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KEYWORDS

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R11, O52, O33

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Abstract

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1 Introduction

The Circular Economy (CE) paradigm has gained increased interest in the policy and academic circles over the last decades, as it represents a promising alternative to the traditional linear model of "take, make, and dispose" (Barros et al., 2020; Murray et al., 2017). The European Commission defines CE as an economy that aims to maintain the value of products, materials and resources for as long as possible while minimizing waste generation (European Commission, 2015).

The transition towards a CE is an integral part of the European Green Deal and the Circular Economy Action Plan (European Commission, 2020). At the heart of this transition are CE technologies and the knowledge needed to develop and implement them. We define CE technologies as technological innovations that enable the reduction, reuse, recycling, and recovery of materials and energy across production and consumption systems (Smol et al., 2017). This includes technologies for eco-design, resource-efficient manufacturing, recycling processes, industrial symbiosis, and product life extension, among others. With CE knowledge, on the other hand, we refer to scientific knowledge that underpins the development and implementation of CE technologies and practices. This includes research in environmental engineering, industrial ecology, materials science, waste management, and sustainability science that contributes to advancing circular strategies in different sectors (European Environment Agency, 2016).

In view of the relevance of innovation in achieving the transition to CE, a growing number of empirical studies have investigated the determinants and effects of both the adoption and generation of CE innovations, using different measurement approaches (de Jesus & Mendonça, 2018). On the one hand, studies focusing on adoption have exploited information drawn from ad hoc surveys to gain information on firms' actual decisions to change their business models, suppliers, raw materials, or product and process technologies to align with the pillars of the CE paradigm (Ren & Albrecht, 2023).

On the other hand, the focus on innovation development has largely dealt with CE and green technologies, exploiting patent data as the main source of information (Cova et al., 2023; D'Ambrosio et al., 2016; Fusillo et al., 2025). This literature has been grounded on the well-known recombinant knowledge approach, according to which new scientific and technological advances emerge from the combination of existing pieces of knowledge in novel ways. The capacity to combine ideas that are far away in the knowledge landscape is crucial to developing highly impactful innovations (Fleming, 2001; Nightingale, 1998; Weitzman, 1998). A basic tenet stemming from this literature posits that green and CE technologies are often more complex than conventional technologies and frequently rely on unique or rarely attempted combinations of knowledge components (Barbieri et al., 2020; Fusillo, 2023; Orsatti et al., 2024).

In view of this evidence, it is surprising that the previous empirical literature has mostly overlooked the analysis of how basic science related to CE is produced at the regional level. Yet, we know that basic science is a key driver of technological progress since the most valuable technologies often build directly on locally generated scientific research (Ahmadpoor & Jones, 2017).

Scientific discoveries not only inform technological development, they often lay the foundation for it. A crucial point is that the creation of scientific knowledge contributes directly to the development of new technologies, particularly at the regional level. This relationship between science and technology has been widely studied (Callaert et al., 2014; Narin et al., 1997). The seminal study by Jaffe et al. (1993) was among the first to show that knowledge produced by universities and research institutions benefits local innovation, since it tends to spill over within the same geographic area, supporting regional technological progress.

This implies that scientific knowledge, mostly in the form of academic publications, plays a key role for regions aiming to develop expertise in specific scientific and technological domains (Balland & Boschma, 2022; Catalán et al., 2022). Balland and Boschma (2022) show that regional scientific capabilities are a strong predictor of future technological development in the same domain, highlighting the importance of aligning science and technology strengths to support smart specialization strategies. Catalán et al. (2022) exploit the concept of scientific and technological cross-density to show that countries are more likely to diversify into new technologies that are closely related to their existing scientific knowledge bases.

For these reasons, it is important to look at where scientific knowledge is being produced, as university research often leads to local benefits for nearby industries, especially when green innovation is at stake (Jaffe et al., 1993). These dynamics are especially important for strategic green domains like the CE, where building strong research foundations can significantly boost a region's capacity to innovate and lead in sustainable technologies (Quatraro & Scandura, 2019). A strong scientific knowledge base is relevant due to the analytical nature of green technological knowledge and its intrinsic heterogeneity and complexity (Fusillo, 2023; Marzucchi & Montresor, 2017).

This paper aims to fill the gap by examining the regional production and uptake of scientific knowledge in the CE domain in Italy. Italy represents a compelling case study, as it is one of the most significant economies in the EU and globally. The country has limited natural resources and is highly dependent on imports, especially fossil fuels and metals (Eurostat, 2025). A transition to a CE would enhance the sustainability, competitiveness, and security of the Italian economy by reducing its vulnerability to resource dependency. Natural resources are particularly important for Italy's manufacturing sector, which underpins its strong export performance (Ghisellini & Ulgiati, 2020). Italy has shown a strong policy commitment to CE through measures such as Law 221/2015 and related legislative decrees. These define, for example, criteria for calculating municipal waste collection rates and guidelines for the eco-design of waste electrical and electronic equipment. Additionally, the Italian National Strategy for Circular Economy (Italian Ministry of the Environment and Energy Security, 2022) outlines the country's strategic vision, reaffirming its commitment to the core principles of CE.

While previous research has largely overlooked the geography of basic science in CE, we provide a comprehensive overview of how CE-related scientific activity has developed across Italian regions over a 30-year period (1995–2024). Using publication data in which at least one author is affiliated with an Italian institution, we analyze both the volume and evolution of CE research outputs from a geography of innovation perspective (Feldman, 1994). In addition, we examine knowledge flows by considering not only CE publications themselves, but also publications in any field that cite CE research. This allows us to map regional scientific capabilities and to construct a taxonomy of Italian regions based on their role in the CE knowledge ecosystem. Finally, we track how these roles evolve over time, identifying regions that strengthen their position in CE research.

This study adds to the literature in two key respects. First, it contributes to the literature on CE innovation in that, to the best of the authors' knowledge, it is the first systematic quantitative analysis of scientific knowledge production in the CE field in Italy. Second, it contributes to the regional science literature by articulating an original taxonomy of regions according to the capacity to develop and integrate scientific knowledge. Specifically, we assess whether there is an overlap between a region's scientific productivity in CE and its CE knowledge base, as measured by citations of CE-related publications. Based on this analysis, we identify four types of regions in Italy, classified according to the degree of alignment between their scientific output and their integration of CE knowledge.

The remainder of the paper is organized as follows. Section 2 describes the data used in the analysis and introduces the regional typology, based on the degree of overlap between scientific production and uptake in the CE domain. Section 3 presents the findings from the exploratory analysis. Finally, Section 4 concludes and outlines directions for future research.

2 Data and Methods

In recent years, many scholars have proposed different definitions of the CE (Figge et al., 2023; Kirchherr et al., 2017; Nobre & Tavares, 2021). According to Kirchherr et al. (2017), the main difficulty in reaching a common definition lies in CE's complexity and its broad scope, which includes economic, social, and environmental dimensions. Similarly, Geissdoerfer et al. (2017) argue that this complexity stems from CE's multidisciplinary nature.

To identify CE-related publications, scholars have mainly relied on keyword searches. This keyword-based approach uses predefined terms to retrieve documents related to CE. For instance, Baldassarre & Saveyn (2023), Dragomir & Dumitru (2024) and Fontana et al. (2021) use this method to identify academic papers, and similar strategies are applied to identify patents in CE domains (see e.g., de Jesus & Mendonça, 2018).

Although keyword searches are technically simple to perform, they face an important limitation. Given the broad and evolving nature of the CE concept, it is, in fact, difficult to fully capture it with a fixed list of keywords. This can result in missing relevant publications that use non-standard terminology, or including others that are only loosely related.

In this study, use the OpenAlex (OA) database (Priem et al., 2022) to retrieve scientific publications data. OA is an extensive open-access bibliographic database launched in 2022 that includes over 260 million scientific publications, such as journal articles, book chapters, and conference proceedings.

In doing so, we improve on basic keyword searches by using the OA topic classifications, which assigns topics to articles using a machine learning model that draws on the title, abstract, journal, and citation graph of each publication. OA identifies 4516 topics; each publication can be assigned up to three topics, the topic with the highest score is the publication's "primary topic", we refer to the others as secondary topics. These topics are organized into 252 subfields, grouped into 26 fields and further combined into 4 top-level domains.

To select topics related to CE, we searched for the term "circular economy" in the titles, descriptions, and keywords of OA's topics. We identified eight topics related to CE, which are described in Table A.1 in the Appendix A.

Based on this information, we extracted from OA all documents that meet the following criteria: (i) they are published in English, (ii) they appear in international scientific journals, (iii) they are linked to at least one of the selected CE-related topics (considering both the publication's primary and secondary topics), and (iv) they include at least one author affiliated with an institution based in Italy. This dataset spans the period from 1995 to 2024 and includes a total of 9,080 publications. We will refer to this sample of articles as the "CE publications set" throughout the remainder of the analysis.

We assign each publication to an Italian region based on the author's affiliation, using full counting. This means that if a publication is co-authored by authors affiliated with institutions in different Italian regions, each region receives full credit for the publication. However, if an author has multiple Italian affiliations, we only consider their first affiliation as their main one and assign the publication to the region of that affiliation.

In addition to the "CE publications set," which forms the core of our exploratory analysis, we also identify from OA all publications – regardless of the field – that have at least one author affiliated with an Italian institution and cite a publication from any country related to one of the eight CE topics. This allows us to capture not only the production of CE knowledge by Italian regions but also the extent to which Italian science is integrating CE knowledge into subsequent research. We refer to this group of articles as the "publications citing CE set," which includes a total of 70,100 scientific articles. Based on this set, we classify Italian regions into four categories, as explained in the next section.

2.1 Classifying regional profiles in the CE domain

Based on the "CE publications set" and the "publications citing CE set", we compare the regional distribution in Italy of CE publications per 100 researchers and publications that cite CE research, also per 100 researchers. As shown in Figure 1, we identify four types of regions:

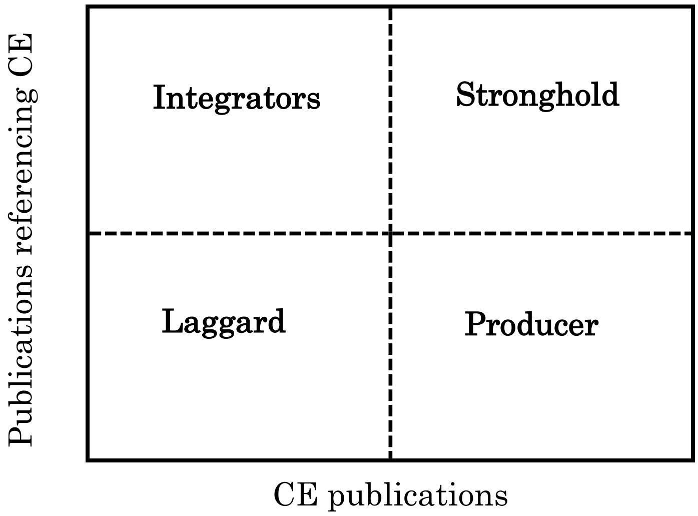
1. *Strongholds* are regions that perform well both in producing CE publications and in generating publications that cite CE research. This indicates a strong and active local CE research community. These regions are in the top 25% for both CE publications and publications citing CE research.

2. *Producers* have a high level of CE research output but a lower level of publications citing CE work. This suggests that, although these regions generate CE knowledge, they are less engaged in using or building on CE research themselves. They rank in the top 25% for CE publications, but not for citing CE research.

3. *Integrators* are regions with relatively few CE publications but a high number of publications citing CE research. This indicates that they actively engage with and incorporate CE knowledge produced elsewhere. These regions fall in the top 25% for citing CE research, but not for CE publications.

4. *Laggards* are regions that do not rank in the top 25% for either CE publications or citations. They show limited CE research activity and weak engagement with existing CE knowledge.

Figure 1: Typology of regions



3 Descriptive Analysis

Building on the data presented in the previous section, this chapter provides an exploratory analysis of the key patterns and trends in scientific publications related to the CE in Italy. The goal is to highlight the main characteristics of CE research in terms of topics, time evolution, and geographical distribution.

3.1 Distribution by CE Topic

Figure 2 shows the distribution of CE articles across the eight OA's topics. Most of these topics fall under the Engineering field, except for three. "Bioeconomy and Sustainable Development," classified under the Agriculture and Biological Sciences field, accounts for 4.6% of CE publications. "Chemistry and Chemical Engineering," which falls under the Environmental Sciences field, represents 11.8%. "Sustainable Supply Chain Management," classified under the Social Sciences field, has the largest share, with 41.7% of CE articles. This single topic almost equals the combined share of the remaining five Engineering-related topics, which together make up 41.8%. Among these five Engineering-related topics, two fall under the Mechanical Engineering subfield – "Extraction and Separation Processes" and "Industrial Engineering and Technologies" – which together account for 19.3% of CE publications. Two belong to Building and Construction – "Utilization of Waste Materials in Construction and Ceramics" and "Sustainable Design and Development" – making up 15.6% of CE publications. The last topic in Engineering, "Sustainable Industrial Ecology," represents almost 7% of CE articles.

Figure 2: Share of articles by CE topic

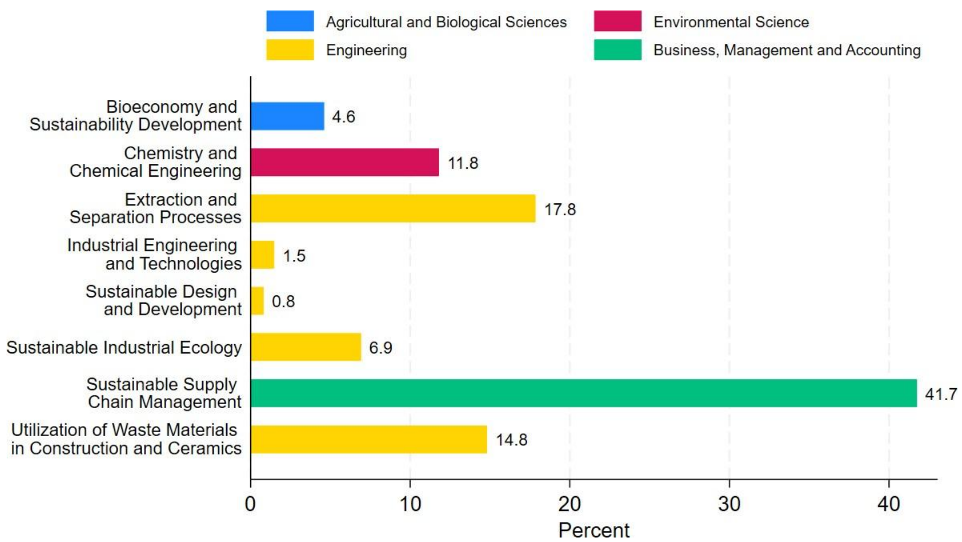


Table 1 provides an overview of the distribution of scientific articles across these topics over six distinct time windows (from 1995 to 2024). The data reveals significant trends and shifts in research focus over time, reflecting the evolving priorities and advancements within the CE domain.

We can observe from the table that topics like "Bioeconomy and Sustainability Development" and "Sustainable Supply Chain Management" show a clear upward trend, particularly from 2010 onwards. The latter, for example, increased from 6.1% in 1995–1999 to 51.2% in 2020–2024, indicating growing interest in integrating sustainability into supply chain processes as a response to global environmental challenges.

Table 1: Share of articles across CE topics by time window

Topic	1995-99	2000-04	2005-09	2010-14	2015-19	2020-24
Bioeconomy and Sustainability Development	0.4	1.0	1.9	3.5	5.8	5.3
Chemistry and Chemical Engineering	26.0	21.0	21.0	15.0	10.0	8.7
Extraction and Separation Processes	32.5	30.0	21.6	19.5	17.6	14.9
Industrial Engineering and Technologies	2.8	3.7	2.7	0.9	0.9	1.4
Sustainable Design and Development	0.8	0.0	1.3	0.9	0.7	0.8
Sustainable Industrial Ecology	4.1	2.5	5.3	5.5	7.6	7.8
Sustainable Supply Chain Management	6.1	10.9	19.4	34.8	43.7	51.2
Utilization of Waste Materials in Construction and Ceramics	27.2	30.9	26.9	19.8	13.6	9.8

Notes: Further details on OA's CE-related topics are reported in Table A.1 in Appendix A. The full list of topics with their associated subfields, fields, and domains is available from OA's technical documentation (see: https://docs.openalex.org/api-entities/topics, last visited in April 2025).

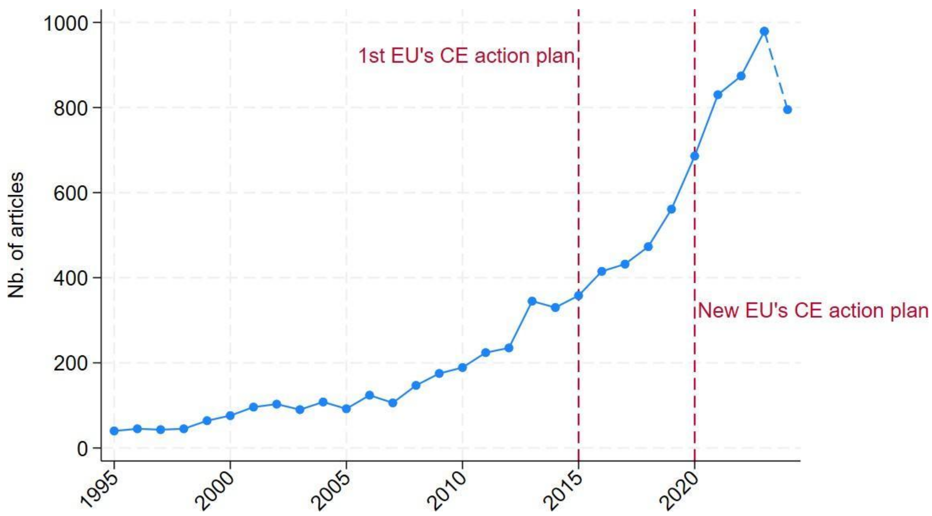
In contrast, topics such as "Extraction and Separation Processes," "Chemistry and Chemical Engineering," and "Recycling and utilization of industrial and municipal waste in materials production" exhibit a visible decline. In particular, the latter's share dropped from a steady share of around 27-30% in the period 1995–2009 to less than 10% in the last time window, potentially signaling a recent shift towards more innovative or diverse approaches to waste management within the CE framework.

Other fields like "Sustainable Industrial Ecology," "Sustainable Design and Development," and "Industrial Engineering and Technologies" demonstrate a more consistent presence over time, even with a slight increase in recent years, in the case of the first. On the other hand, the latter two fields have a negligible representation in recent time windows. This indicates that these areas are still relatively minor additions to the CE discourse. This suggests the need for more interdisciplinary approaches that integrate technological innovation, industrial processes, and ecological principles in technology, policy shifts, and global sustainability goals.

3.2 Time Trend in CE Publications

Figure 3 illustrates the growth in the number of scientific articles on CE across Italy over time. Until the early 2010s, the number of articles remained relatively low, with only a modest and steady increase. This reflects the early stages of CE research in Italy, likely influenced by limited global and national focus on the topic during this period. A noticeable acceleration in the number of CE-related articles is observed around 2015, the year of the European Union's first CE Action Plan, which likely spurred research efforts in Italy, aligning national priorities with European policy objectives. Another increase is evident after 2020, correlating with the introduction of the EU's new CE Action Plan. This highlights the continued prioritization of CE within European and Italian policy frameworks, driving increased academic and industrial interest. The drop for the year 2024 is due to truncation and delays in updating publications on OA.

Figure 3: Number of CE articles in Italy (1995-2024)



3.3 Geographical Distribution of CE Research

Figure 4 shows that the increase in CE publication volume is primarily driven by a few regions, notably Lombardy and Lazio. Their respective capitals, Milan and Rome, are the cities with the highest concentration of CE-related articles over the entire period, with nearly 1,400 articles originating from Milan and almost 1,800 from Rome (see Figure 5). The third-highest region for CE article production is Campania, located in southern Italy. Campania's surge in publications is the most recent, beginning after 2020, and it has now surpassed both Piedmont and Tuscany. Naples, the capital of Campania, ranks as the third city in CE article production over the entire period, ahead of Turin and Bologna, the capitals of Piedmont and Emilia-Romagna, respectively (see again Figure 5). Figure 6 shows the same variable, but weighted by the regional number of University researchers.[2]

Figure 4: Number of CE articles, by NUTS2 region and year (1995-2023)

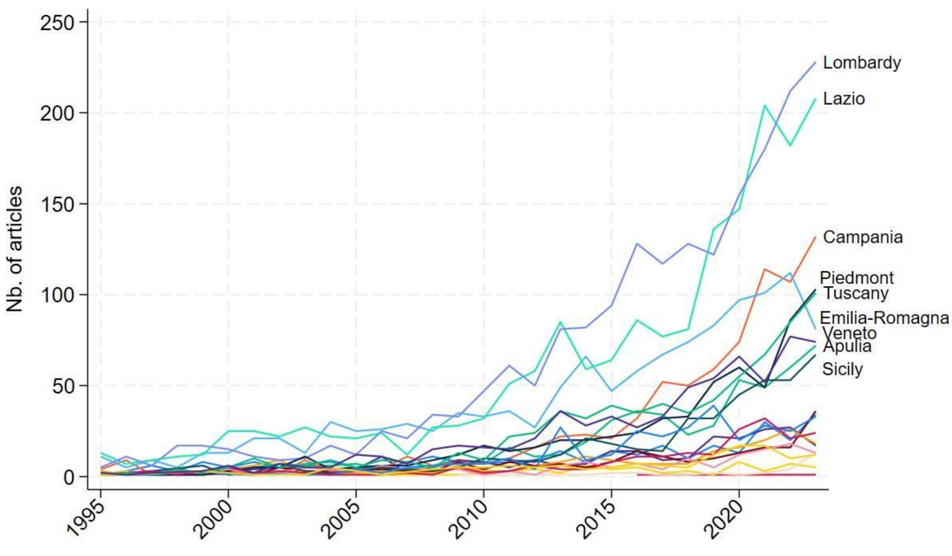


Figure 7 shows the regional distribution of CE articles published in Italy between 1995 and 2024. The size of the circles represents the total number of articles

[2] We retrieve this data from the official statistics of the MUR for the years 2000–2023, and from Coda Zabetta & Geuna (2020) for the period before 2000. To compute the population of researchers, we consider full, associate and assistant professors, both tenured and untenured, active in Italian universities as of December 31 of each calendar year.

produced in each city (only cities with at least 10 CE articles are shown), while the color scale highlights the overall regional contribution.

From a geographical point of view, CE articles are concentrated in a few key regions. The main contributors are Lombardy, Lazio, and Emilia-Romagna, followed by Campania to a lesser extent. Northern Italy emerges as one of the most active areas, with significant contributions from multiple cities in each region. For example, in Lombardy, Milan, Ispra, and Brescia stand out, while Emilia-Romagna benefits from the contributions of Modena and Bologna.

Figure 5: Number of CE articles, by top 20 city

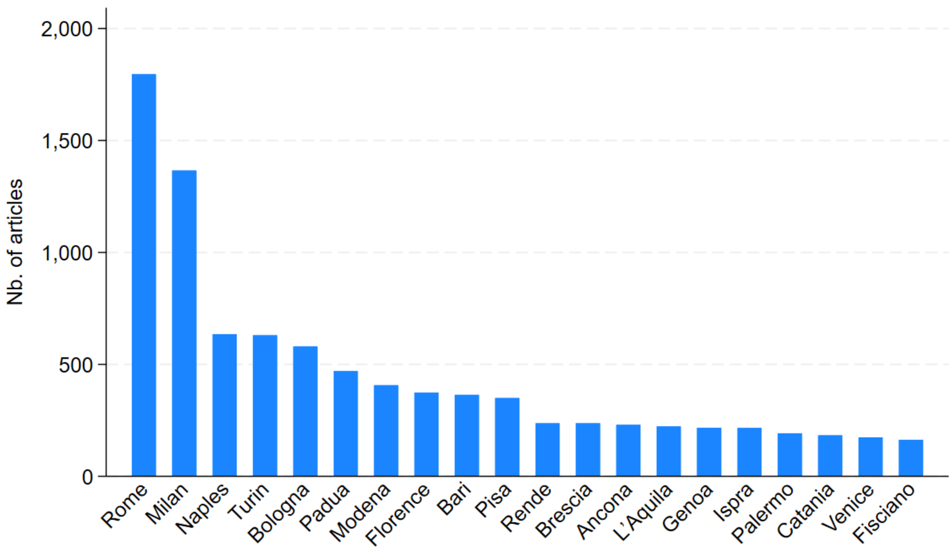


Figure 6: Number of CE articles per 100 researchers, by NUTS2 region

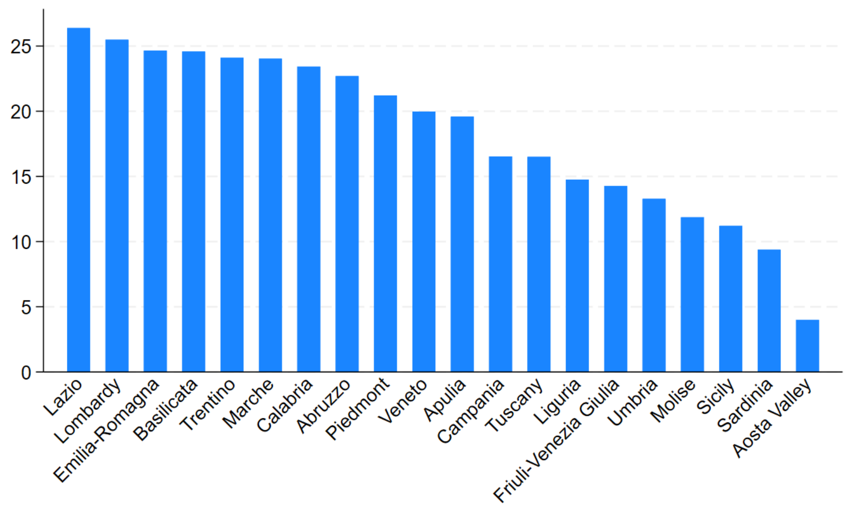
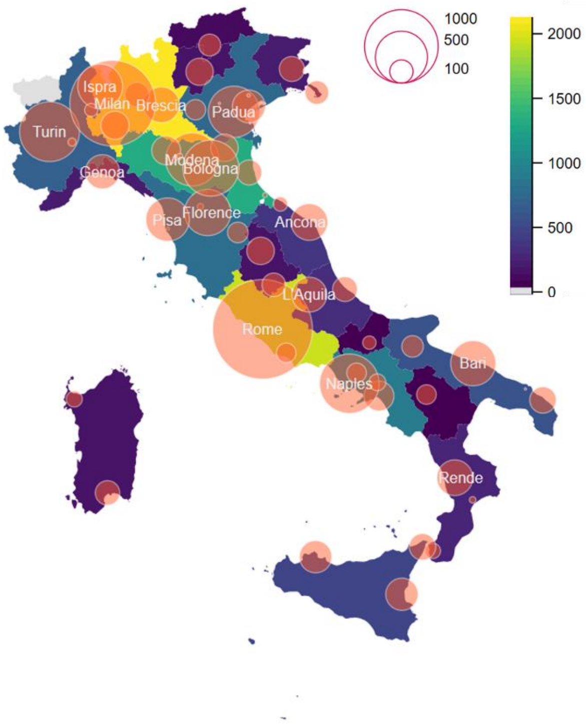


Figure 7: Distribution of CE articles in Italy



In contrast, in central and southern Italy, CE research is more centralized, with publications concentrated around major hubs. Rome dominates in Lazio, while Naples plays a similar role in Campania. Despite this, southern Italy and the islands still show notable participation, with cities such as Bari, Rende (home to the University of Calabria), and Cagliari contributing to the overall output.

This highlights a key difference between the north and the center-south of the country: northern regions tend to be multipolar, with several cities contributing significantly to CE research, while in the center-south, research is concentrated in a single dominant hub. Overall, the map highlights the crucial role played by universities and research centers in metropolitan areas in advancing CE studies across Italy.

3.3.1 Topic-Specific Regional Contributions

There is also significant regional variation in contributions to CE publications across the eight CE topics (see Figure A.1 in Appendix A). Lombardy stands out particularly in "Chemistry and Chemical Engineering," "Sustainable Design and Development," and "Sustainable Supply Chain Management." Lazio, on the other hand, plays a key role in "Bioeconomy and Sustainability Development," "Extraction and Separation Processes," and "Industrial Engineering and Technologies." Both of these regions are important contributors to the topic of "Sustainable Industrial Ecology," while Emilia-Romagna is particularly prominent in "Utilization of Waste Materials in Construction and Ceramics."

3.4 Top Contributing Institutions

Table 2 highlights the top 20 institutions in Italy based on the number of CE publications. At the top of the ranking, Polytechnic University of Milan stands out as the clear leader, with 656 publications accounting for more than 6% of the total CE publications in Italy. It has more than 200 publications more than the institutions ranked second, Sapienza University of Rome and the University of Bologna, both of which have 447 publications, representing 4.26% of the total.

Table 2: Top 20 institutions for CE articles production

Rank	Institution Name	Nb.	%
1	Polytechnic University of Milan	656	6.24
2	Sapienza University of Rome	447	4.26
3	University of Bologna	447	4.26
4	University of Padua	425	4.05
5	University of Modena and Reggio Emilia	346	3.29
6	Polytechnic University of Turin	331	3.15
7	University of Naples Federico II	272	2.59
8	National Research Council	236	2.25
9	Joint Research Centre	204	1.94
10	ENEA	203	1.93
11	University of Brescia	203	1.93
12	Marche Polytechnic University	179	1.70
13	University of Calabria	176	1.68
14	University of Turin	169	1.61
15	University of L'Aquila	166	1.58
16	University of Rome Tor Vergata	161	1.53
17	University of Palermo	160	1.52
18	Polytechnic University of Bari	155	1.48
19	Parthenope University of Naples	150	1.43
20	Scuola Superiore Sant'Anna	138	1.31

Notes: The number of publications is computed using full counting.

Following these two universities, the University of Padua ranks third, also with a high volume of research output, exceeding 400 publications. The group of institutions with over 300 publications includes the University of Modena and Reggio Emilia and the Polytechnic University of Turin. Among the top 10, the University of Naples Federico II is the only institution located in southern Italy, emphasizing the north-central concentration of research in this field.

The last three positions in the top 10 are occupied by research institutions rather than universities: the National Research Council (CNR), the Joint Research Centre

(JRC), and ENEA. These organizations play a fundamental role in applied research and policy development. CNR and ENEA are both based in Rome, while JRC is located in Ispra, which explains the presence of this city in Figure 5. Notably, no companies appear in this ranking, highlighting the still limited role of Italian firms in producing CE knowledge. The only exception is ENI, which plays a modest role through its research center near Milan. This center accounts for a small share, around 3%, of publications in the CE topic "Industrial Engineering and Technologies" (see Table A.2 in Appendix A).

Looking at the entire top 20, the ranking is dominated by institutions in northern and central Italy, with only a few representatives from the south, such as the University of Calabria and the University of Palermo. However, their presence highlights that CE research is gaining relevance across the country, even in regions traditionally less involved in high-volume academic publishing.

3.5 Mapping regional patterns of CE knowledge production and use

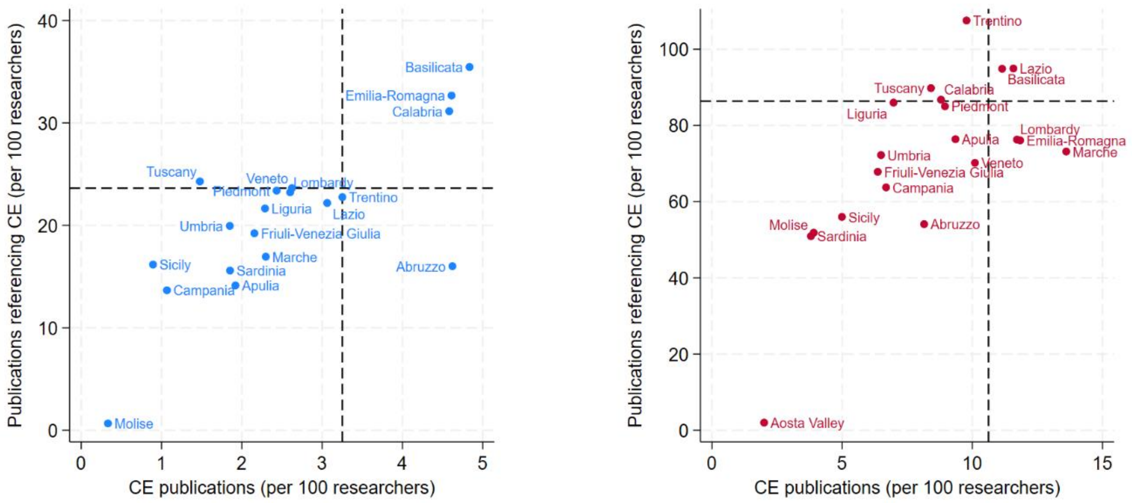
As explained in Section 2, we use information on CE publications and publications that cite CE research to classify Italian regions into four groups: *Strongholds*, *Producers*, *Integrators*, and *Laggards*. Figure 8 shows this classification for two periods: 2001–2010 and 2011–2020.

In each scatterplot, the x-axis shows the number of CE publications per 100 researchers, while the y-axis shows the number of publications citing CE research per 100 researchers. The horizontal and vertical lines represent the 75th percentile thresholds for each variable. These lines divide the plot into four quadrants, corresponding to the four regional categories, as introduced in Figure 1.

Panel (a) shows that in the period 2001-2010 only a few regions exceed the 75th percentile thresholds for both CE publications and citations. Basilicata stands out as a Stronghold, combining a high output of CE publications with strong engagement in citing CE research. Emilia Romagna and Calabria also qualify as *Stronghold* regions, though their performance is slightly weaker. Abruzzo shows strong publication output but limited citation activity, classifying it as a *Producer*. Trentino is similarly categorized as a *Producer*, just below the citation threshold. In contrast, Toscana and Veneto act as *Integrators*, with high levels of CE citation activity but not enough CE publications to qualify as *Strongholds*. Interestingly, some of the larger northern Italy regions – such as Lombardy and Piedmont – that are strong in scientific output, do not surpass the thresholds once their performance is scaled by the number of researchers. As a result, they fall into the *Laggard* category for this time-window.

Panel (b) reveals a more widespread and balanced engagement with CE science across regions in the 2011-2020 period. Several regions improved their classification compared to the previous period. For example, Marche and Lombardy moved into the *Producer* category, reflecting growth in CE-related scientific output. Trentino advanced to the *Integrator* quadrant due to an increase in publications referencing CE. Meanwhile, Lazio improved on both indicators and moved into the *Stronghold* quadrant, joining Basilicata, which was already positioned there. At the same time, some regions lose ground. Abruzzo and Veneto now fall below the thresholds becoming *Laggard* regions. Other regions, such as Molise, Campania and Puglia, remain in the *Laggard* quadrant, although they show improved performance compared to the earlier period.

Figure 8: Classification of regions in the CE scientific domain



(a) 2001 – 2010

(b) 2011 – 2020

3.6 Knowledge Base and Conceptual Structure

Figure 9 shows a conceptual co-occurrence map based on the "CE publication set". The map is generated by identifying and linking terms that frequently appear together in the titles and abstracts of these publications. Each node represents a concept, with its size reflecting the number of occurrences in the dataset. The links between nodes indicate how often two concepts appear together in the same publication, while the spatial arrangement and color-coded clusters reflect thematic proximity and disciplinary alignment.

The map reveals a clear division into major disciplinary clusters. The red cluster includes concepts primarily from the fields of social sciences, economics, and management; it is the largest and most dense, since CE is primarily an economic concept. Core terms such as *business*, *economics*, *sustainability*, *marketing*, and *supply chain* suggest a strong emphasis on the organizational, policy, and market dimensions of the CE. This cluster underscores the relevance of the research on governance, institutional change, and business strategies in enabling circular transitions in Italy.

The green cluster brings together concepts from the natural sciences and engineering. Dominant terms like *engineering*, *materials science*, *chemistry*, *waste management*, and *environmental science* reflect a more technical contribution to the Italian CE research landscape. This area highlights the importance of research on the role of technological innovation, materials recovery, and industrial processes in advancing circular practices, with engineering and chemistry serving as central nodes. The blue cluster represents computational and quantitative disciplines. It includes concepts such as *computer science*, *machine learning*, *operations research*, and *process management*. This cluster suggests the growing integration of digital tools and data-driven methods in CE studies, particularly in modelling, optimization, and systems analysis. These approaches are increasingly seen as critical enablers of circular solutions.

At the top of the figure, a smaller yellow cluster contains terms such as *environmental economics*, *natural resource economics*, and *geography*. This group reflects research focusing on spatial dynamics, resource valuation, and environmental impact assessment – topics that, while more specialized, complement the broader circular economy agenda.

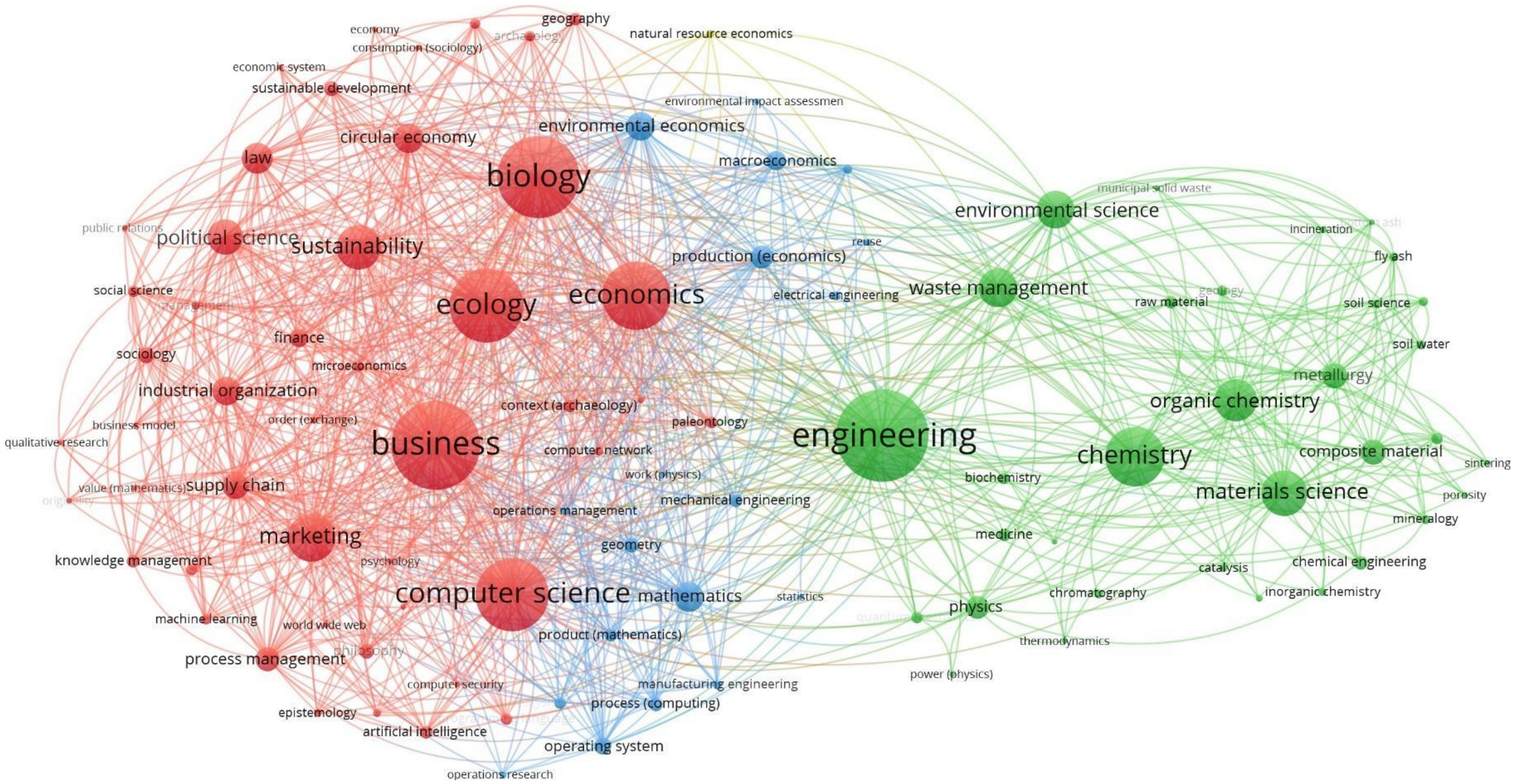
Overall, the map provides evidence of a clear division between CE research grounded in the social sciences (red cluster) and research situated in the natural sciences and engineering (green cluster). This reflects the inherently multidisciplinary nature of the CE, which spans from technical and environmental issues to institutional and behavioral change.

Concepts like *sustainability*, *ecology*, *engineering*, and *economics* sit at the core of the network, acting as bridges across different disciplinary areas. Their position reflects not just their frequency, but their role in connecting otherwise distinct research areas. These bridging concepts act as "brokers" within the conceptual space, helping to link clusters that would otherwise remain isolated, and enabling hybridization across domains. This suggests that while CE research in Italy spans a wide range of fields, there is a shared conceptual ground where ideas and methods converge.

This high level of connectivity is important because it demonstrates that CE research in Italy is not only multidisciplinary in scope but also integrated across disciplinary boundaries. Rather than existing as disconnected silos, thematic areas interact and inform one another. This hybrid configuration is crucial for addressing the systemic nature of circular transitions, which require co-evolution of technologies, institutions, business models, and social practices.

In sum, what emerges from the map is a picture of a research landscape that is both broad and well-connected. Italian studies on the CE bring together technical innovation, environmental concerns, economic reasoning, and social considerations. Rather than being fragmented, the field shows a high degree of integration, which is a promising sign for tackling the kinds of systemic challenges the CE sets out to address.

Figure 9: CE concepts co-occurrence



4 Conclusions

This paper contributes to the literature on the geography of innovation by providing the first comprehensive analysis of scientific production and uptake in the CE domain at the regional level in Italy. Using OpenAlex topic classification for identifying CE-related publications, we analyze over 9,000 publications with at least one Italian affiliation produced between 1995 and 2024. We complement this with a much larger set of over 70,000 publications that cite CE research, providing insight into regional knowledge uptake patterns. This dual perspective allows us to characterize regions not only by their scientific output but also by their engagement with external knowledge.

Our analysis uncovers several key findings. First, CE scientific activity in Italy has expanded significantly in the last decade, particularly after the release of major EU policy frameworks such as the CE Action Plans of 2015 and 2020. This suggests a strong alignment between research agendas and European policy priorities, highlighting the role of policy in steering scientific efforts. Second, CE research is highly concentrated in a limited number of regions and institutions. Rome and Milan emerge as dominant urban centers, while regions such as Emilia-Romagna, Lazio, and Trento consistently outperform others in both the production and uptake of CE knowledge.

To synthesize these dynamics, we introduce a typology that classifies regions into four categories: *Strongholds*, *Producers*, *Integrators*, and *Laggards*. This framework reveals important asymmetries in the CE knowledge ecosystem. While some regions exhibit both high production and use of CE-related knowledge (*Strongholds*), others show imbalances – for example, producing CE research but not citing it extensively (*Producers*), or relying on external CE research without producing much themselves (*Integrators*). A substantial number of regions remain in the *Laggard* category, characterized by low engagement on both dimensions. The typology not only captures static differences, but also reveals dynamic changes over time. Between 2001–2010 and 2011–2020, regions such as Lombardy and Marche improved their standing, moving into more active roles. Others, like Abruzzo and Veneto, lost ground. This suggests that CE scientific capabilities are dynamic and can evolve over time, highlighting the need for targeted policy support and sustained institutional investment to foster their development.

For each of the four regional types identified in our taxonomy, it is possible to formulate targeted policy recommendations to support their role in the CE transition. In the case of *Strongholds*, where both CE scientific production and knowledge uptake are high, policy should aim to sustain scientific excellence and ensure that the integration of research outputs into the regional system remains strong and dynamic. This includes supporting frontier research, reinforcing collaborations between academic, industrial, and public actors, and maintaining mechanisms that translate scientific advancements into practical applications.

Producers represent an especially interesting case. These are regions where scientific output in CE is high, yet this knowledge is not fully integrated into the local context. Policy efforts here should focus on removing barriers (be they institutional, infrastructural, or related to a lack of coordination) that limit the diffusion and use of CE scientific knowledge. Supporting mechanisms that enhance collaboration between universities, firms, and local institutions, as well as fostering environments where research can be more readily applied, would help ensure that CE-related science does not remain disconnected from regional development.

On the other hand, *Integrators* are regions that show relatively strong capacity to uptake CE knowledge but lack a solid local scientific base. Our findings suggest that these regions often face difficulties in advancing to Stronghold status. A key policy risk in this context is the potential for lock-in, where the region remains dependent on external scientific sources without developing a robust internal research base (Sánchez-Barrioluengo, 2014). To prevent this, regional policy could support the development of CE-focused research infrastructure, create incentives for local scientific production, and promote research agendas that are responsive to regional priorities.

Finally, Followers are regions where both CE scientific activity and knowledge uptake are limited. Here, the challenge is to avoid the usual policy mistake of investing in high-end research infrastructure without ensuring that the conditions for local knowledge integration are in place, a phenomenon often referred to as building "cathedrals in the desert" (Marques et al., 2019). Instead, policy should focus on foundational efforts, such as improving human capital, fostering local networks of collaboration, and supporting the gradual development of scientific and institutional capacities that can eventually underpin both knowledge production and integration.

Our paper is not without limitations, which also open avenues for future research. First, the study is descriptive and does not aim to establish causal relationships. While the patterns we identify are informative, future work could use causal or longitudinal approaches to better understand what drives regional specialization in CE science and how this affects innovation and sustainability outcomes. Second, our analysis focuses solely on Italy. Future research could apply the regional typology we propose to other countries or to the European level, enabling international comparisons and offering a clearer picture of how Italian research fits into the broader CE landscape. Third, our analysis focuses exclusively on the production of scientific knowledge, and does not capture other dimensions of the CE, such as its adoption by firms, industries, or other economic actors. While this scope allows us to highlight where CE-related science is being generated, it does not provide evidence on how this knowledge is subsequently mobilized and implemented. Future research could therefore explore how regional scientific capabilities relate to the development of CE technologies, business models, or even labor market dynamics. This would help deepen our understanding of how science contributes to regional transitions toward sustainability and circularity. Finally, in this paper we identify CE-related articles based on the topic classification provided by OpenAlex. This represents a step forward compared to the keyword-based retrieval methods commonly used in the literature to identify CE publications (Baldassarre & Saveyn, 2023; Dragomir & Dumitru, 2024; Fontana et al., 2021). However, future research could aim to develop ad hoc, fine-tuned large language models specifically designed to identify articles within the CE domain, following a similar approach to recent empirical work on the classification of CE patents (Manera & Quatraro, 2025).

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Appendix

A Data information

Table A.1: List of OA's topics related to CE

Id	Topic name	Subfield	Field	Domain	Summary
13240	Bioeconomy and Sustainability Development	Agricultural and Biological Sciences	Agricultural and Biological Sciences	Life Sciences	This cluster of papers explores the role of biomass and bioenergy in the bioeconomy, focusing on policies, sustainability, innovation, and the transition to a circular economy. It covers a wide range of topics including national strategies, governance, societal perceptions, industrial transformation, and the potential impact on regional development.
13180	Chemistry and Chemical Engineering	Environmental Chemistry	Environmental Science	Physical Sciences	This cluster of papers focuses on the principles and applications of green chemistry, with a particular emphasis on sustainable chemistry, solvent selection, green engineering, metrics for assessing greenness, catalysis, life cycle assessment, circular economy, process mass intensity, medicinal chemistry, and environmental impact. The papers cover various aspects of incorporating green chemistry into research, development, and manufacturing processes across the pharmaceutical and chemical industries.
11091	Extraction and Separation Processes	Mechanical Engineering	Engineering	Physical Sciences	This cluster of papers focuses on the recycling of lithium-ion batteries, recovery of rare earth elements, and sustainable technology for metal recovery. It discusses hydrometallurgical processes, circular economy implications, environmental impact, and global supply concerns related to battery recycling and rare earth recovery.
13045	Industrial Engineering and Technologies	Mechanical Engineering	Engineering	Physical Sciences	This cluster of papers focuses on the intersection of digital economy, sustainable development, and technological innovation within the mineral resource sector. It covers topics such as energy efficiency, carbon sequestration, hydrogen initiatives, lithium-ion batteries, and renewable energy, with a specific emphasis on resource efficiency and circular economy principles.
13477	Sustainable Design and Development	Building and Construction	Engineering	Physical Sciences	This cluster of papers covers a wide range of topics related to sustainable design, urban development, and environmental management. It includes discussions on circular economy, resource recovery, green urbanism, climate change, product development, biomimicry, and social innovation.
12746	Sustainable Industrial Ecology	Industrial and Manufacturing Engineering	Engineering	Physical Sciences	This cluster of papers explores the concept of industrial symbiosis and the development of eco-industrial parks, focusing on topics such as circular economy, industrial ecology, sustainability, network analysis, waste management, urban industrial symbiosis, environmental assessment, and regional development. The papers cover case studies from various countries and provide insights into the potential benefits and challenges of implementing industrial symbiosis initiatives.
10539	Sustainable Supply Chain Management	Strategy and Management	Business, Management and Accounting	Social Sciences	This cluster of papers explores the conceptualization and implementation of the circular economy, with a focus on sustainable supply chain management, green practices, supply chain network design, remanufacturing, and business model innovation. It emphasizes the integration of environmental management and resource efficiency into product design and supply chain operations to achieve triple bottom line sustainability.
11672	Utilization of Waste Materials in Construction and Ceramics	Building and Construction	Engineering	Physical Sciences	This cluster of papers focuses on the utilization of various waste materials, such as incineration residues, sewage sludge ash, and glass-ceramics, in the production of bricks and ceramic materials. It explores the recycling and sustainable use of these waste materials, as well as their leaching behavior and potential applications in promoting a circular economy.

Notes: The full list of topics with their associated subfields, fields, and domains is available from OA's technical documentation (see: https://docs.openalex.org/api-entities/topics, last visited in April 2025).

Figure A.1: Regional distribution of CE articles production, by CE topic

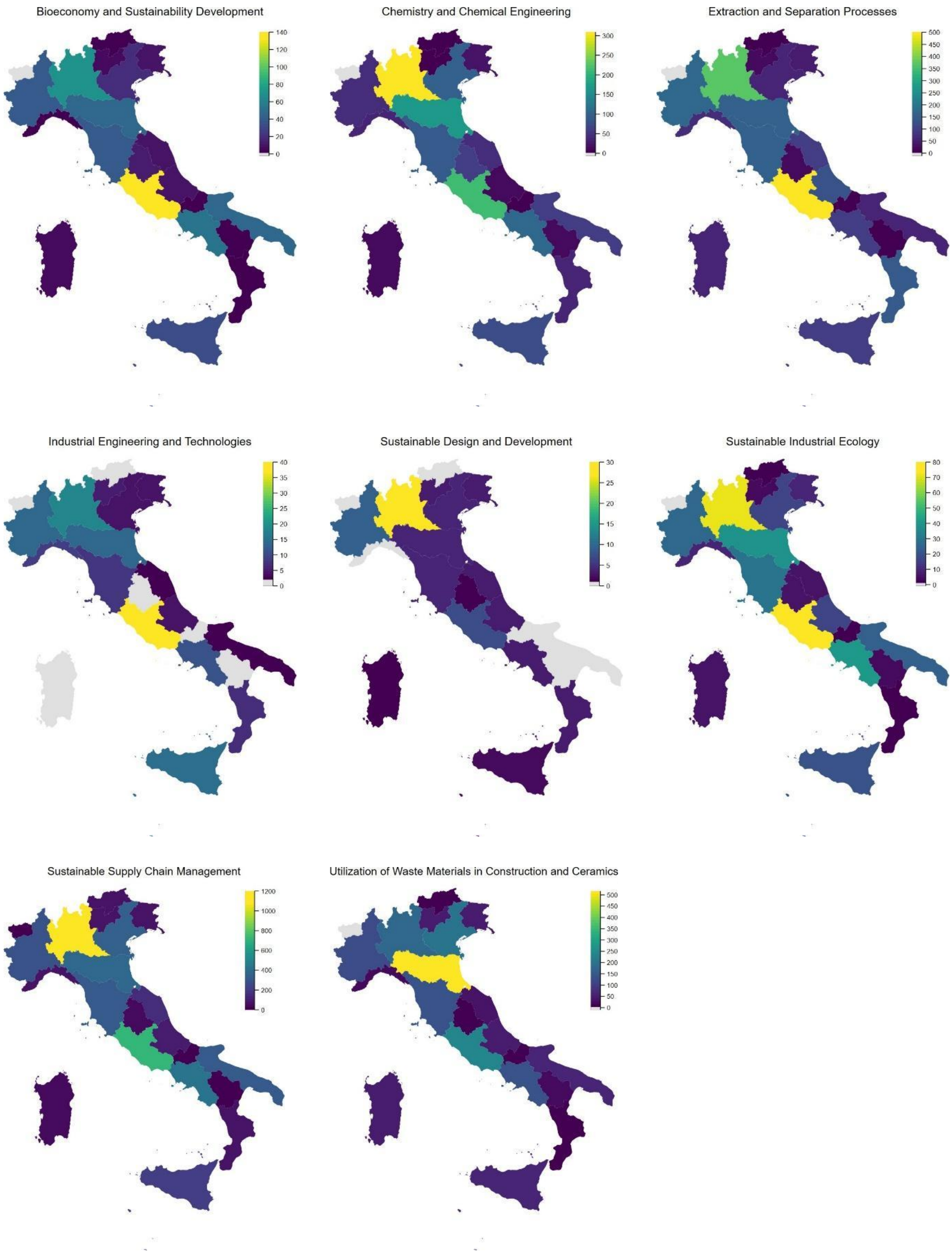

Table A.2: Top 10 institutions for CE articles production, by CE topic

Institution	Nb.	%	Institution	Nb.	%
Bioeconomy and Sustainability Development			*Chemistry and Chemical Engineering*		
Sapienza University of Rome	31	6.09	University of Bologna	87	6.53
University of Bologna	28	5.50	Mario Negri Institute for Pharmacological Research	68	5.10
Joint Research Centre	27	5.30	Joint Research Centre	52	3.90
Unitelma Sapienza University	24	4.72	University of Perugia	49	3.68
University of Naples Federico II	17	3.34	Ca' Foscari University of Venice	49	3.68
University of Foggia	16	3.14	University of Naples Federico II	48	3.60
National Research Council	15	2.95	University of Milan	46	3.45
University of Turin	15	2.95	Sapienza University of Rome	43	3.23
University of Catania	13	2.55	Polytechnic University of Milan	36	2.70
University of Florence	13	2.55	IRCCS	36	2.70
Extraction and Separation Processes			*Industrial Engineering and Technologies*		
Sapienza University of Rome	195	9.22	University of Palermo	11	7.75
ENEA	113	5.34	Polytechnic University of Milan	10	7.04
Polytechnic University of Milan	112	5.30	Polytechnic University of Turin	8	5.63
University of Calabria	102	4.82	University of Genoa	7	4.93
Polytechnic University of Turin	101	4.78	University of Calabria	6	4.23
University of L'Aquila	94	4.44	Sapienza University of Rome	6	4.23
Institute on Membrane Technology	81	3.83	University of Bologna	6	4.23
University of Bologna	81	3.83	Eni (Italy)	5	3.52
National Research Council	68	3.22	University of Naples Federico II	5	3.52
University of Pavia	51	2.41	University of Florence	4	2.82
Sustainable Design and Development			*Sustainable Industrial Ecology*		
Polytechnic University of Milan	23	33.82	Polytechnic University of Milan	22	5.99
Polytechnic University of Turin	9	13.24	Sapienza University of Rome	20	5.45
University of Chieti-Pescara	3	4.41	ENEA	19	5.18
University of Reggio Calabria	3	4.41	Polytechnic University of Turin	17	4.63
University of Bologna	3	4.41	Polytechnic University of Bari	17	4.63
University of Trento	3	4.41	Parthenope University of Naples	15	4.09
Sapienza University of Rome	2	2.94	University of Bologna	15	4.09
Roma Tre University	2	2.94	University of Chieti-Pescara	14	3.81
University of Camerino	1	1.47	Scuola Superiore Sant'Anna	11	3.00
University of Campania "Luigi Vanvitelli"	1	1.47	University of Modena and Reggio Emilia	11	3.00
Sustainable Supply Chain Management			*Utilization of Waste Materials in Construction and Ceramics*		
Polytechnic University of Milan	410	9.46	University of Modena and Reggio Emilia	259	14.33
University of Padua	195	4.50	University of Padua	151	8.35
University of Bologna	149	3.44	Institute of Science and Technology for Ceramics	103	5.70
Sapienza University of Rome	143	3.30	University of Bologna	80	4.42
Polytechnic University of Bari	130	3.00	Polytechnic University of Turin	66	3.65
University of Brescia	115	2.65	National Research Council	62	3.43
University of Naples Federico II	113	2.61	Sapienza University of Rome	60	3.32
Scuola Superiore Sant'Anna	113	2.61	University of Naples Federico II	51	2.82
University of Rome Tor Vergata	110	2.54	University of Brescia	48	2.65
Polytechnic University of Turin	108	2.49	Polytechnic University of Milan	42	2.32