPROACH INDICATORS	**Partnerships for technological advancements**	The number of partnerships with other companies, research institutions, or technology startups, specifically implemented by the company to advance technological innovation for CE.	Barford & Ahmad, 2023
	Partnerships for addressing ecological aspects within the value chain	The number of collaborations with various stakeholders implemented by the company to address ecological, and environmental aspects within its value chain (reducing environmental impact, improving sustainability practices, or promoting eco-friendly processes).	Gandolfo & Lupi, 2021; Kanda et al., 2021; Pera and Ferrulli, 2023; Reinecke et al., 2023
	Initiatives to collect feedback among the clients	The number of initiatives to gather feedback from clients to improve CE products or services	Bernardes et al., 2023
	Employees trained with skills for CE	The number of employees who have undergone training specifically focused on skills to facilitate the implementation of the CE.	Baah et al., 2023; Bloise, 2020; Ren et al., 2023; Ul-Durar et al., 2023
ADVOCATIVE STAKEHOLDER APPROACH INDICATOR	**Citizens' CE events participation**	The number of public events organized by citizens to raise CE awareness in which the company participates.	Gobert et al., 2021
	CE norms and standards	The number of Circular Economy (CE) non-governmental (NGOs) or governmental standards and norms that the company complies with.	Abbate et al., 2023; Charef & Lu, 2021; Droege et al., 2023; Ghaffar et al., 2020; Jabbour et al., 2019

ECOSYSTEMIC STAKEHOLDER APPROACH INDICATOR	**Collaborative Projects cross-industry**	The number of projects involving cross-sector and cross-industry collaboration aimed at circular economy goals.	Schultz et al., 2023; Aarikka-Stenroos et al., 2023
	Innovation and Knowledge Sharing	The number of platforms created for regular stakeholder interaction and knowledge exchange to facilitate CE.	Giorgi et al., 2022; King et al., 2023
	Joint Value Creation	The number of workshops and co-design sessions organized to align stakeholder visions and foster the co-creation of value.	Moggi and Dameri,2021; Takahashi, 2020
	Engaging Unconventional Stakeholders	The number of non-traditional stakeholders (such as local farms, startups, and incubators) collaborating to bring diverse perspectives and solutions.	Hull et al., 2021; Millette et al. 2020
	Resource Sharing Efficiency	The percentage of shared resources (data, infrastructure, knowledge) utilized in CE projects.	McEwan et al., 2023; Quintelier et al., 2023;

References

Aarikka-Stenroos, L., Kokko, M., & Pohls, E.-L. (2023). Catalyzing the circular economy of critical resources in a national system: Case study on drivers, barriers, and actors in nutrient recycling. Journal of Cleaner Production, 397(136380), 136380. https://doi.org/10.1016/j.jclepro.2023.136380

Abbate, S., Centobelli, P., & Cerchione, R. (2023). From fast to slow: An exploratory analysis of circular business models in the Italian apparel industry. International Journal of Production Economics, 260(108824), 108824. https://doi.org/10.1016/j.ijpe.2023.108824.

Aschemann-Witzel, J., & Stangherlin, I. D. C. (2021). Upcycled by-product use in agri-food systems from a consumer perspective: A review of what we know, and what is missing. Technological Forecasting and Social Change, 168(120749), 120749. https://doi.org/10.1016/j.techfore.2021.120749

Awan, U., Sroufe, R., & Shahbaz, M. (2021). Industry 4.0 and the circular economy: A literature review and recommendations for future research. Business Strategy and the Environment, 30(4), 2038–2060. https://doi.org/10.1002/bse.2731

Baah, C., Agyabeng-Mensah, Y., Afum, E., & Kumi, C. A. (2023). Do circular economy practices accelerate CSR participation of SMEs in a stakeholder-pressured era? A network theory perspective. Journal of Cleaner Production, 394(136348), 136348. https://doi.org/10.1016/j.jclepro.2023.136348

Barford, A., & Ahmad, S. R. (2023). Levers for a corporate transition to a plastics circular economy. Business Strategy and the Environment, 32(4), 1203–1217. https://doi.org/10.1002/bse.3182

Bernardes, M., Moraes, F. T. F., Tanaka, K. H., & da Silva Lima, R. (2024). Engaging the end user in waste from electrical and electronic equipment management: An action research study. Systemic Practice and Action Research, 37(1), 105–126. https://doi.org/10.1007/s11213-023-09646-y

Bhattacharjee, P., Howlader, I., Rahman, M. A., Taqi, H. M. M., Hasan, M. T., Ali, S. M., & Alghababsheh, M. (2023). Critical success factors for circular economy in the waste electrical and electronic equipment sector in an emerging economy: Implications for stakeholders. Journal of Cleaner Production, 401(136767), 136767. https://doi.org/10.1016/j.jclepro.2023.136767

Bloise, C. (2020). Collaboration in a circular economy: Learning from the farmers to reduce food waste. Journal of Enterprise Information Management, 33(4), 769–789. https://doi.org/10.1108/jeim-02-2019-0062

Charef, R., & Lu, W. (2021). Factor dynamics to facilitate circular economy adoption in construction. Journal of Cleaner Production, 319(128639), 128639. https://doi.org/10.1016/j.jclepro.2021.128639

Denyer, D., & Tranfield, D. (2009). Producing a systematic review. In D. A. Buchanan & A. Bryman (Eds.), The Sage handbook of organizational research methods (pp. 671–689). Sage Publications Ltd.

Donaldson, T., & Preston, L. E. (1995). The stakeholder theory of the corporation: Concepts, evidence, and implications. Academy of Management Review, 20(1), 65. https://doi.org/10.2307/258887

Droege, H., Kirchherr, J., Raggi, A., & Ramos, T. B. (2023). Towards a circular disruption: On the pivotal role of circular economy policy entrepreneurs. Business Strategy and the Environment, 32(3), 1142–1158. https://doi.org/10.1002/bse.3098

Esposito, B., Raimo, N., Malandrino, O., & Vitolla, F. (2023). Circular economy disclosure and integrated reporting: The role of corporate governance mechanisms. Business Strategy and the Environment, 32(8), 5403–5419. https://doi.org/10.1002/bse.3427

Freeman, R. E. (2010). Strategic Management: A Stakeholder Approach. Cambridge University Press.

Freeman, R. E., Phillips, R., & Sisodia, R. (2020). Tensions in stakeholder theory. Business and Society, 59(2), 213–231. https://doi.org/10.1177/0007650318773750

Gandolfo, A., & Lupi, L. (2021). Circular economy, the transition of an incumbent focal firm: How to successfully reconcile environmental and economic sustainability? Business Strategy and the Environment, 30(7), 3297–3308. https://doi.org/10.1002/bse.2803

Gåvertsson, I., Milios, L., & Dalhammar, C. (2020). Quality labelling for re-used ICT equipment to support consumer choice in the circular economy. Journal of Consumer Policy, 43(2), 353–377. https://doi.org/10.1007/s10603-018-9397-9

Ghaffar, S. H., Burman, M., & Braimah, N. (2020). Pathways to circular construction: An integrated management of construction and demolition waste for resource recovery. Journal of Cleaner Production, 244(118710), 118710. https://doi.org/10.1016/j.jclepro.2019.118710

Giorgi, S., Lavagna, M., Wang, K., Osmani, M., Liu, G., & Campioli, A. (2022). Drivers and barriers towards circular economy in the building sector: Stakeholder interviews and analysis of five European countries policies and practices. Journal of Cleaner Production, 336(130395), 130395. https://doi.org/10.1016/j.jclepro.2022.130395

Greenwood, M. (2007). Stakeholder engagement: Beyond the myth of corporate responsibility. Journal of Business Ethics, 74(4), 315–327. https://doi.org/10.1007/s10551-007-9509-y

Gobert, J., Allais, R., & Deroubaix, J.-F. (2021). Repair and reuse: Misalignments between stakeholders and possible users. Journal of Cleaner Production, 317(128454), 128454. https://doi.org/10.1016/j.jclepro.2021.128454

Govindan, K., & Hasanagic, M. (2018). A systematic review on drivers, barriers, and practices towards circular economy: a supply chain perspective. International Journal of Production Research, 56(1–2), 278–311. https://doi.org/10.1080/00207543.2017.1402141

Greenwood, M., & Van Buren, H. J., III. (2010). Trust and stakeholder theory: Trustworthiness in the organisation–stakeholder relationship. Journal of Business Ethics, 95(3), 425–438. https://doi.org/10.1007/s10551-010-0414-4

Güsser-Fachbach, I., Lechner, G., Ramos, T. B., & Reimann, M. (2023). Repair service convenience in a circular economy: The perspective of customers and repair companies. Journal of Cleaner Production, 415(137763), 137763. https://doi.org/10.1016/j.jclepro.2023.137763

Hull, C. E., Millette, S., & Williams, E. (2021). Challenges and opportunities in building circular-economy incubators: Stakeholder perspectives in Trinidad and Tobago. Journal of Cleaner Production, 296(126412), 126412. https://doi.org/10.1016/j.jclepro.2021.126412

Jabbour, C. J. C., Jabbour, A. B. L. de S., Sarkis, J., & Filho, M. G. (2019). Unlocking the circular economy through new business models based on large-scale data: An integrative framework and research agenda. Technological Forecasting and Social Change, 144, 546–552. https://doi.org/10.1016/j.techfore.2017.09.010

Jakhar, S. K., Mangla, S. K., Luthra, S., & Kusi-Sarpong, S. (2019). When stakeholder pressure drives the circular economy: Measuring the mediating role of innovation capabilities. Management Decision, 57(4), 904–920. https://doi.org/10.1108/md-09-2018-0990

Kanda, W., Geissdoerfer, M., & Hjelm, O. (2021). From circular business models to circular business ecosystems. Business Strategy and the Environment, 30(6), 2814–2829. https://doi.org/10.1002/bse.2895

Khan, O., Bellini, N., Daddi, T., & Iraldo, F. (2023). Effects of behavioral intention and dynamic capabilities on circular economy adoption and performance of tourism SMEs. Journal of Sustainable Tourism, 31(8), 1777–1796. https://doi.org/10.1080/09669582.2022.2066683

King, M. R. N., Timms, P. D., & Mountney, S. (2023). A proposed universal definition of a Digital Product Passport Ecosystem (DPPE): Worldviews, discrete capabilities, stakeholder requirements and concerns. Journal of Cleaner Production, 384(135538), 135538. https://doi.org/10.1016/j.jclepro.2022.135538

Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular Economy: The Concept and its Limitations. Ecological Economics: The Journal of the International Society for Ecological Economics, 143, 37–46. https://doi.org/10.1016/j.ecolecon.2017.06.041

Kujala, J., Sachs, S., Leinonen, H., Heikkinen, A., & Laude, D. (2022). Stakeholder engagement: Past, present, and future. Business and Society, 61(5), 1136–1196. https://doi.org/10.1177/00076503211066595

Marques-McEwan, M., Xu, B., Bititci, U. S., & Jiang, M. (2023). Unveiling the rules for creating circular business ecosystems: A case study in the chemical industry. Journal of Cleaner Production, 427(139185), 139185. https://doi.org/10.1016/j.jclepro.2023.139185

McMahon, K., Johnson, M., & Fitzpatrick, C. (2019). Enabling preparation for re-use of waste electrical and electronic equipment in Ireland: Lessons from other EU member states. Journal of Cleaner Production, 232, 1005–1017. https://doi.org/10.1016/j.jclepro.2019.05.339

Millar, N., McLaughlin, E., & Börger, T. (2019). The circular economy: Swings and roundabouts? Ecological Economics: The Journal of the International Society for Ecological Economics, 158, 11–19. https://doi.org/10.1016/j.ecolecon.2018.12.012

Millette, S., Eiríkur Hull, C., & Williams, E. (2020). Business incubators as effective tools for driving circular economy. Journal of Cleaner Production, 266(121999), 121999. https://doi.org/10.1016/j.jclepro.2020.121999

Modgil, S., Gupta, S., Sivarajah, U., & Bhushan, B. (2021). Big data-enabled large-scale group decision making for circular economy: An emerging market context. Technological Forecasting and Social Change, 166(120607), 120607. https://doi.org/10.1016/j.techfore.2021.120607

Moggi, S., & Dameri, R. P. (2021). Circular business model evolution: Stakeholder matters for a self-sufficient ecosystem. Business Strategy and the Environment, 30(6), 2830–2842. https://doi.org/10.1002/bse.2716

Murray, A., Skene, K., & Haynes, K. (2017). The circular economy: An interdisciplinary exploration of the concept and application in a global context. Journal of Business Ethics, 140(3), 369–380. https://doi.org/10.1007/s10551-015-2693-2

Nag, U., Sharma, S. K., & Govindan, K. (2021). Investigating drivers of circular supply chain with product-service system in automotive firms of an emerging economy. Journal of Cleaner Production, 319(128629), 128629. https://doi.org/10.1016/j.jclepro.2021.128629

Oberholzer, S., & Sachs, S. (2023). Engaging stakeholders in the circular economy: A systematic literature review. In Stakeholder Engagement in a Sustainable Circular Economy (pp. 57–97). Springer International Publishing.

Parmar, B. L., Freeman, R. E., Harrison, J. S., Wicks, A. C., Purnell, L., & de Colle, S. (2010). Stakeholder theory:the state of the art. Academy of Management Annals, 4(1), 403–445. https://doi.org/10.1080/19416520.2010.495581

Pedrini, M., & Ferri, L. M. (2019). Stakeholder management: a systematic literature review. Corporate Governance, 19(1), 44–59. https://doi.org/10.1108/cg-08-2017-0172

Pera, R., & Ferrulli, E. (2024). Consumers' textile disposal practices and their perceived value in the circular economy: A platform focused ethnography approach. Business Strategy and the Environment, 33(4), 2931–2948. https://doi.org/10.1002/bse.3616

Pereira, Á., & Vence, X. (2021). The role of KIBS and consultancy in the emergence of Circular Oriented Innovation. Journal of Cleaner Production, 302(127000), 127000. https://doi.org/10.1016/j.jclepro.2021.127000

Pourranjbar, A., & Shokouhyar, S. (2023). Shedding light on the efficiency of the product-service system in waste from electrical and electronic equipment: A social media analysis of consumer tweets. Journal of Cleaner Production, 415(137545), 137545. https://doi.org/10.1016/j.jclepro.2023.137545

Quintelier, K. J. P., van Bommel, K., van Erkelens, A. M., & Wempe, J. (2023). People at the heart of circularity: A mixed methods study about trade-offs, synergies, and strategies related to circular and social organizing. Journal of Cleaner Production, 387(135780), 135780. https://doi.org/10.1016/j.jclepro.2022.135780

Reed, M. S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C. H., & Stringer, L. C. (2009). Who's in and why? A typology of stakeholder analysis methods for natural resource management. Journal of Environmental Management, 90(5), 1933–1949. https://doi.org/10.1016/j.jenvman.2009.01.001

Reinecke, P. C., Küberling-Jost, J. A., Wrona, T., & Zapf, A. K. (2023). Towards a dynamic value network perspective of sustainable business models: the example of RECUP. Journal of Business Economics, 93(4), 635–665. https://doi.org/10.1007/s11573-023-01155-7

Ren, Y., Wu, K.-J., Lim, M. K., & Tseng, M.-L. (2023). Technology transfer adoption to achieve a circular economy model under resource-based view: A high-tech firm. International Journal of Production Economics, 264(108983), 108983. https://doi.org/10.1016/j.ijpe.2023.108983

Saha, K., Dey, P. K., & Papagiannaki, E. (2021). Implementing circular economy in the textile and clothing industry. Business Strategy and the Environment, 30(4), 1497–1530. https://doi.org/10.1002/bse.2670

Shah, M. U., & Rezai, R. (2023). Public-sector participation in the circular economy: A stakeholder relationship analysis of economic and social factors of the recycling system. Journal of Cleaner Production, 400(136700), 136700. https://doi.org/10.1016/j.jclepro.2023.136700

Tapaninaho, R., & Heikkinen, A. (2022). Value creation in circular economy business for sustainability: A stakeholder relationship perspective. Business Strategy and the Environment, 31(6), 2728–2740. https://doi.org/10.1002/bse.3002

Ul-Durar, S., Awan, U., Varma, A., Memon, S., & Mention, A.-L. (2023). Integrating knowledge management and orientation dynamics for organization transition from eco-innovation to circular economy. Journal of Knowledge Management, 27(8), 2217–2248. https://doi.org/10.1108/jkm-05-2022-0424

Villalba-Eguiluz, U., Sahakian, M., González-Jamett, C., & Etxezarreta, E. (2023). Social and solidarity economy insights for the circular economy: Limited-profit and sufficiency. Journal of Cleaner Production, 418(138050), 138050. https://doi.org/10.1016/j.jclepro.2023.138050

Wang, J. X., Burke, H., & Zhang, A. (2022). Overcoming barriers to circular product design. International Journal of Production Economics, 243(108346), 108346. https://doi.org/10.1016/j.ijpe.2021.108346

Wrålsen, B., Prieto-Sandoval, V., Mejia-Villa, A., O'Born, R., Hellström, M., & Faessler, B. (2021). Circular business models for lithium-ion batteries - Stakeholders, barriers, and drivers. Journal of Cleaner Production, 317(128393), 128393. https://doi.org/10.1016/j.jclepro.2021.128393

13. Stakeholder cognitive biases in the circular economy

13.1 Introduction

The prevailing "take-make-waste" linear business model is significantly increasing waste production and depleting resources (Preston, 2012). This urgent issue has led to global interest in transitioning to a circular economy (CE), defined as a regenerative and restorative economic system (Ghisellini et al., 2016). The CE promotes reducing, reusing, and recycling resources to minimize waste and maximize efficiency (Ellen MacArthur Foundation, 2022), offering a new approach to sustainability challenges (Zhang et al., 2019). Transitioning to a circular model requires profound changes that extend beyond individual companies, involving the entire ecosystem where stakeholders and businesses collaborate to achieve economic, social, and environmental goals (Aarikka-Stenroos et al., 2023). Despite recognizing the importance of transitioning to a circular economy, most CE scholarship has focused primarily on ecological challenges and limitations. It has largely neglected a comprehensive analysis of how social dynamics and stakeholder interests, values, expectations, and perceptions can support or hinder CE. This oversight includes the critical role of human behavior (Beaurain et al., 2023; Murray et al., 2017; Korhonen et al., 2018; Souza Piao et al., 2024). Consequently, while there is extensive research on technological, economic, and legislative barriers, there is a limited exploration of how stakeholder cognitive biases impede the transition to CE (Cristofaro et al., 2023). To address this gap, we aim to develop indicators specifically designed to identify the cognitive biases that influence stakeholders' decisions to engage in circular economy projects, building on the literature on cognitive biases in environmental sustainability decisions adapted to CE decision-making (Palmucci & Ferraris, 2023).

13.2 Literature Review

Concerning the study of cognitive biases, the contribution of Kahneman and Tversky (1979) was fundamental in introducing the concept of Cognitive Bias to the scientific community. Such research led to a revolutionary breakthrough regarding human decision-making under uncertain conditions: people make their decisions not using sophisticated rational processes, but using a limited number of heuristics, or mental shortcuts (Tversky and Kahneman, 1974). If the decision-making process, as has already been stated, presents numerous cognitive biases due to the high degree of uncertainty that this process involves, then these biases are also relevant in decisions regarding environmental actions that are undertaken by people (Hoffman and Bazerman, 2007). This is the main point of attention of the current study: the psychological aspect that prevents individuals from concretely carrying out actions that would facilitate environmental mitigation, adaptation, and sustainability. This aspect is beyond the control of the individual himself (Palmucci and Ferraris, 2023; Mazutis e Eckardt, 2017).

13.3 Methodology

We use a qualitative methodology that includes interviews with a) managers of companies that have adopted circular business models; b) managers of companies involved in circular economy projects; and c) stakeholders such as customers, NGOs, suppliers, and others who actively or passively participate in circular economy projects. Our interview questions are structured based on the literature on cognitive biases in environmental sustainability decisions (Palmucci and Ferraris, 2023), which we have applied and adjusted to CE decision-making.

Table 1: KPI for cognitive biases in the circular economy

KPI	DESCRIPTION	REFERENCES
BIAS PRESENT AND DISCOUNT THE FUTURE	• The company strongly believes that prioritizing short-term financial gains could potentially diminish the urgency to invest in the circular economy and sustainability initiatives, which, conversely, offer results in the long-term	Shu e Bazerman, 2010; Mazutis e Eckardt, 2017; Gifford, 2011; Weber, 2017; Newell e Pitman, 2010
OPTIMISM BIAS	• The company believes that stakeholders are reluctant to engage in circular economy initiatives because they think sustainability issues will be resolved by science and do not see it as a shared responsibility. • The company thinks that stakeholders are unwilling to participate in circular economy initiatives because they believe that sustainability issues belong to other parts of the world and/or will not have visible impacts in the immediate future.	Shu e Bazerman, 2010; Mazutis e Eckardt, 2017; Gifford, 2011;
AVAILABILITY BIAS	• The company believes that the stakeholders collaborate on circular economy initiatives when they have experienced or witnessed negative environmental and/or social events in the past.	Singh e Ryvola, 2018; Mazutis e Eckardt, 2017; Arvai et al, 2012; Newell e Pitman, 2010;
BIAS DELL'AZIONE SINGOLA	• The stakeholders do not want to participate in circular economy initiatives because they overestimate the contribution of a single small action they take (e.g., recycling, or buying an electric car) and with this single action they assuage their conscience, believing they have enough, ignoring everything else they could still do.	Singh e Ryvola, 2018; Gifford, 2011; Holmgren e colleghi, 2022;
BIAS OF DIFFUSION OF RESPONSIBILITY	• The company believes that stakeholders may not want to participate in circular economy initiatives because they are convinced that the primary responsibility for the problem lies with others. For instance, Europeans may think that the primary responsibility lies with India and China, and therefore, until they take action, their contribution is futile. Conversely, India and China may believe that the primary responsibility lies with the industrialization of Europe in past centuries, and now that it's their turn to industrialize and grow, there's no need to stop. Or yet, small businesses may think that the primary responsibility lies with large corporations, and until they act, their contribution is pointless, etc.	Shu e Bazerman, 2010; Mazutis e Eckardt, 2017; Gifford, 2011; Engler et al., 2019

STATUS QUO BIAS	• The tendency is to think that before embarking on new paths and investing in Circular Economy initiatives, it is better to make the most of what already exists and fully exploit what has already been invested in.	Singh e Ryvola, 2018; Mazutis e Eckardt, 2017; Gifford, 2011; Weber, 2017; Engler et al., 2019 Arvaj et al., 2012; Newell e Pitman, 2010;

References

Aarikka-Stenroos, L., Kokko, M. and Pohls, E.-L. (2023) “Catalyzing the circular economy of critical resources in a national system: Case study on drivers, barriers, and actors in nutrient recycling,” Journal of cleaner production, 397(136380), p. 136380.

Arvai J., Campbell-Arvai V., Steel P. (2012), “Making Sustainable Choices. A Guide for Managers”, Network for Business Sustainability

Ellen MacArthur Foundation (2022). Ellen MacArthur Foundation. Circulate products and materials. Retrieve from https://ellenmacarthurfoundation.org/circulate-products-and-materials.

Engler, J. O., Abson, D. J., Von Wehrden, H. (2019), “Navigating cognition biases in the search of sustainability”. Ambio, 48(6), 605-618

Beaurain, C., Chembessi, C. and Rajaonson, J. (2023) “Investigating the cultural dimension of circular economy: A pragmatist perspective,” Journal of cleaner production, 417(138012), p. 138012.

Cristofaro, M. et al. (2023) “Unlocking the sustainability of medium enterprises: A framework for reducing cognitive biases in sustainable performance management,” Journal of management & organization, pp. 1–31.

Ghisellini, P., Cialani, C. and Ulgiati, S. (2016) “A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems,” Journal of cleaner production, 114, pp. 11–32.

Gifford R. (2011), “The Dragons of Inaction: Psychological Barriers That Limit Climate Change Mitigation and Adaptation”, American Psychologist, Vol. 66 (4), pp. 290-302

Hoffman A., Bazerman M.H. (2007), “Changing practices on sustainability: Understanding and overcoming the organizational and psychological barriers to action”, In Sharma S., Starik M., Husted B., Organizations and the Sustainability Mosaic, Edward Elgar Publishing

Holmgren, M., Threadgold, E., Marsh, J. E., Andersson, H., Nelson, M., Ball, L. (2022), “Biased Estimates of Environmental Impact in the Negative Footprint Illusion: The Nature of Individual Variation”. Frontiers in psychology, 12, 648328

Kahneman D., Tversky A. (1979), “Prospect theory: An analysis of decision under risk”, Econometrica, Vol. 47, pp. 263-291

Korhonen, J., Honkasalo, A. and Seppälä, J. (2018) "Circular Economy: The Concept and its Limitations," Ecological economics: the journal of the International Society for Ecological Economics, 143, pp. 37–46.

Mazutis D., Eckardt A. (2017), "Sleepwalking into Catastrophe: Cognitive Biases and Corporate Climate Change Inertia", California Management Review, Vol. 59 (3), pp. 74-108

Murray, A., Skene, K. and Haynes, K. (2017) "The circular economy: An interdisciplinary exploration of the concept and application in a global context," Journal of business ethics, 140(3), pp. 369–380.

Newell, B. R., Pitman, A. J. (2010), "The psychology of global warming: Improving the fit between the science and the message". Bulletin of the American Meteorological Society, 91(8), 1003-1014

Palmucci, D. N. and Ferraris, A. (2023) "Climate change inaction: Cognitive bias influencing managers' decision making on environmental sustainability choices. The role of empathy and morality with the need of an integrated and comprehensive perspective," Frontiers in psychology, 14, p. 1130059.

Preston, F. (2012), A Global Redesign? Shaping the Circular Economy, Chatham House, London.

Shu L.L., Bazerman M.H. (2010), "Cognitive Barriers to Environmental Action: Problems and Solutions", Oxford Handbook of Business and the Environment, Capitolo 13

Singh R., Ryvola R. (2018), "Cognitive Biases In Climate Risk Management", Red Cross Red Crescent Climate Centre BRACED, Vol. 5

Souza Piao, R. et al. (2024) "Barriers toward circular economy transition: Exploring different stakeholders' perspectives," Corporate social responsibility and environmental management, 31(1), pp. 153–168.

Tversky A., Kahneman D. (1974), "Judgment under Uncertainty: Heuristics and Biases", Science, Vol. 185 (4157), pp. 1124-1131

Weber E.U., (2017), " Breaking cognitive barriers to a sustainable future ", Nature Human Behaviour, Vol. 1, Art. n. 0013

Zhang, A. et al. (2019) "Barriers to smart waste management for a circular economy in China," Journal of cleaner production, 240(118198), p. 118198.

14. Relationship among firms patenting in circular economy

Leveraging from the economic context described in paragraph 12, we will measure competitiveness of firms patenting in circular economy by considering their supply relationships.

More specifically, starting from an original database of payment flows that Intesa Sanpaolo customers manage through the Intesa Sanpaolo payment network, we will map the purchases made by firms to their Italian suppliers to understand if and to what extent companies attentive to circular economy issues refer to local suppliers (which may allow them to maintain control over the phases of the value chain) or are more prone to maintain relationships with other companies that demonstrate the same attention to circular issues.