


## Article

# Theoretical Research on Circular Economy and Sustainability Trade-Offs and Synergies

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**Abstract:** Circular economy (CE) and sustainability are interrelated, without being exchangeable. While sustainability tries to reconcile the management of productive resources with their increasing consumption, CE aims to make the productive process more efficient, reducing, reusing and recycling the results of the productive process as much as possible. The aim of this paper is to ascertain the systemic structure of interactions between sustainability and CE through the analysis of the existing literature from 2004 to 2021. For this purpose, a computational literature review and a content analysis of the main contributions of CE and sustainability, within the framework of the Sustainable Development Goals (SDGs), were conducted. The results show that there is a positive impact of the synergy between CE strategies and certain SDGs. Specifically, the circular strategies that generate the greatest synergies have to do with preserving materials through recycling, downcycling, and the measurement of indicators or reference scenarios. This is what has led to the inclusion of these concepts in the formulation of policies and strategies, as their multidisciplinary nature allows them to have an impact on areas such as agriculture or innovation, which currently lack specific measures. Therefore, the knowledge derived from this study will contribute favorably to future decisions and actions to be considered, as there is still the potential to legislate in favor of an even more sustainable framework.

**Keywords:** circular economy strategies; priority sectors; sustainable development goals; content analysis; matrix of relationships



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## 1. Introduction

### *Research in the Era of Sustainability and Circular Economy*

In recent years, growing concerns have emerged about the ability of current European transition pathway to meet climate change, waste generation, pollution and resource depletion challenges. We find evidence of those concerns in the European Green Deal, which accelerates the systemic attitude in the area of sustainability and circular economy issues. The sustainability paradigm could be decrypted from several axes, one of which is the framework provided by the 17 Sustainable development goals (SDG) established by the United Nations in 2015, which supply a quantitative set of indicators to facilitate the assessment of sustainability improvements at different scales of analysis [1,2]. Herein, sustainability is understood as the dynamic equilibrium between the allocation of resources in the production process and consumers' behavior patterns [3–5]; in that respect, sustainability is not a synonym of circularity. Circular economy (CE) is understood as the regenerative system that promotes the minimization of waste generation by closing and extending loops, and improving eco-efficiency technologies, while maintaining its value in

the economy for as long as possible [6]. In CE, a few things are critical: the level of analysis or scope, the typology of the existing strategies, and the priority business economy sectors in which those strategies have been deployed.

This study intends to propose a coherent scientific framework in the intersection of sustainability and CE which is capable of recognizing negative interactions (trade-offs) and positive synergies, with the aim of establishing coherent systemic agendas. The methodology of this study uses a computational literature review (CLR) and the content analysis method (CAM) of existing scientific production on the interaction between CE and sustainability from 2004 to 2021. This methodology is based on four phases: pre-analysis, duplicate removal, data exploitation (categorization and coding), and the processing of the outcome. The applied methodology facilitates the identification of relationships between interventions and outcomes mediated by generative mechanisms operating in a context-dependent manner for the evolution trends, actors' behaviours and socio-political implications. The authors claim that the development of a prescriptive knowledge displaying CE priority areas, for which the design proposition suggests specific generative CE strategies deployed through an adapted scale of analysis, will encourage the emergence of synergies and the reduction of trade-offs in the SDGs. The aim of this paper is twofold: (1) to supply a milestone in the state of the art on the existing sustainability goals influencing the implementation of CE strategies and vice-versa; and (2) to provide prescriptive knowledge based on the existing literature to support policy coherence. The political agenda addressed in the European Commission's Green Deal sets out the path for a fundamental transformation of Europe's economies and societies, which seeks to consolidate the efforts of policymakers, industry and research [7]. This paper investigates the following research questions: (1) Are the systemic interactions between sustainability and CE found in the literature analysis supported by empirical observations or studies? (2) If so, has this knowledge played a prescriptive role in policy making?

A set of 960 articles in English was collected using the words "circular economy" and "sustainability", and synergies or trade-offs, interactions, relationships, collaboration or systemic in the title, abstract and keywords from Scopus<sup>®</sup> and Web of Science<sup>®</sup>. Out of this first set of articles, 229 scientific documents were identified in which the topic of sustainability is analyzed based on its relationship with CE strategies throughout CLR and CAM through a realistic synthesis [8] of the subject, which was the main outcome of this study. Bibliometric analysis is a comprehensive method to manage the review, evaluation and objective representation of the state of the art of a specific research field [6,9–11]. The outcomes of this study establish the countries' productivity in this matter; the research content clusters out of keyword co-occurrence mapping, the CE priority areas and their scale of analysis, the matrix of interactions within SDGs and CE strategies implemented in the existing literature, and the social-political implications that define the current state of the art.

## 2. Theoretical Framework

### 2.1. Applications of Systems Thinking Theory

Systems thinking emerges in this study as a framework which is able to deal with complexity, as the more actors there are in the network the more complex the challenge becomes. However, there is a lack of tools and methods which are capable of integrating the systems theory in the complexity of sustainability and CE assessments. The systemic approach emerges as the framework which is able to deal with the complexity of causality knowledge, which supplies insights about how some generative mechanism(s) influence the intervention that produces suitable outcomes from the specific problematic context faced by policy and decision-makers. Socioeconomic ecosystems entail a high level of complexity because allocation decisions are submitted to many constraints and motivations.

Several studies have attempted to link the concepts of systems analysis with the issues of sustainability and CE, but very few use systematic literature review methods, such as the CLR and the CAM, which emphasize the comprehensiveness to deal with

the review, evaluation and the objective of representing the state of the art of a specific intervention. CLR is characterized by analyzing the content of published research, as well as by identifying emerging areas in the scientific community. These methodologies are currently needed because the growing interest in numerous research areas makes it increasingly difficult to follow a rigorous research review process on a specific topic [12]. For this reason, journals such as *Applied Research in Quality of Life* and *Organizational Research Methods* use this methodology [13,14]. CAM, which is based on systematically identifying the content of the documents that make up the sample to be analyzed, is frequently used in the social sciences. Moreover, this methodology is characterized by its objectivity, as the information is processed in numerical quantities, rather than in linguistic characters for further numerical processing [15,16]. For instance, the current systems thinking literature uses three theories as the main framework for explaining causality in the analysis of complex systems: (1) the theory of proximity, (2) ecosystem theory, and (3) the theory of complex adaptive systems (CAS) [17]. In this study, we address the prescriptive role of systems thinking causality through the third theoretical framework approach of CAS. In this sense, CAS [18] highlights two basic characteristics: (1) the whole cannot be reduced to the sum of its parts, and (2) complexity introduces the notion of balance / instability dualism, suggesting that sustainable trade-offs could cause an imbalance in environmental flows and organizational disruption, triggering the systems' collapse or change. The idea of an open, dynamic system that evolves towards a stabilizing balance could encourage the consensus needed to integrate more towards CAS.

## 2.2. Sustainability and Circular Economy

The international community committed, in 2015, to set the 17 SDGs, with the expectancy for them to be accomplished within the horizon of 2030. The 17 SDGs form a system of interacting components that reflects the highly systemic and complex nature of sustainability [19,20]. Although they represent a breakthrough in the assessment of sustainability, SDGs are not exempt of criticism, expressed in the form of over simplistic and linear narratives far behind the desirable systems thinking approach. In spite of the large amount of interpretations and approaches bundled together under the term CE, as evidenced by the paper published by Kirchherr et al. [21] in 2017, the authors agree on defining it as "the regenerative system in which resource input, waste, emissions and energy leakage are minimized by slowing, closing and narrowing material and energy loops" [6]. Counterintuitively, the authors find that analyzing complex targets in the sustainability area with the wrong methodological tools and along a misunderstood scale may lead to trade-off acceleration or the interruption of existing synergies. This highlights the fact that practical allocation decisions to implement CE policies aiming for sustainability are generally disconnected from the socioeconomic and environmental context because of the systems' complexity [22–25]. For instance, bio-waste recovery may be necessary to compensate for the lack of organic carbon in agricultural soils, to provide phosphorus and nitrogen to these, and to produce locally renewable energy or molecules with higher benefit.

Perfect circularity cannot be attained because of the biophysical and socioeconomic limitations already identified in the literature [23]. However, regarding sustainability synergies with CE, both frameworks are, in theory, complementary and incremental, but in practice, the society needs to figure out public policy interventions to reinforce the multiplier effects. CE is not necessarily more sustainable, i.e., more circular firms need to stabilize or even increase the waste (by-product) production included as an input in the production process of another partner firm to maintain or increase their production. In this same logic, circularity does not guarantee sustainability, understood as the dynamic equilibrium between the resources' allocation in the production process and the consumers' behavior patterns. For example, low transportation, transaction and labor costs can lead firms to offshore their waste for recycling, disregarding the environmental impact of what takes place abroad [23], which is mostly considered as an externality. Interconnected sys-

tems enable the transition to sustainability within circular policies. However, the long-term consequences of such interventions can be difficult to predict [26,27]. Thus, sustainability and CE agendas do not always act consistently, which can result in interventions that sometimes inhibit each other's goals. The European Union (EU) has increased interest in CE issues, revealing potential trade-offs with sustainability goals [28,29] as of 2011. For example, in France, discussions on CE emerged during the Grenelle Environmental bill in 2007 and the Energy Transition Law for Green Growth (Law No. 2015-992, 17 August 2015) positioning waste treatment within the CE's broader framework.

The authors incorporate the CE priority business economic sectors in the methodological framework of this study, as defined by the European Commission in 2015 in the EU Action plan for the Circular Economy [30], and the scales of analysis on which the CE strategies have been deployed to supply a coherent and systemic policy agenda. There is no consensus in the literature about the existing strategies promoting CE [4]; therefore, authors use and adapt the existing CE strategy classification applied by Ronzon and Sanjuan [19] in 2020, which was inspired by Moraga et al.'s [4] insights. Thus, six categories set the classification ground according to the impact object; the first five stand for preservation, while the sixth considers measurement and indicators:

- Preserve systems' functionality, entailing innovative models like sharing platforms and Product Service-Systems (PSS).
- Look after the product and its components through its lifetime, trying to keep them in the economy as long as possible by increasing their durability, reuse, restoring, refurbishing, remanufacturing and the repurposing of parts.
- Pool the available infrastructure and boost the sharing economy in distribution, storage, waste management and other commodity services.
- Maintain the materials and processes through closing and extending strategies like recycling and downcycling.
- Look after the energy embodied in a productive system through energy recovery and intensification.
- Measure and indicate progress or regression towards CE. For example, the indicator of the waste share that is recycled or the lack of measures in specific production activities and areas [31,32].

All CE strategies can be analyzed at different scales: (a) micro, as in innovative firms and corporations, single products, or consumers who are usually without the life-cycle thinking approach [33]; (b) meso, as in platforms, communities, eco-industrial parks, industrial symbiosis and other industrial ecosystems where a full or partial life cycle analysis approach along the value chain can be found; and [34] macro, as in cities, provinces, regions or countries that set functional boundaries where the basic needs for citizens are covered in a cause-and-effect chain. However, herein the scales of analysis are directly related with the six previous CE strategies, which means that each one of the six strategies could be approached according to a different scale of analysis. For example, regarding the products and the product components strategy, the macro level refers to the raw materials extraction and design that takes place in the regions and countries. The meso level addresses the production structure when manufacturing, logistics and use decisions take place in the platforms, industries sectors and industrial parks; finally, the micro level in the products strategy refers to the system, wherein end-of-life assessments are performed regarding specific value chains in firms.

### 3. Data and Methodology

This research describes a Systematic literature review (SLR) of existing scientific production using the CLR technique proposed here as a complementary part of the literature review process. The CLR software COVIDENCE<sup>®</sup> (COVIDENCE, Melbourne, Australia) is used to support the analysis of the specific area's literature review. The CLR analysis of a research corpus comprises three dimensions: (1) Impact (citation counts, number of published articles, etc.), (2) Structure (the country's network of publications), and (3) Content

(keywords co-occurrence map) [35]. While SLR can be quantitative or qualitative, very few CLRs aim to integrate CAM to handle large volumes of existing literature, and thus rely on qualitative analysis and descriptive approaches. Thus, CLR stands as a response to the issue of selecting, filtering and analysing large volumes of research articles complementing the human SLR process, rather than replacing it. As observed in Table 1, CLR aims to perform an analysis of a research area comprising 960 papers about the existing sustainability goals, which influence the implementation of CE strategies and vice-versa. In the CLR process, an SLR was conducted to map and assess the existing intellectual territory in a transparent and reproducible way (using algorithms) to produce a realistic synthesis capable of supplying prescriptive insights from the review process.

**Table 1.** Stages of the bibliometric analysis process.

Stages of the Process	Selection Criteria	Results
1. Pre-analysis	Search and analysis of the term (“circular economy” AND “sustainability” AND (synergies OR trade-offs OR relationship OR interaction OR collaboration OR systemic) in Scopus® and Web of Sciences® databases on 25 April 2021.	Search: TITLE-ABS-KEY (“circular economy” AND “sustainability” AND (synergies OR trade-offs OR relationship OR interaction OR collaboration OR systemic) AND (LIMIT-TO (LANGUAGE, “English”) Scopus®: 478 articles Web of Sciences®: 482 articles TOTAL = 960
2. Duplicates removed	Verification of the duplicate articles and papers’ coincidence within both databases (Scopus® and Web of Sciences®).	When analyzing conformity of the literature review, 367 duplicate materials were removed from both collections using Covidence® software analysis in the CLR process.
3. Data exploitation (Studies screened)	3.1. Analysis of the title, keywords and the abstract in that order, to isolate the papers that were out of the scope of this systemic analysis because of pointed out meta-analysis or merely because they solely address technical issues, without looking at the relationship or influence between sustainability and CE, even if indirectly. 3.2. Second round screening analysis, pointed out theoretical studies (bibliometric analysis, narratives, reviews, etc.), disregarding the potential synergies or trade-offs among sustainability and CE framework.	593 documents screened, 337 articles were identified as irrelevant and excluded from the sample in the first screen round.  256 full text-studies assessed for eligibility; 27 studies were excluded in the second round of the screen process.
4. Processing of the outcome	Assessment of the computational literature review type of analysis, Covidence® and adequate tools for scientific CAM and co-occurrence mapping through VOSViewer.	Indicators and bibliometric maps with VOSViewer from the final 229 articles collection. - Annual number of articles, - Scientific journals prevalence, - Countries productivity, - Co-occurrence of keywords, - Priority business sectors and its scale of analysis, - Matrix of interactions identified within SDGs and CE strategies in the literature.

Source: authors.

The systemic approach gives a basic understanding on why certain outcomes emerge in the SDGs assessment; this may explain how certain CE strategies subject to different scale of analysis will change their reasoning, and hence their behavior, faced with a specific CE business economic priority sector. The underlying mechanisms (CE strategies) can be

expected to generate a range of different outcomes (synergies or trade-offs) in the SDG targets' evolution. The prescriptive role of systems finds a common framework in the scales selection for CE strategies implemented by policy- and decision-makers following how things should be. The relationship between CE and sustainability goals will be further described in the cross-impact matrix to settle the allocation among CE strategies and SDGs in order to perform the systemic analysis of priority settings.

#### *Period and Analyzed Variables*

The period analyzed covers 17 years, from 2004 to 2021, in which the first paper "Analysis of the dynamic coupling processes and trend of regional eco-economic system development in the Yellow River Delta" stands out, published in 2012 by Wang and Wu [36]. This study aims to provide evidence based on the existing literature to delve into the five identified clusters of research, which range from the environment (green cluster) to politics (purple), efficiency (blue), innovation (yellow) and resource's sustainability (red) to identify the interventions triggering synergies and tensions between CE and sustainability in the existing literature. This paper investigates the causality of the drivers that support policy coherence in the political agendas. The bibliographic indicators included in this study are the annual number of articles, the total number of citations per author and per year, the scientific journal's prevalence, the scientific institution's interlinkages and country's productivity, keyword analysis, case studies' priority business economic sectors and their scale of analysis.

The interactions identified within SDGs and CE strategies in the literature are not determinant, but they offer a fair idea about the trends, relevance and cartography of the systemic interaction between these concurrent and sometimes controversial topics. In this study, a series of diagrams and the outcomes and analysis obtained in this study is presented. COVIDENCE<sup>®</sup> software was used for a better systematic review management, as well as VOSviewer<sup>®</sup> software (version 1.6.11, CWTS, Leiden, The Netherlands), specialized in the bibliometric cartography representation of co-quotation and co-occurrence [11,37,38].

In Table 1, we can observe that a list of 960 papers was obtained from a collection of articles from the Scopus and Web of Science databases on 25 April 2021. From the search on the Web of Science, 478 papers and 482 from Scopus were extracted. After one round of verification through the Covidence software analysis, in which the conformity of the literature were corroborated, 367 duplicate materials were removed from the 960 article collection. Up to two rounds of data screening analysis were drawn regarding the title, keywords and the abstract, in that order, to isolate the papers that were out of the scope of this systemic analysis. The scientific documents that pointed out meta-analysis or that only addressed technical issues were excluded from the sample in the screening process, along with those that disregarded the potential synergies or trade-offs among sustainability and the CE framework, even if indirectly. Therefore, 337 irrelevant articles were discarded in the first round, together with 27 articles in the second round that dealt with specific technical and theoretical studies (bibliometric analysis, narratives, reviews, etc.). Then, after the identification of the irrelevant articles in the preliminary analysis and the elimination of the 364 articles in the two consecutive rounds of screening, a final list of 229 articles was obtained, which was further processed through piece of network mapping analysis software called VOSviewer, through which the map of countries' productivity and keywords co-occurrence was built.

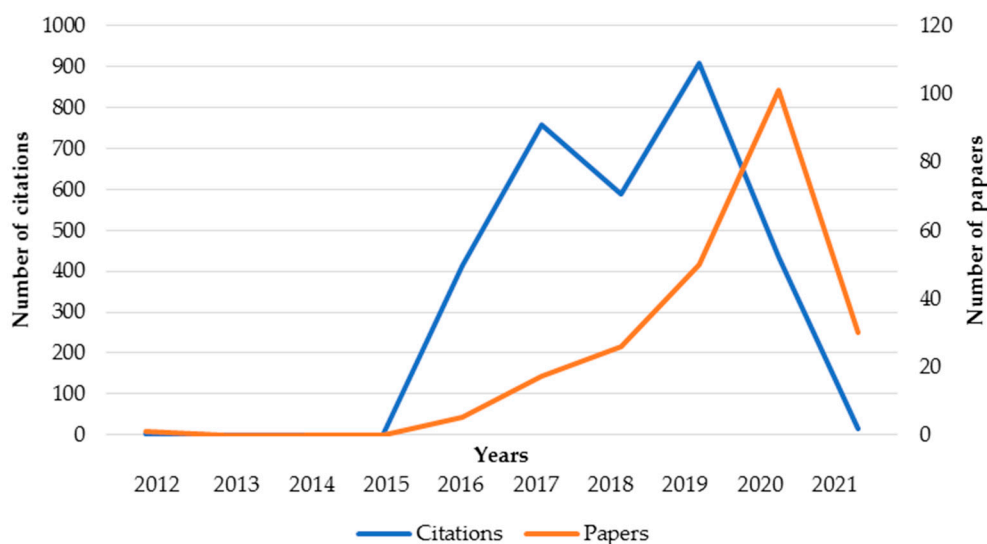
#### **4. Results and Discussion**

Evidence from the field of sustainability and CE interactions was tested in this section in various settings within the overall application domain, seeking to give further insight with which to design optimal interventions and help to predict outcomes in specific settings, e.g., a scale of analysis for each CE priority area through case-based reasoning. Indeed, identifying common elements can facilitate progress and accelerate the achievement of the SDGs by preventing one goal from stalling another. A better understanding of the

complexity in these issues raises the following questions: (a) Are the interactions found in the analysis of the literature scientifically sound? (b) If so, has this knowledge been taken into account for policy formulation? (c) How do the socioeconomic ecosystems co-evolve, thus helping in the identification of the patterns that arise in such evolution? Systems thinking theory (i.e., emphasizing time and change) can be used to recognize changes in the strategies, the priorities, the interrelationship drivers, and the environment.

#### 4.1. Productivity of the Authors, Authors' Network and Subject Evolution

It is clear from what we observed in the outcomes of the study that the systemic approach in the intersection between sustainability and CE is attracting interest. Compared to only five publications in 2016, there were 101 publications in 2020, which means that the number of publications grew 20 times over the last 5 years. The evolution of scientific production in CE and sustainability subjects' field intersection can be seen in Figure 1 using the number of published papers and the citations per year during the observed 17 years. The scientific community is showing an increasing interest in the topic, as evidenced by the evolution in the number of papers and citations per year, from one in 2012 to 101 articles in 2020. In 2019, the yearly citations average is clearly the highest from all of the analyzed periods, reaching 908. In the last 4 years (2018–2021), 90% of the observed articles were published, with 206 articles out of 229.



**Figure 1.** Total number of published papers and annual citations from the 2012–2021 observation.

Once the period of study was defined, it was evident that the first time that citations increased was in 2016, going from 0 to 412. After that, the following citation values are displayed in Figure 1 in the year 2017 (758), 2018 (590), 2019 (908) and 2020 (435). The year 2019 has the highest number of citations (908) reported. The paper published by Genovese et al. (2017), “Sustainable supply chain management and the transition towards a circular economy: Evidence and some applications”, is the one with the highest number of citations, i.e., 321. In the second place, with 214 citations, Witjes and Lozano published the paper “Towards a more Circular Economy: Proposing a framework linking sustainable public procurement and sustainable business models”, in 2016. The top ten list of articles with the highest number of citations is displayed in Table 2 (1265), representing 40.8% of the total number.

**Table 2.** Papers with the highest number of citations.

Authors	Article Title	Year	Source Title	Total Citations
Genovese A.; Acquaye A.A.; Figueroa A.; Koh S.C.L.	Sustainable supply chain management and the transition towards a circular economy: Evidence and some applications.	2017	Omega (United Kingdom)	321
Witjes S.; Lozano R.	Towards a more Circular Economy: Proposing a framework linking sustainable public procurement and sustainable business models.	2016	Resources, Conservation and Recycling	214
Saidani M.; Yannou B.; Leroy Y.; Cluzel F.; Kendall A.	A taxonomy of circular economy indicators.	2019	Journal of Cleaner Production	124
Pieroni M.P.P.; McAloone T.C.; Pigosso D.C.A.	Business model innovation for circular economy and sustainability: A review of approaches.	2019	Journal of Cleaner Production	123
Nasir M.H.A.; Genovese A.; Acquaye A.A.; Koh S.C.L.; Yamoah F.	Comparing linear and circular supply chains: A case study from the construction industry.	2017	International Journal of Production Economics	103
Iacovidou E.; Velis C.A.; Purnell P.; Zwirner O.; Brown A.; Hahladakis J.; Millward-Hopkins J.; Williams P.T.	Metrics for optimizing the multi-dimensional value of resources recovered from waste in a circular economy: A critical review.	2017	Journal of Cleaner Production	92
Herczeg G.; Akkerman R.; Hauschild M.Z.	Supply chain collaboration in industrial symbiosis networks.	2018	Journal of Cleaner Production	78
Lazarevic; D; Valve; H	Narrating expectations for the circular economy: Towards a common and contested European transition.	2017	Energy Research and Social science	73
Sun, L; Li, H; Dong, L; Fang, K; Ren, JZ; Geng, Y; Fujii, M; Zhang, W; Zhang, N; Liu, Z	Eco-benefits assessment on urban industrial symbiosis based on material flows analysis and energy evaluation approach: A case of Liuzhou city, China.	2017	Resources, Conservation and Recycling	71
Supino S.; Malandrino O.; Testa M.; Sica D.	Sustainability in the EU cement industry: The Italian and German experiences.	2016	Journal of Cleaner Production	66

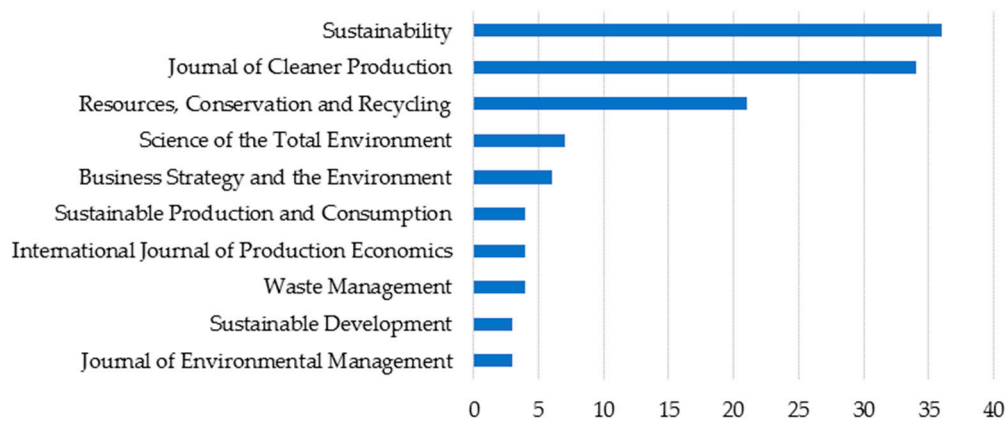
Source: Authors, with data gathered from Scopus and Web of Science after the CLR analysis in the observed period from 2004 to 2021.

Among the ten most cited papers, 50% used a meso level analysis approach, and 40% used a multiscale analysis, without defining the specific boundaries of the study. The top ten list outlines, overall, the CE strategies, with one seeking to preserve the function of products and services, and four seeking to preserve the materials through recycling and downcycling. Herein, the authors acknowledged the link to SDGs related to sustainable cities and communities (SDG 11), to responsible consumption and production (SDG 12), and partnership for the goals (SDG 17). Among the most cited articles, the link with the SDGs can be recognized, especially SDGs 11, 12 and 17.

#### 4.2. Journals' Prevalence, Scientific Institutions' Interlinkages, and Countries' Productivity

The ten main scientific journals identified in Figure 2 represented 53% of all of the analyzed papers in the sample during the 2004–2021 period. The first paper in the sample was published in 2012 in the Shengtai Xuebao/ Acta Ecologica Sinica. This is the only article from this source in the analyzed sample. The Sustainability MDPI journal published the highest number of papers (36) in the sample, which represents 16%, and ranks in the first position. However, it comes fourth in terms of the number of citations, with 120. The second journal with the highest number of papers (34) is the Journal of Cleaner Production, which specializes in environmental sciences, and industrial and manufacturing engineering, among other categories. This journal has 985 citations, holding the first place in the rank with the highest number of citations in the sample of the study. Resources, Conservation and Recycling, with 21 papers (532 citations), is in the third position in terms of productivity in the ranking.





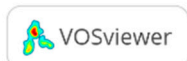
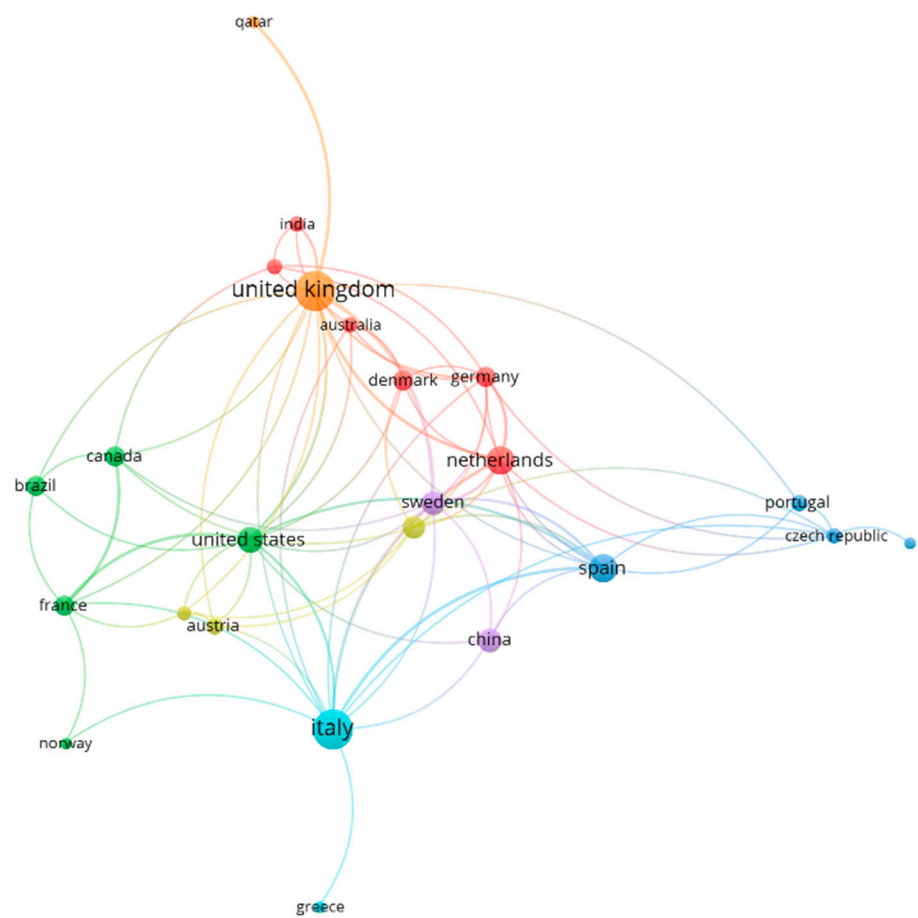
**Figure 2.** Main journals that published papers from 2004 to 2021.

The International Journal of Production Economics (IJPE) has four documents published, and the highest average of citations per document (34.3), followed by the Journal of Cleaner Production, with 34 published papers in the analyzed period and an average citation of 29 per paper. Journals and the number of citations they possess are an important indicator for the assessment of the impact of the research work carried out [10]. Interdisciplinarity is also essential, as it provides a broader theoretical framework and opens up greater opportunities for dissemination in the scientific community and civil society. The journal Science of the Total Environment, which has 7 papers published, holds the fourth place in productivity and the fifth place in the number of citations, with 13.3 per document. The authors claim in this study that the increase in the number of papers, the number of citations, and in the number of authors, institutions, journals and countries confirms the rise in interest for CE and sustainability's systemic interaction.

The countries' scientific productivity was calculated in this study through the first author affiliation (Figure 3). Italy is the country with the highest scientific productivity based on the origin of the first authors, with 33 documents; the United Kingdom takes the second place (32 articles) but it holds the first place in the rank of citations, with 1142. The Netherlands, Spain and Sweden join the UK and Italy with 16, 17 and 11 articles, respectively, as the five main countries in article productivity. Herein, the authors state that Europe stands out as the most relevant region in the world regarding the development of scientific literature seeking to investigate the interactions between CE and sustainability, with a representation of 48% in the scientific literature within the previous five countries. The Netherlands is located in the second position in terms of the total amount of citations, with 471, before Italy, which ranks third with 295 citations, and Spain with 258.

#### 4.3. Keyword Analysis

The keyword analysis was developed in Figure 4 taking into account five clusters: green (environmental), blue (efficiency), yellow (industrial innovation), red (resource sustainability) and purple (political). The terms "circular economy" and "sustainability" are at the heart of the bibliometric analysis. The network map represents the words used in research by the authors and the Scopus and Web of Science databases. Specifically, this map, with a minimum of five co-occurrences, indicates the topics of interest (clusters) and the strength between these terms.



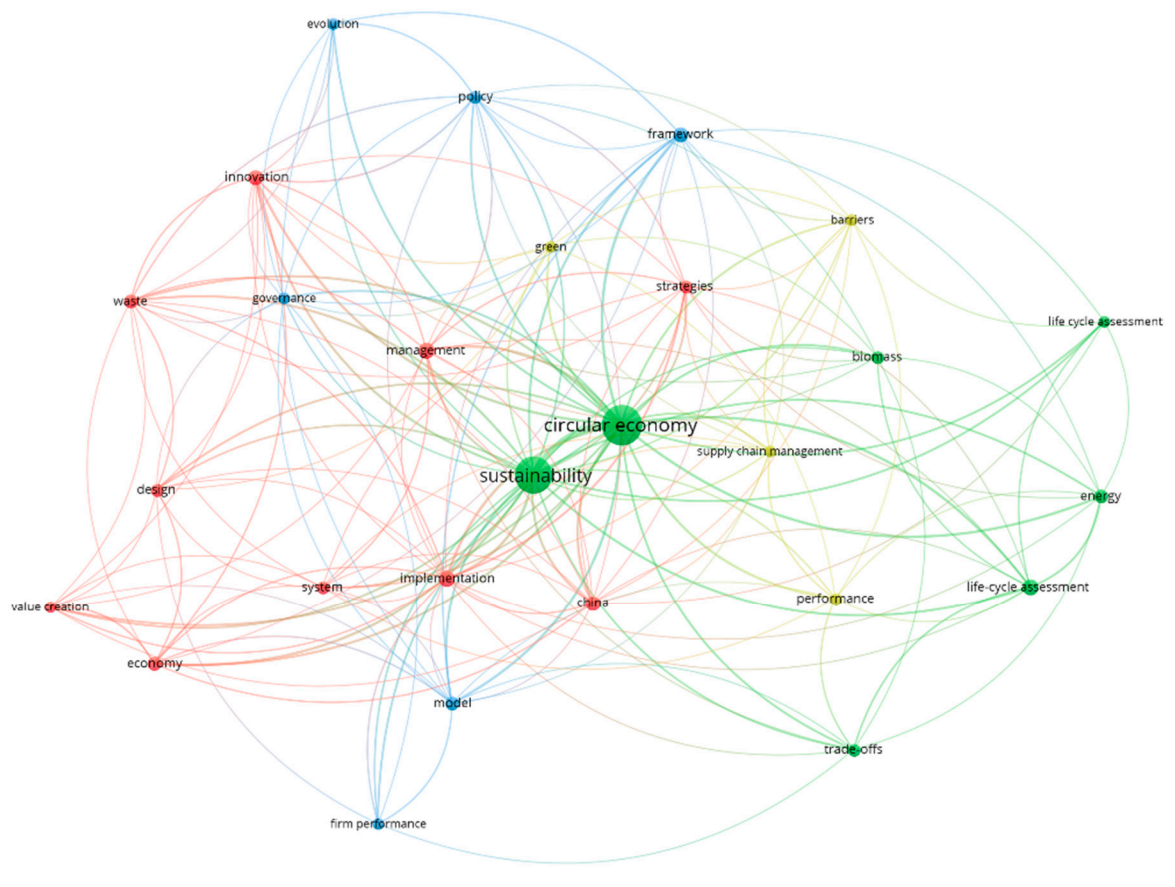
**Figure 3.** Countries with the highest number of papers published.

The first cluster, in green, studies the interaction between sustainability and CE, with a focus on bioeconomy and environmental protection. Within the most relevant keywords, “ecosystem”, “biodiversity”, “bioeconomy”, and “environmental protection” can be identified, among others. This cluster is usually related to the SDGs of Life and land (15), Climate action (13), Zero hunger (2) and Clean water and sanitation (6) [39–42].

The second cluster (in blue) studies the business and managerial efficiency in the interaction of sustainability and CE. The papers from the sample included in this cluster stand out for the following keywords: “resource efficiency”, “trade-offs”, “competition”, “supply chain performance” and “waste management”, among others. Cluster 2 is usually related to the SDGs 9 (Industry innovation and infrastructure) and 7 (Affordable and clean energy) [43,44].

The third cluster, in yellow, is usually related to SDGs 11 (Sustainable cities and communities) and 17 (Partnership for goals) [45]. What is more, it studies the industrial innovation in the interaction between CE and sustainability, delving into different forms of organization and governance; therefore, “circular economy”, “industrial symbiosis”, “innovation” and “industry” are its main keywords.

Cluster 4 sheds some light on the resource allocation issues between sustainability and the EC. In addition, the keywords in this cluster are “environmental economics”, “sustainability”, “resource use”, “business models” and “life cycle”, which are related to SDGs 12 (Responsible consumption and production) and 8 (Decent work and economic growth) [46,47].

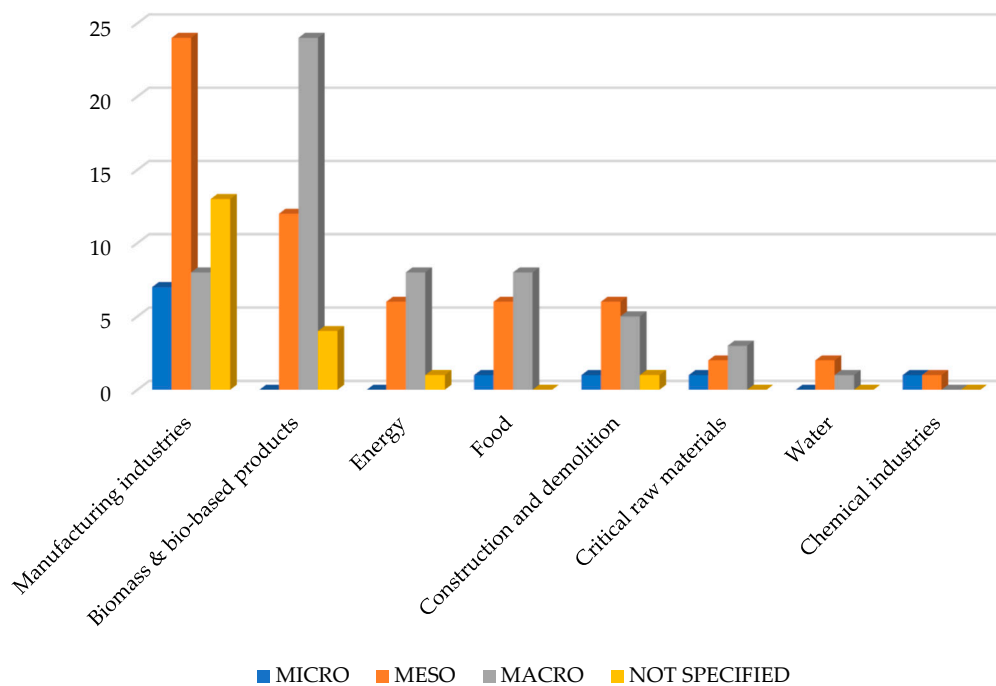


**Figure 4.** Keyword analysis set by the CLR research cluster.

Finally, Cluster 5 studies political economic issues in the interaction between sustainability and CE. The most relevant keywords linked to this cluster are “industrial economics” and “economic conditions”, and they are usually related to the issues assessed in SDGs 10 (Reduced inequalities), 4 (Quality education) and 3 (Good health and well-being) [48–50]. In this sense, this cluster analysis provides a classification of trends, priority areas and research topics for each theme and for the overall field of interaction between sustainability and CE.

#### 4.4. Circular Economy Priority Areas and Scales of Analysis

In Figure 5, it is to be highlighted that 80% of the analyzed literature in the topic is linked to a specific scale of analysis; in the missing 20%, the scale of analysis is not specified because the literature refers to ambiguous scales of implementation, or simply does not specify the systemic operationalization of the sustainability and CE issues. The authors defined the scale of analysis within the analyzed literature, where 47% is linked to the macro scale, 41% to a meso scale, and only the 12% correspond to a micro scale of analysis. The different scales of analysis are not always clearly defined among the authors; thus, for the sake of understanding, to the micro, meso and macro terminology a specific range of analysis has been attached (e.g., firm, life cycle, supply chain, value chain, city, region, nation or globe).



**Figure 5.** Circular economy priority business economic sectors and their most frequent scale of analysis.

Figure 5 shows the eight CE business economic sectors defined in the report *Circular economy closing the loop*, published by the European Commission in 2015 [30], adapted to the aims of this study by the authors. The eight priority areas identified in the study are: (1) Manufacturing industries, (2) Biomass and bio-based products, (3) Energy, (4) Food, (5) Construction and demolition, (6) Critical raw materials, (7) Water, and (8) Chemical industries. The most important CE area is Manufacturing industries, which represents 23% (52 articles) of all of the documents analyzed. The Manufacturing industries category is composed of electric and electronic equipment, furniture, health sector, plastics, textiles and transport, among many other non-specified manufacturing industries.

Figure 5 shows that, disregarding the literature in which the scale of analysis was not specified, the meso-scale analysis is predominant in the Manufacturing (62%), Construction and demolition (50%) and Water (67%) areas. The macro scale of analysis is strongly predominant in the areas of Biomass and bio-based products (67%), Food (53%), Energy (57%) and Critical raw materials (50%), when the literature where the scale of analysis is not specified is not taken account of, which represents just 20% of the sample. Only 12% of the literature in the study about the systemic interaction between sustainability and CE refers to the micro-scale analysis, which turned out not to be significant in this field. However, the study of this research area has not been limited to supplying political coherence in the public authorities' agendas; other actors in society—such as civil society, industry and businesspeople—encourage the implementation of the six previously defined CE strategies claiming a systemic understanding in relation to sustainability and its existing indicators and assessments (SDGs) [51,52]. Having a better understanding of the drivers defining the level of analysis, the typology of the CE strategies and the priority business economic sectors on which those CE strategies have been deployed will bridge the gap in the current state of the art on how the existing sustainability goals influence the implementation of CE strategies and vice-versa. If a better systemic understanding is reached, a coherent plan including the bases of the actors' behaviors could trigger the build-up of systemic and synergetic public policies. Indeed, the sustainability approach portrayed through the SDGs entails cross-sectional and interdisciplinary studies thanks to its ability to handle complex challenges and CE strategies in a diversity of scales of analysis, providing rigorous and replicable methods.

#### 4.5. SDGs and CE Strategies Matrix of Relationships

Through this analysis, five different clusters were identified from the keyword CAM which are not isolated but rather composed of interconnected topics within CE strategies and SDGs indicators. The systems approach creates its environment (dynamic and emergent realities) because there are feedbacks among the systems in terms of the competition or cooperation of the same limited resources [17]. In relation with CE, five main SDGs can be recognized among the existing 17: (1) To increase the share of renewables in the energy mix (SDG target 7.2); (2) To increase the rate of energy efficiency improvements (SDG target 7.3); (3) To reduce the waste generation rate (SDG target 12.5); (4) To achieve structural change in the ecosystem so as to allow for greater diversity (Resilience); and (5) To maintain a critical natural capital (Ecosystem functioning).

Figure 6 makes it clear that Industrial innovation and Infrastructure (goal 9) together with the Partnership for the goals (goal 17) have supplied the ground for scientific research in the five previously mentioned Clusters during the last 17 years. It is important to highlight that, within the framework of sustainability and CE, systemic policies have promoted the emergence of synergies and trade-off reduction when following the insights provided by the evidence based on the existing literature to support policy coherence in the European Commission’s Green Deal.

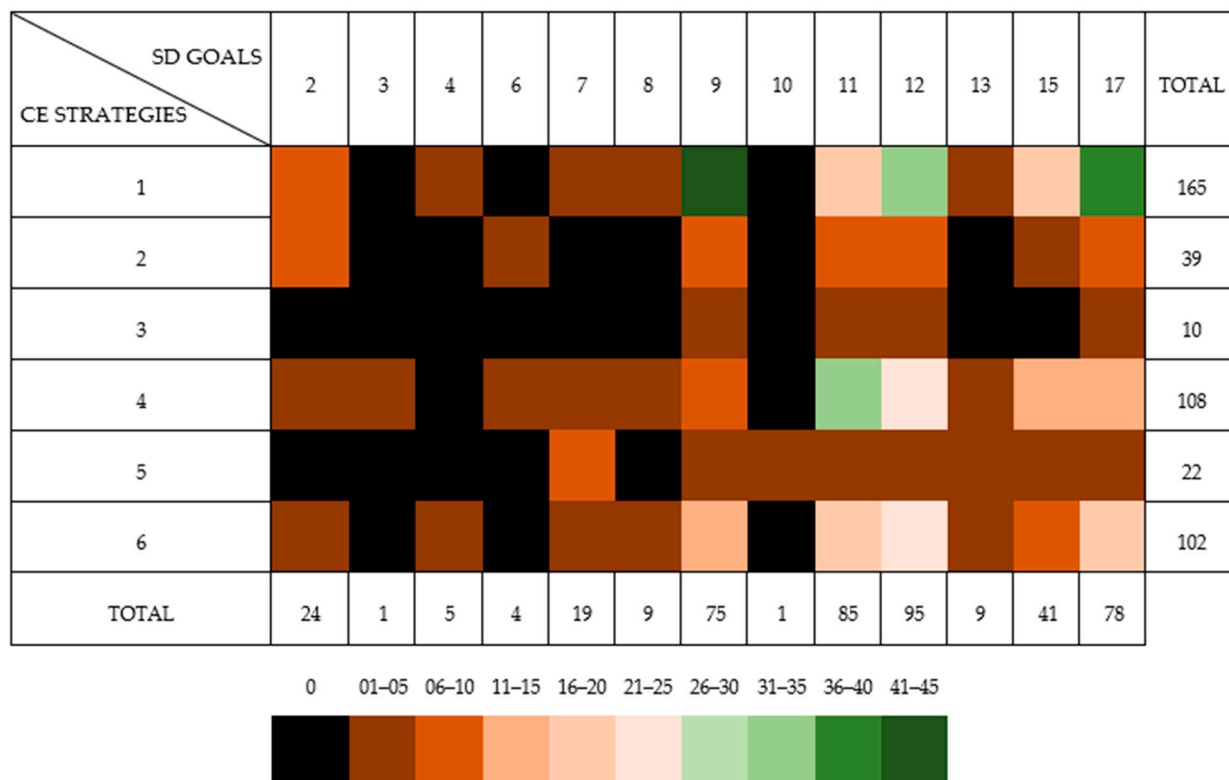


Figure 6. SDGs and CE strategies matrix of the relationship resulting from the analyzed literature.

Most of the literature assessed the benefits and positive impacts of the aforementioned synergies in the system. As can be observed in Figure 6, the most frequent interventions triggering synergies lie in the intersection between SDGs 9, 11, 12 and 17 with CE strategies 1, 4 and 6. Strategy 1 is the most widespread CE strategy, which seeks to preserve the function of products or services provided by circular business models such as sharing platforms, product service-systems (PSS) use, result-oriented and schemes-promoting product redundancy and multifunctionality [45,53]. Moreover, CE strategy 4 seeks to preserve the materials through recycling and downcycling. Most of the literature analyzes the synergies and assesses the benefits coming from the systemic relationship between these

two fields of study. There are very few cases in the scientific literature in which the tensions between CE and sustainability have been stressed. The very few tensions are documented mainly in the Biomass and bio-based products area, where the goal of Zero hunger and Ecosystem functioning preservation entail some friction with the goal of Affordable and clean energy when it comes to the renewable energy policies and Bio-refineries.

This study supplies breakthrough insights to improve the understanding on which generative mechanisms (CE strategies) produce the most suitable improvements in SDG outcomes. Furthermore, the system also entails feedback loops; thus, SDGs also explain how the choice of the scale of analysis in the CE strategies influences the overall mindset, and hence behavior, of a specific CE priority business economic sector. The authors claim in this paper that the interactions encountered in the literature analysis were found to be supported by the empirical observations, and this knowledge played a role in policy making seeking to understand how the socioeconomic ecosystems co-evolve, thus helping in the identification of the circular business model patterns that arise. If a better systemic understanding should be reached about the determinants of the level of analysis, the typology of the CE strategies and the priority business economic sectors in which those CE strategies have been deployed, a coherent SDG plan including the bases of the actors' behaviors could trigger the build-up of systemic and synergetic public policies. For example, when analyzing the Slovakian forest policies, the authors apply a macro-scale approach that highlights CE strategy 6 [54], but when referring to the Finnish forest-based transition [55] the approach implemented was a micro-scale one based on CE strategy 1, achieving a better overall systemic synergy in relation to the different contextual environments.

#### 4.6. Discussion

European scientific literature is dominating the research avenues; from the keywords analysis we came out with the existence of five clusters, which could be grouped around five lines of research: on the environment, on efficiency, on industrial innovation, on resource sustainability and, finally, a cluster on public policies. The ideal area to engage the synergies required to boost complex and systemic strategies like the Green Deal was identified in the Environmental and Innovation clusters, where the interaction between CE and sustainability is highlighted thanks to the use of CLR. Likewise, the most frequent SDGs in the keyword analysis are those corresponding to Responsible consumption and production (SDG 12), Decent work and economic growth (SDG 8), the Reduction of inequalities (SDG 10), Quality education (SDG 4) and Good health and well-being (SDG 3). The analysis of the CE strategy, according to its scale, reports that the meso analysis is predominant in the studies on Manufacturing, Construction, Demolition and Water, while the macro approach predominates in the areas of Biomass, Bio-products, Food and Energy. Thus, only 12% of the literature presents a micro approach in the study of the interaction between sustainability and CE. Finally, the study suggests that the most frequent interrelationships occur between CE strategies 1, 4 and 6, and SDGs 9, 11, 12 and 17. In other words, the circular strategies that generate the greatest synergies have to do with preserving materials through recycling, downcycling, and the measurement of indicators or reference scenarios.

#### 5. Conclusions

This paper establishes a direct relationship between numerous objectives of the EC and sustainability, together with the targets of the SDGs. What is more, it is identified that the circular strategies that generate greater synergies have to do with the preservation of materials through recycling, downcycling and the measurement of indicators or reference scenarios. This line of research has a multidisciplinary character; as the clusters of keywords indicate, this research not only takes into account the environment but also efficiency, politics and technological innovation. Likewise, special mention is made of the link it has with numerous SDGs that are directly related to life, water and health. For this reason, it is essential to mention the decisive role that political formulators have, as they

will be in charge of guiding the adequate implementation of actions directly related to the issues discussed.

In this context, it is demonstrated that there is a positive impact of the synergy between the strategies of the CE and certain SDGs. All of this has led to the inclusion of these concepts in the formulation of policies and strategies, although there is still potential to legislate an even more sustainable framework. Therefore, in order to broaden the knowledge about the systemic structure of the interactions between sustainability and CE, as well as speeding up the introduction of effective measures that imply favorable results, future research is proposed on (a) actions that distinguish between CE and sustainability in the field of SDGs, (b) results that show the influence caused by the clarification of concepts in the field of CE and sustainability, or (c) the extent to which each SDG is favorably affected by the introduction of the EC and sustainability.

Finally, this study has limitations, such as the choice of Scopus and Web of Science databases as the support for the analysis. Therefore, the incorporation of other databases and qualitative or quantitative tools could provide more information and solidity to the study carried out, and thereby, demonstrate the robustness of the methodology.

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