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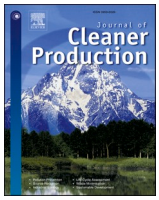

Implementing circular economy in a regional context: A systematic literature review and a research agenda

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ABSTRACT

Regions are the most important administrative units of the EU's development policies and so far, have been extensively used for framing and implementing strategic priorities. However, when it comes to regional implementation of the circular economy (CE), there is lack of systematicity both in academic literature and policy documents. Therefore, the main purpose of this study is to improve the understanding of the regional adoption of CE, by systematically reviewing and synthesises the current academic literature in this emerging field, unveiling research gaps and discussing a future research agenda. The review was conducted by identifying relevant academic papers from leading journals using the Scopus and Web of Science databases. Overall, 82 relevant papers were identified through the review, which proceeded to descriptive, bibliometric and content analysis. This study has found that generally, the adoption of the circular economy on the regional level is underexplored, which was supported by the dearth of relevant academic contributions detected at the beginning of the process. To the best of the researchers' knowledge, this is the first attempt to provide a holistic systematic literature review in the regional circular economy domain. Hence, the present study is considered as a crucial initial contribution in the direction of establishing robust conceptual frameworks which involve the constructs of regional circular economy and laying the groundwork for future studies in this field.

1. Introduction

Worldwide, the extraction of resources increased tenfold over the past century, and the pace is expected to escalate even faster, with forecasts predicting the global material use by 2030 to be twice that of 2010 (EEA, 2016). At the same time, the population has increased fourfold from the total at the beginning of the 20th century, and projections show another 50% rise by the year 2100 (IISD, 2017). Such developments are pushing humanity firmly en route to greater scarcity of – and imbalanced access to – non-renewable resources and energy, along with environmental, social, and geopolitical issues (Avdiushchenko, 2018). Nevertheless, these challenges have not been evenly distributed, and the most vulnerable geographic territories have the least resources to adjust on the frontline (IPCC, 2014). Taking into consideration the substantial dependence of European industry on imports of raw materials, increasing international competition for these resources places upward pressure and risk on the industry from impending price instability and supply disruptions (Defra and BIS, 2012). While confronting decreased resource security and aggravated environmental deterioration, EU policy-makers are facing a twofold challenge (Taranic et al., 2016). To tackle these concerns, the notion of the circular economy (CE) has been explored as an alternative economic model, focusing on optimising the value of products, materials, and resources as long as possible, while minimising waste (European Commission, 2015).

The existing body of academic literature looks at the CE implementation on three levels: micro (single company or individual consumer), meso (eco-industrial park, supply chain) and macro (city, province, region, nation) (Scarpellini et al., 2019; Vanhamaki et al., 2019; Marra et al., 2018; Ghisellini et al., 2016). However, this categorisation is not consistently used nor defined across the scientific community. Despite the inconsistency of the main levels of implementation, the regional level of CE adoption started emerging in the literature (Avdiushchenko and Zajaç, 2019; Vanhamaki et al., 2019; Aranda-Usón et al., 2018; Avdiushchenko, 2018; Strat et al., 2018). Barbero and Pallaro (2018) argues that regions, henceforth level 2 of the EU Nomenclature of Territorial Units for Statistics (NUTS 2) is used when referring to European regions, have a pivotal role in supporting the implemention of EU and national strategies, laws and regulations and coordinating

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local actors. Additionally, regions are in the most suitable position to detect and address the main challenges, which often require inter-institutional policy responses at all levels. Regions and cities are frequently seen by practitioners as pioneers in the transition towards sustainability, since they often begin to implement changes before national policies have been devised (CIRCTER, 2019). This is due to their scale and controllable economic systems; their proximity to environmental, social, and economic issues; and their ability to use the local experience of relevant stakeholders (CIRCTER, 2019). Regions are responsible for framing and putting into practice a wide range of policies in different fields. In many instances, regions have legislative and regulatory power to create and deploy strategies and manage EU structural funds, thereby boosting innovation and resource efficiency (Barbero and Pallaro, 2018). More importantly, they have deep knowledge and understanding of their local territories, their capacities, and potential, which puts them in the most favourable position for establishing appropriate framework conditions, enforcing targeted policies, mobilising regional stakeholders, and boosting synergies between various economic sectors (Barbero and Pallaro, 2018). According to Strat et al. (2018), the regional circular economy (RCE), is the foundation stone of a functional global CE. To ensure the worldwide implementation of the CE, national interrelated CEs must be in place, but they can be constructed incrementally only if interconnected regional CEs are established. Synchronised efforts are required, not only in the technical direction, but also to ensure supportive governance frameworks that can create incentives, encourage innovation, and generate information (OECD, 2020). However, there is a lack of a unified perspective on the role to be played by regions in the CE, especially in the academic literature; this is testified by the fact that there is no systematic literature review to date.

Considering the factual role regions have in the EU's development policy, and the evolutionary path that CE is undergoing in the EU's new sustainability agenda, this study has the main goal to holistically review the current understanding and usage of the RCE concept in the current literature and identify the research gaps. This is a crucial step in order to stimulate future research in the RCE area. Therefore, the study addresses the following focal research question: How does the academic community approach the RCE? This central question gave rise to a line of inquiry:

- What are the underlying theories and pillars of the circular economy?
- Which geographic territories are considered as 'regions' in the context of CE implementation?
- How regional circular economy is positioned in the policies and policy-making process?
- Which approach of implementation is preferred in the academic literature, top-down vs. bottom-up? What are the drivers and barriers of RCE implementation? What are the policy mechanisms of implementing RCE?
- How do we measure and monitor RCE?

In order to tackle these questions, a systematic literature review was conducted and the content of the final dataset of 82 papers was analysed against specifically selected structural dimensions.

This paper is organised as follows: the employed research methodology and material collection are described in **section 2**; **section 3.1** presents the descriptive analysis and **section 3.2** the bibliometric evaluation of the results; **section 3.3** presents the results from the content analysis based on predefined structural dimensions; **section 4** provides discussion of the main findings and emerging research gaps while **section 5** identifies the limitations of the study and recommends future research agenda.

2. Research methodology

A literature review was conducted to explore the existing knowledge base regarding the adoption of CE practices at the regional level. To circumvent the limitations and inherent biases of the traditional narrative literature review (Tranfield et al., 2003), a systematic literature review method was chosen. This entails the adoption of a procedure that is replicable, scientific, and transparent, while ensuring an audit trail of the reviewers' decisions, procedures, and conclusions (Tranfield et al., 2003). The systematic review approach has been frequently used in the field of CE (Goyal et al., 2021; Gregorio et al., 2018; Homrich et al., 2018; Merli et al., 2018; Prieto-Sandoval et al., 2018). Therefore, to achieve the aim described in **section 1**, the process began with the systematic review, synthesising the current academic literature on implementing the CE at the regional level, critically analysing and evaluating the research sources, and revealing the research gaps. To the best of the researchers' knowledge, this is the first attempt to provide a holistic systematic literature review in this research area.

The review was performed using SCOPUS and Web of Science (WoS), the most comprehensive scientific databases of peer-reviewed journals. According to Chadegani et al. (2013), Mongeon and Paul-Hus (2016), Vieira and Gomes (2009), Bar-Ilan (2010), and Abrizah et al. (2013), these two databases are the most widely used in literature search activities and they also facilitate the execution of an attested bibliometric analysis (Merli et al., 2018; de Oliveira et al., 2018).

2.1. Systematic literature review process

The review was performed by adapting the procedure initially proposed by Tranfield et al. (2003) and used by Gregorio et al. (2018) and Prieto-Sandoval et al. (2018) comprising three stages: planning, execution, and reporting and dissemination. The customised process is shown in Fig. 1 as a flow diagram, outlining the six-step process and search methodology. This adjusted process covers the first two stages proposed by Tranfield et al. (2003) and is explained in the following paragraphs. The final stage of reporting and dissemination of the results and analysis is presented in **section 2.2.**

In **Step I** a search in the SCOPUS and WoS databases was performed, using a compounded three-level keyword structure (Table 1). The first level of the keywords, the context keywords, was intended to capture the papers discussing CE and other closely related concepts. The second level was intended to include papers related to the regional adoption of the CE practices, and the third level concerned papers discussing policy development and implementation. To identify the papers at the intersection of these three levels – and to capture the relevant sources on CE at the regional level, with a focus on policy development – a dataset combining the three levels' keywords was created. The details of the search protocols are provided in Table 2.

⇒ *Criterion 1: Is the paper related to circular economy implementation?*
⇒ *Criterion 2: Is the paper looking at regional circular economy implementation or provides some regional considerations?*
⇒ *Criterion 2: Is the paper looking at regional circular economy implementation or provides some regional considerations?*

The initial data set was then automatically screened in **Step II**, based on four criteria. These criteria[1] and results are shown in Fig. 1. The cut-off date for data extraction, and therefore inclusion in terms of publishing is May 13, 2021. A duplication removal was conducted in **Step III** using VLOOKUP Excel formulae. In order to identify only those papers related to CE, a manual screening of the abstracts was performed based

[1] Relevant subject areas for Scopus: Environmental Science, Social Sciences, Energy, Business/Management/Accounting, Multidisciplinary, Economics/Econometrics/Finance, while relevant subject areas for WoS: Environmental Sciences, Area Studies, Engineering, Environmental, Green Sustainable Science Technology, Social Sciences Interdisciplinary, Development, Environmental Studies, Management, Economics, Ecology, Multidisciplinary Sciences, Urban Studies, Regional Urban Planning, Business, Engineering Industrial/Manufacturing/Multidisciplinary, Geosciences Multidisciplinary.

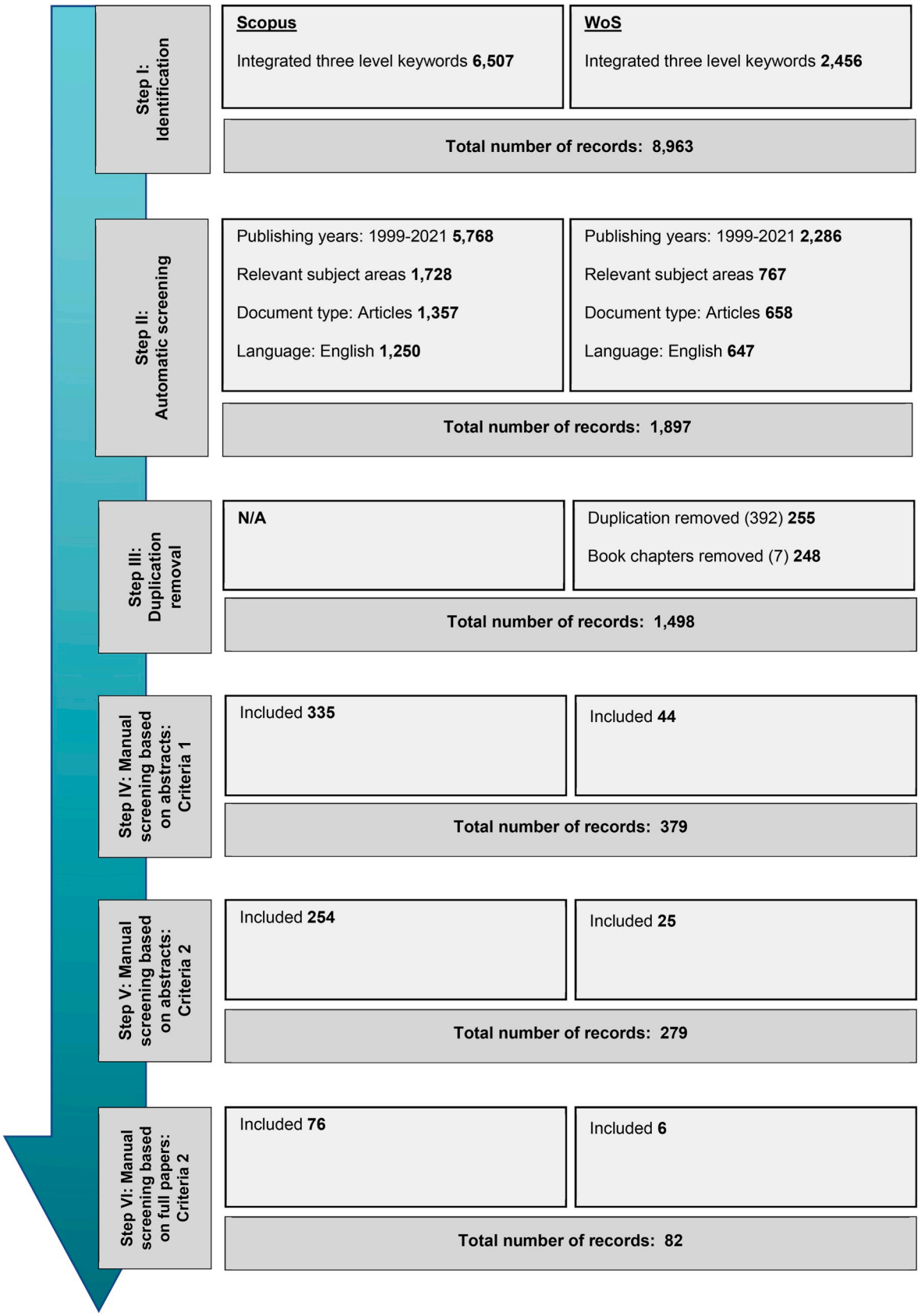


Fig. 1. Systematic literature review process - flow diagram.

Table 1
Integrated three-level keyword structure.

Integrated three-level keyword structure	**Level 1:** Context keywords ('Circular Economy' OR 'CE' OR 'circular' OR 'closed loop' OR 'Industrial Ecology' OR 'Industrial Symbiosis' OR 'Eco-Industrial Parks')	Scopus: 753,774 WoS: 519,239
	Level 2: Regional level keywords AND ('region' OR 'regional' OR 'meso level' OR 'macro level' OR 'regional development')	**Scopus:** 4,844,823 **WoS:** 2,598,554
	Level 3: Policy development keywords AND('policy' OR 'policies' OR 'regulation' OR 'legislation' OR 'directive' OR 'strategy' OR 'government' OR 'governance' OR 'institutions')	**Scopus:** 7,646,196 **WoS:** 4,052,505

Table 2
Search protocol.

Database	Search Field	Search Type	Collection used
Scopus	Article title, Abstract, Keywords	Advanced	
WoS	Topic	Advanced	WoS Core Collection (1900-present)

on the criterion 1 and four categories were developed (Table 3) in **Step IV**. As the level of analysis was regional, a second manual screening of the abstracts was completed in **Step V** based on criterion 2, and three respective categories were developed (Table 4). In the final **Step VI**, a manual screening of the full paper was conducted, again using criterion 2. A decision was made to focus only on implementing CE in European regions, due to the specifics of regions located in Europe, their comparable size, governance mechanisms, institutional structures and policy development. Additionally, this geographical limitation will avail the researchers to concentrate on a more homogeneous sample. Taking this into account, four categories were developed and presented in Table 5. The final dataset included 82 articles that either related to CE implementation at the regional level or which discussed regional considerations. Three papers didn't have any specific region therefore the category 'N/A', one paper was focusing on European regions, but other global regions were included, hence the category 'Global', and finally, two papers from UK regions were also part of the final data set. Seven papers were analysing data from several European regions, hence the category 'EU wide' was developed for these articles. These 82 papers, presented in **Appendix A**, were extensively reviewed and analysed, and the results are shown in the following sections.

Table 3
Classification for Step IV – manual screening based on abstracts.

Categories	Included/ Excluded	Scopus	WoS
Unrelated fields (e.g. agriculture, migration, education) or purely scientific and technical background	Excluded	692	152
Marginal relevance to the research area, focusing on carbon management, externalities, water scarcity	Excluded	223	52
Discussing closely related topics to CE, such as industrial ecology, industrial symbiosis, waste management	Included	179	35
Discussing CE, green economy and decoupling	Included	156	9

Table 4
Classification for Step V -manual screening based on abstracts.

Categories	Included/ Excluded	Scopus	WoS
Closely related concepts and CE but on other levels	Excluded	81	19
Tackling closely related issues to CE at the regional level	Included	152	21
Addressing regional CE	Included	102	4

2.2. Reporting and dissemination of results

The final step of the systematic literature review was the reporting and dissemination of the results. Initially, a descriptive analysis was performed using Excel, and the descriptive findings are presented in **section 3.1**. Bibliometric methods, used extensively to present comprehensive groups of the knowledge structure in a particular literature stream (Goyal et al., 2021; Rialti et al., 2019; Homrich et al., 2018; Prieto-Sandoval et al., 2018; Geissdoerfer et al., 2017), were adopted and the results can be found in **section 3.2**. Except Excel, VOSviewer software was used for the bibliometric analysis, as a tool offering relatively easy way to visually represent the bibliometric networks (Fabregat-Aibar et al., 2019).

The descriptive and bibliometric analyses were finally complemented with content analysis, qualitative and quantitative. According to Homrich et al. (2018) the content analysis is allowing an exhaustive understanding of the research constructs and their connections. This analysis is following an independent and rule-guided procedures in order to construct replicable and valid inferences by analysing (coding) the characteristics of visual, verbal and written documents (Khirfan et al., 2020). Moreover, with the use of systemic evaluation, qualitative data can be translated into quantitative analysis, with the purpose to increase the methodological rigor of literature reviews. Generally, this transparent framework is being used with the goal to describe or assess a topic, offer new insights, understanding, interpretations and subsequently a guide for action (Khirfan et al., 2020). A number of academics in the CE field used content analysis so far, among which Goyal et al. (2021), Homrich et al. (2018), Prieto--Sandoval et al. (2018), Geissdoerfer et al. (2017) and Kirchherr et al. (2017).

In order to enable the whole process of content analysis, concept matrix was developed (Goyal et al., 2021) following a deductive approach of pre-defined research streams (i.e. structural dimensions). This concept matrix included details of the authors, the title of the article, publication year, country, geographic territory, NUTS relation, related theories, pillars of circular economy, policy, implementation approach (top-down/bottom-up), drivers and barriers for implementation, mechanisms of implementation and regional measurement systems of the 82 articles. **Section 3.3** looks at the articles presented in **Appendix A** in the context of identified research streams.

Table 5
Classification for Step VI - manual screening based on full papers.

Categories	Included/ Excluded	Scopus	WoS
Closely related concepts and CE but on other levels	Excluded	162	16
Closely related concepts and CE at the regional level (outside Europe)	Excluded	16	3
Tackling closely related issues to CE at the regional level (Europe)	Included	27	5
Addressing regional CE (Europe)	Included	49	1

3. Results

3.1. Descriptive findings

3.1.1. Historical series

As shown in Fig. 2, 82 papers related to the subject area were considered relevant and therefore analysed in detail. The chart illustrates the distribution of publications per year. The first paper retrieved is the one from Brand and De Bruijn (1999), followed by the work of Mirata (2004) and Mirata and Emtairah (2005). The subsequent nine-year period reveals no interest in the study area, and not even a single contribution is recorded. In 2016, Banaite and Tamošiuniene are publishing the first academic contribution that uses the term 'circular economy' in the title. A sudden increasing trend in publishing papers starting from the year 2018 can be observed, which coincides with the publishing of the 2018 Circular Economy Package by the European Commission. The year 2019 has 17 recorded publications, which is the year when the European Commission adopted the Final Circular Economy Package (European Commission, 2019), and the growing trend continued in 2020 where the publication number peaked at 25. Considering the cut-off date for the data extraction was May 13, 2021, the 16 publications recorded in less than five months are a clear sign of growing academic interest in the field. This can be attributed to the commitment of the EU policy-makers towards the policy design and implementation of the CE.

3.1.2. Academic journals

The Table 6 illustrates the top contributing journals which published the papers in the final data set. Overall, 58% of the papers were published in four journals. More than one-quarter of the papers were published in the Journal of Cleaner Production (22 papers), while Sustainability published 17 papers. What is interesting is that there is no representation of regional sciences journals (e.g. Regional Studies, Journal of Regional Science, Annals of Regional Science, European Urban and Regional Studies).

3.1.3. Research methodologies employed

Regarding the research methodologies employed in the papers, four categories were identified and presented in Fig. 3. Half of the papers deployed qualitative research methods for data collection and analysis. Vanhamäki et al. (2020) used semi-structured interviews for primary data collection and applied a thematic analysis in order to examine the spatial implementation of CE in Europe. Scarpellini et al. (2019) attempted to identify the main barriers and incentives for CE, through a qualitative case study of Aragon, a Spanish region. Obersteg et al. (2019), by using semi-structured interviews, document analysis and workshops devised a list of governance challenges that impede the transition towards CE. Quantitative research methodologies were used in 27% of the papers, for instance, Christis et al. (2019) used Input-Output Analysis (IO), while Santagata et al. (2020) adopted Emergy Accounting method (EMA) to assess the feasibility of a CE scenario within the city of Napoli, Campania region. The qualitative papers were focusing on identifying drivers, barriers, and challenges, while the quantitative ones were more concerned with material flows and environmental impacts. The use of mixed methods was reported in 17% of the papers, like it was the study of Paletta et al. (2019) which used

Table 6
Sources of the published papers.

Journal	No. of Published Papers	% of Published Papers
Journal of Cleaner Production	22	27%
Sustainability (Switzerland)	17	21%
Waste Management	4	5%
Environmental Engineering and Management Journal	4	5%
Journal of Environmental Policy and Planning	2	2%
Sustainable Production and Consumption	2	2%
Economia Politica	2	2%
Urban Planning	2	2%
Journal of Industrial Ecology	2	2%
Economics and Policy of Energy and the Environment	2	2%
Resources, Conservation and Recycling	2	2%
Ecological Indicators	2	2%
19 Journals which published 1 paper	1	23%
Grand Total	**82**	**100%**

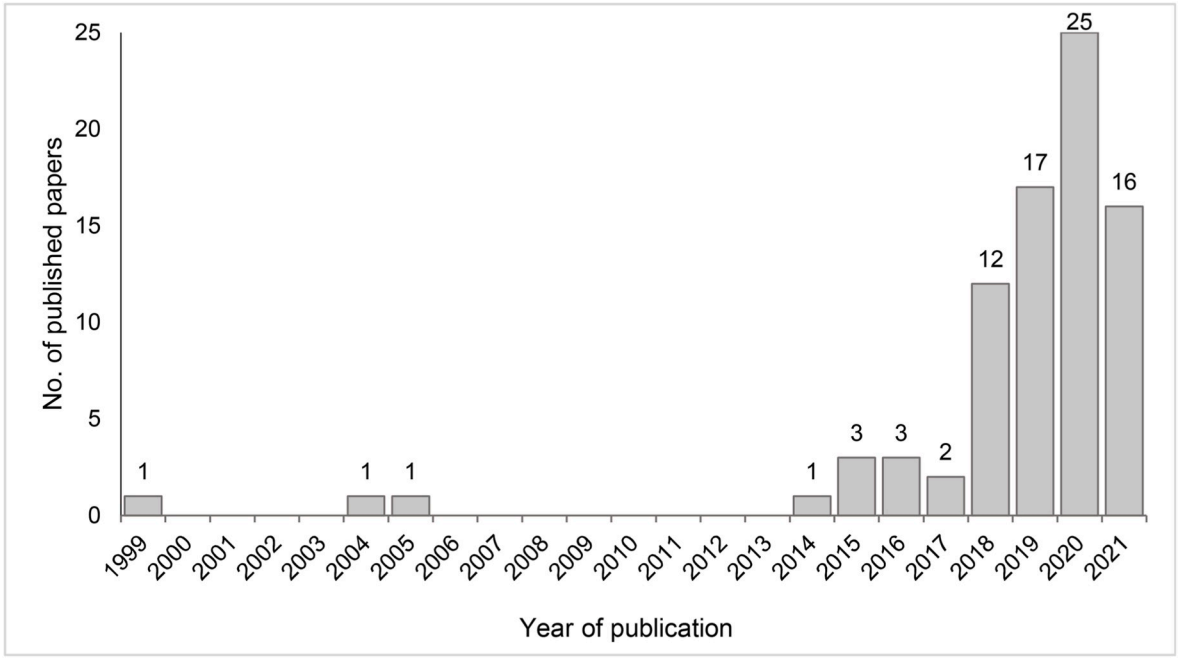


Fig. 2. Historical series.

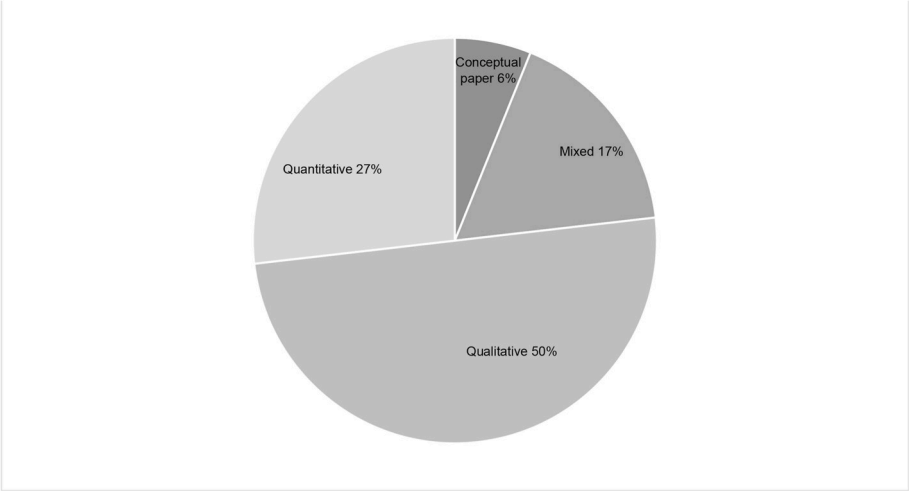


Fig. 3. Employed research methodologies.

surveys in order to evaluate the impact of the European commitment on plastics on business model and supply chain, in combination with qualitative investigation with the purpose to investigate the barriers and challenges for plastic circularity. Around 6% of the papers were conceptual, not providing empirical data but rather discussing possible research focuses and conceptual frameworks. For example, Alaerts et al. (2019) developed a conceptual approach that had the goal to bridge the gap between the micro and macro level indicators, and hence eventually provide more direct feedback for policy-makers. Similarly, Avdiushchenko (2018) constructed the concept for a CE regional monitoring framework for EU countries, which can be employed by regional policy-makers as a mechanism for implementing the CE model of regional development.

The prevailing use of qualitative research methods was anticipated, considering the dearth of relevant academic papers detected at the beginning of the systematic literature review process. Taking into account the predominantly inductive and exploratory nature of qualitative research in social sciences, the deployment of such methods in order to characterise, define and then approach the problem is expected and justified given the infancy stage of RCE investigations. On the other hand, the paucity of quantitative studies can be partially related to the lack of data at a regional level, more thoroughly discussed in **section 3.3.8.1**; this is likely to hinder the potential of statistical and modelling studies.

3.2. Bibliometric findings

3.2.1. Subject/research areas

The subject areas (from Scopus) and research area (from WoS) were extracted to illustrate the top contributing areas. It has been assumed that one paper can belong to several subject/research areas. It is evident that the Environmental Science/Ecology area has the leading position, with 71 papers belonging to it (Fig. 4). Nevertheless, subject/research areas related to regional development and policy formulation and implementation were not represented, which is surprising considering the research topic under investigation.

3.2.2. Keywords co-occurrence analysis

In total 306 author keywords were retrieved from both Scopus and WoS databases. The databases were then manually checked in order to ensure closely related keywords were clustered together and mapped visually with the co-occurrence analysis using the VOSviewer software. The co-occurrence analysis is using the authors keywords to explore the conceptual structure in a research field. This technique, by constructing a measure of similarity, is one of the most effective ways to cultivate trends and emergent topics in a scientific field, as well as paving the avenue for future research (Fabregat-Aibar et al., 2019).

As illustrated in the network visualisation in Fig. 5, 7 clusters have been obtained in the mapping of keywords which appeared twice at least (29 keywords in total), showing there was a relationship between one keyword to another. The thickness of the connecting line showed the strength of pairs of keywords. Apart from clusters and lines, the size of the nodes indicated the frequency with which the keyword appears. From Fig. 5, it can be seen that the dominant keyword by far is 'circular economy', followed by 'industrial symbiosis', 'industrial ecology, 'regional development' and 'waste management'. This implies that these topics in the 1999–2021 period were the most discussed ones by researchers. Nodes or keywords that did not have links to other keywords, have the potential to become new research topics in the future.

The red cluster, where the most dominant keywords are related to the regional element, appears as the densest one, with intra-cluster links (i.e. connections among nodes within the same cluster) showing a strong relationship among keywords in the cluster. In this cluster, belong studies conducted in the 'Emilia-Romagna region' (Foschi et al., 2021; Sani et al., 2021), or 'regional case study' like the ones performed by Drejerska et al. (2020) and Vanhamäki et al. (2020). These papers are more concerned with strategic policy design by regional authorities, also emphasising the presence of specific drivers and barriers.

Similarly, intra-cluster links can be observed both in the green cluster and the yellow cluster, which also exhibit very strong inter-cluster linkages. Such intra-cluster links reveal the presence of some more consolidated research areas, related to sub-sets of the RCE agenda, which have been investigated in the analysed period.

In the yellow cluster papers exploring 'industrial ecology' (the central keyword of this set of papers) as the prominent dimension are grouped, like Taddeo et al. (2017), Taddeo (2016), and Mirata and Emtairah (2005); these papers look at specific place-based initiatives which could be useful to the transition towards a CE at a regional level. Specifically, the role of local industrial systems and districts within the transition to a Circular Economy is analysed. Great prominence is given to *Eco-Industrial Parks* and *Ecologically Equipped Industrial Areas*; these papers reflect on specific experiences emerging from the implementation of practical initiatives and propose useful lessons to be learned for future developments.

In the green cluster, papers investigating 'waste' and 'resources' (Savini, 2019) according to a 'networks' perspective (Mirata, 2004) within 'industrial symbiosis' mechanisms (Lombardi, 2017; Iacondini et al., 2015) are grouped; in other words, these studies specifically deal with the relevance of Industrial Symbiosis networks to the transition towards a Circular Economy. The strong linkages shown by the

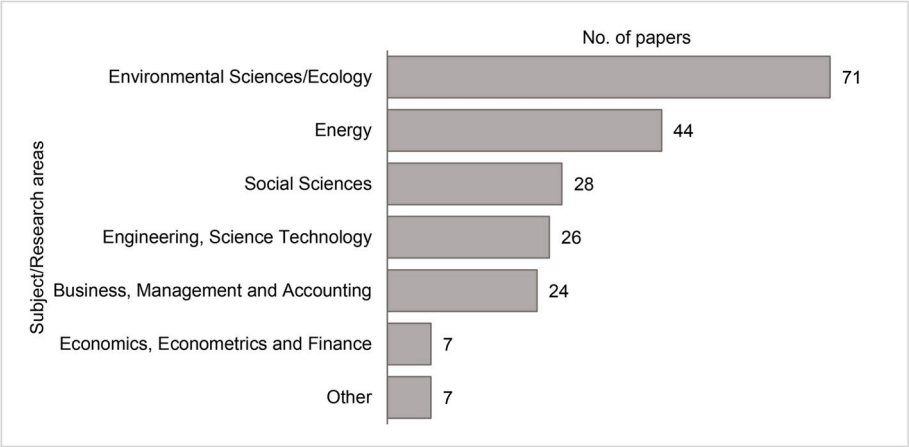


Fig. 4. Subject/research areas of the published papers.

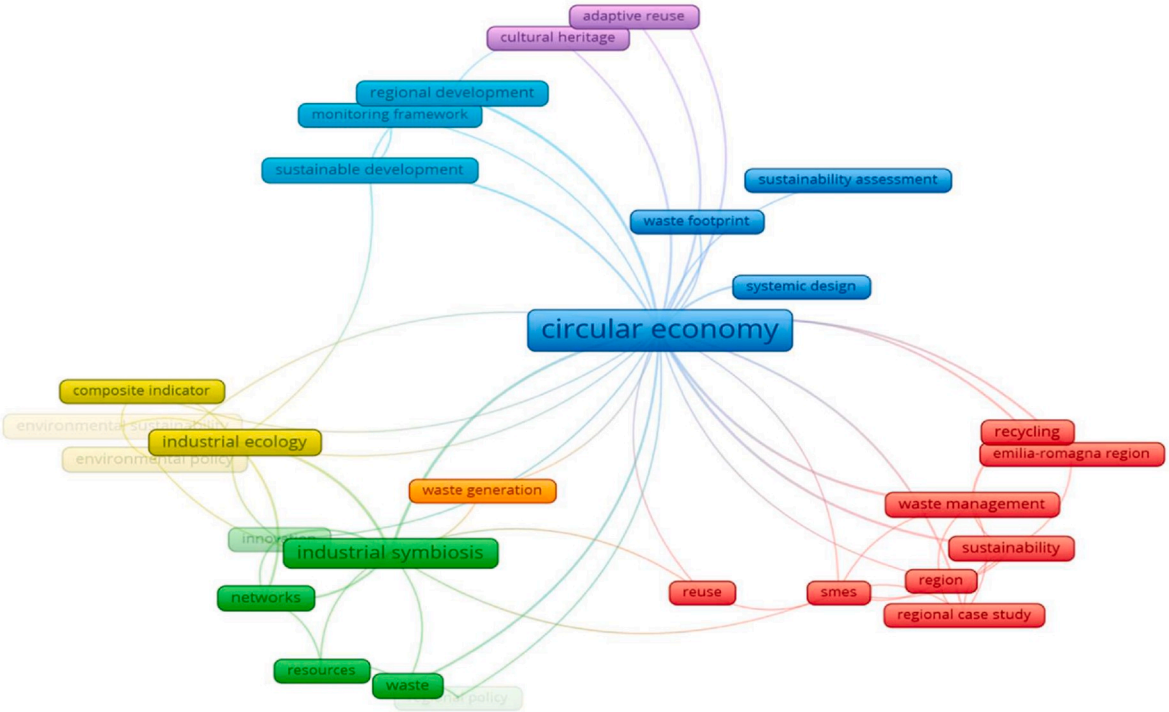
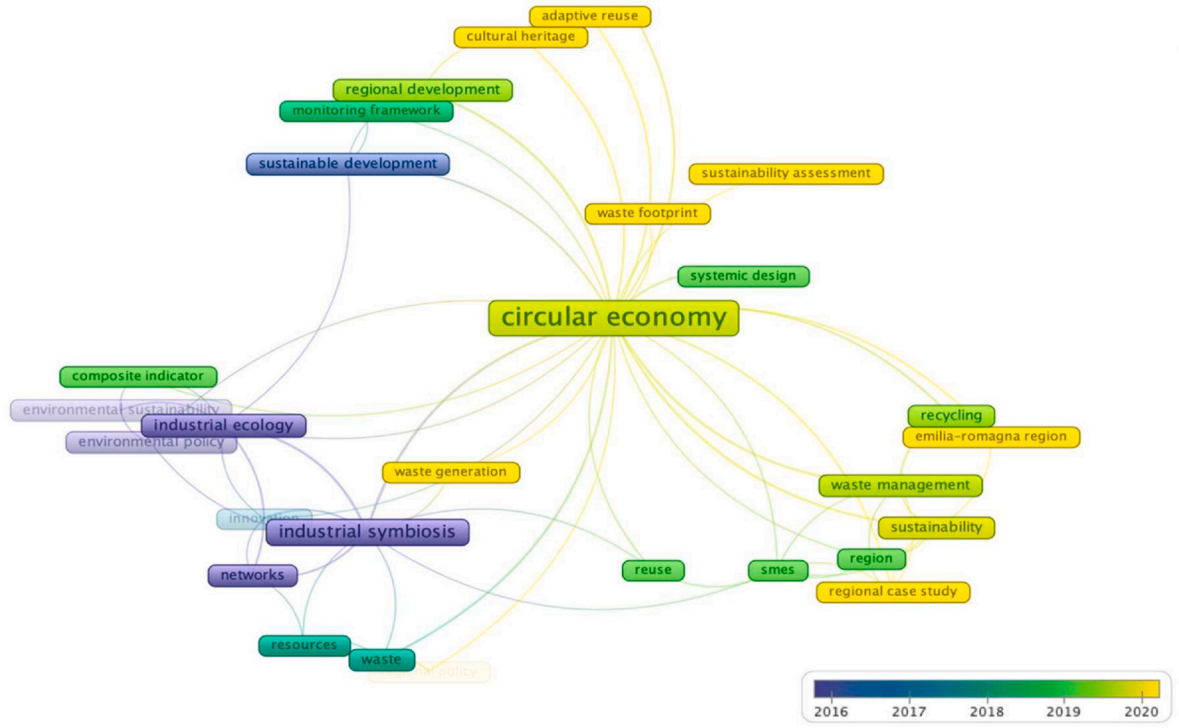


Fig. 5. The network visualisation of keywords (minimum keyword occurrence - 2).

'Industrial Symbiosis' keyword to other clusters also shows the importance of this concept to both the theorisation and practical applications of CE and Industrial Ecology at a regional level.

In comparison, intra-cluster links are not visible in the remaining four clusters, where each keyword is rather linked just to the main keyword 'circular economy'. The orange cluster, represented by the sole keyword 'waste generation', has links only to 'circular economy' (blue cluster) and 'industrial symbiosis' (green cluster), having the potential of becoming new research area. Except the individual connection of the keywords in the light blue cluster to 'circular economy', 'sustainable development' is linked to the yellow cluster with 'industrial ecology' and 'regional development' to the purple cluster with 'cultural heritage'. Furthermore, 'adaptive reuse' from the purple cluster seems to be linked to the blue cluster with 'waste footprint'. Lastly, intra-cluster links are not detected within the blue cluster, but every keyword of the remaining clusters have links to the main keyword belonging to this cluster – 'circular economy'.

The overlay visualisation in Fig. 6 shows the year-to-year trends related to the keyword being used. The colors in the keywords indicate the period of research. As reported in **section 3.1.1** the earliest reported research is related to 'industrial symbiosis', 'network', 'industrial ecology' and 'sustainable development' (purple cluster), and the latest research reports keywords like 'regional case study', 'sustainability assessment', 'waste footprint', 'Emilia-Romagna region' (yellow cluster). This shows the shift of research focus during the period under investigation, positioning the 'yellow cluster' keywords as the most topical ones. It could be noted that the main keywords which appeared in this analysis, are aligned with the keywords this study used for the systematic literature review (**section 2.1**, Table 1). Additionally, it can be observed that 'circular economy' is the central keyword to which all remaining 28 keywords are linked. Very rarely a connection between the other keywords can be observed; this implies that the concept of circular economy was investigated in different contexts (e.g. 'circular economy' in the context of 'cultural heritage', 'adaptive reuse', 'region') or



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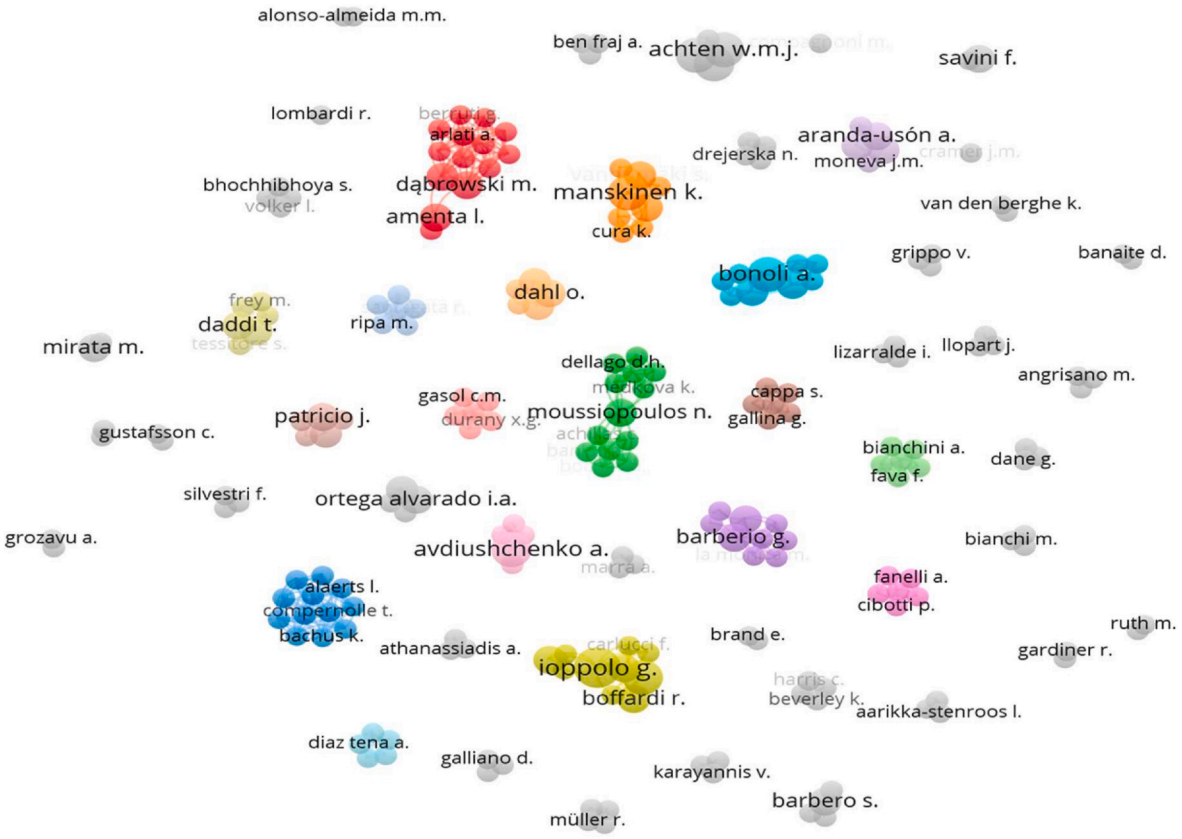

Fig. 7. The network visualisation of co-authorship (minimum number of documents of an author - 1).

academics explored the link between 'circular economy' and other related concepts (such as 'regional development', 'sustainable development', 'industrial ecology').

3.2.3. Co-authorship and citation of authors analysis

In order to analyse the co-authorship links, the number of publications two researchers have co-authored, a co-authorship analysis was performed. The network visualisation, presented in Fig. 7, revealed a scattered picture with 52 clusters, implying that individual authors are exploring the topic and very few links between the 228 authors exist in terms of co-authorship. This could be explained by the novelty of the research topic and the infancy stage it is currently.

With the purpose to complement the analysis, a further investigation was performed to map the citation links between authors. The network visualisation presented in Fig. 8 showed a scattered picture with 151 clusters, implying the authors in the dataset did not cite each other. Only 11 clusters were comprised of more than one author, the remaining 140 clusters were comprised of one author. Taking into regard that 50% of the papers were published from January 1, 2020 until May 13, 2021, and the information regarding the number of citations was extracted on June 12, 2021, the results are somewhat expected since all contributions are relatively novel, and the research area is in infancy stage.

3.2.4. Sources citation analysis

Citation analysis of sources was performed, with the goal to visually map the citation links among the 29 sources, i.e. journals. The network visualisation, illustrated in Fig. 9, showed very loose citation links among sources, similarly with the results from the authors citation analysis in **section 3.2.3**. The 29 sources were categorised into 22 clusters, with only 3 clusters containing more than 1 source, and the remaining 19 papers were comprising a stand-alone cluster by its own. These fragmented results are suggesting that only a few journals within the dataset are being cited by the rest of the journals in the same dataset, which again can be rationalized by the novelty of the field. It is obvious that Journal of Cleaner Production and Sustainability are the most dominant sources with the highest citation links.

3.2.5. Citations statistics

To identify the most cited academic papers the relevant data was extracted from Scopus and WoS databases and sorted accordingly in Excel. The extraction was made on June 12, 2021, hence the citations per paper were considered until then. The top ten cited papers are shown in Table 7. Overall, five of the ten most cited paper were published in Journal of Cleaner Production, followed by Sustainability with two papers. In order to better understand whether there is a concentration of

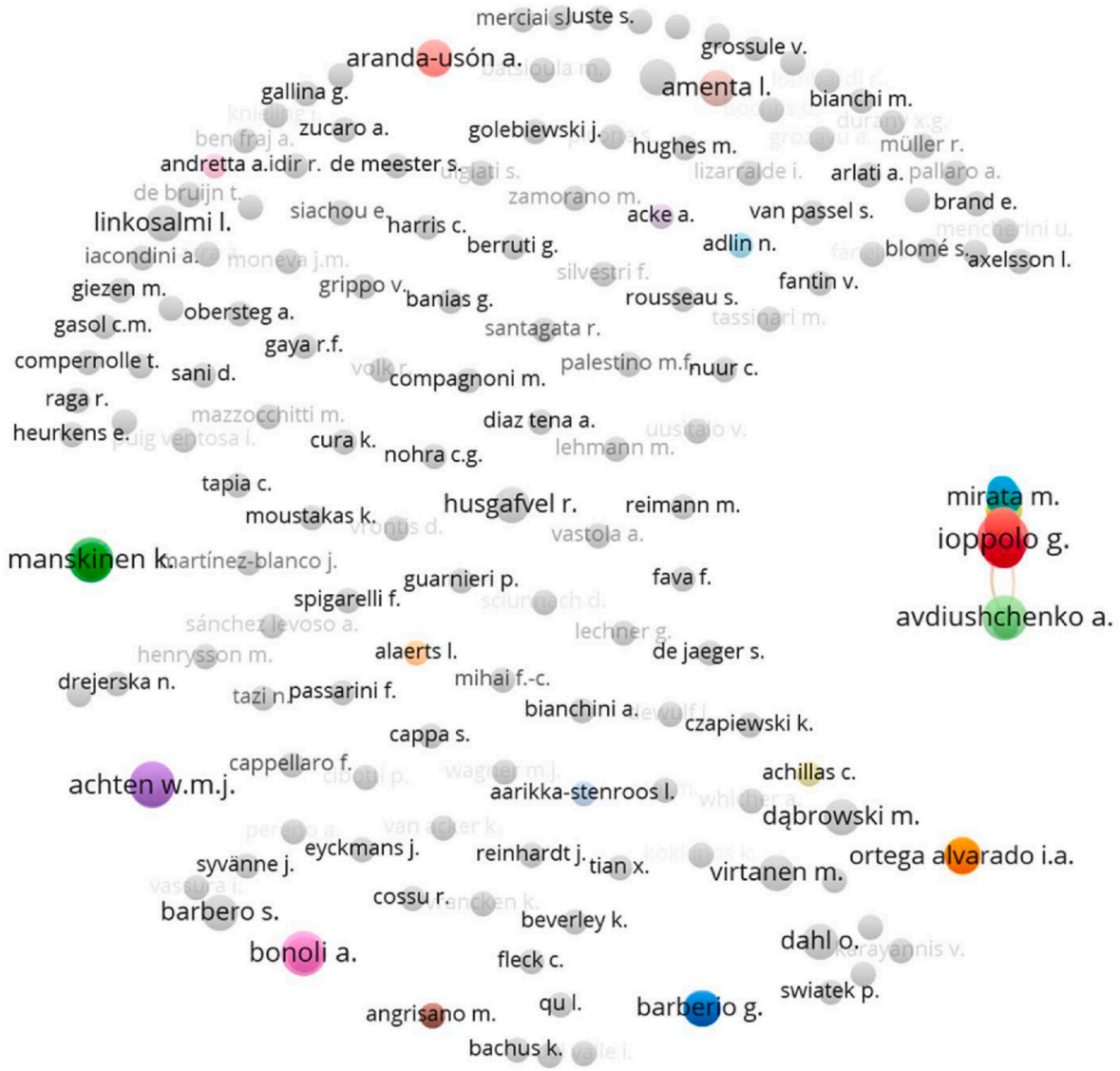

Fig. 8. The network visualisation of authors citation (minimum number of documents of an author – 1).

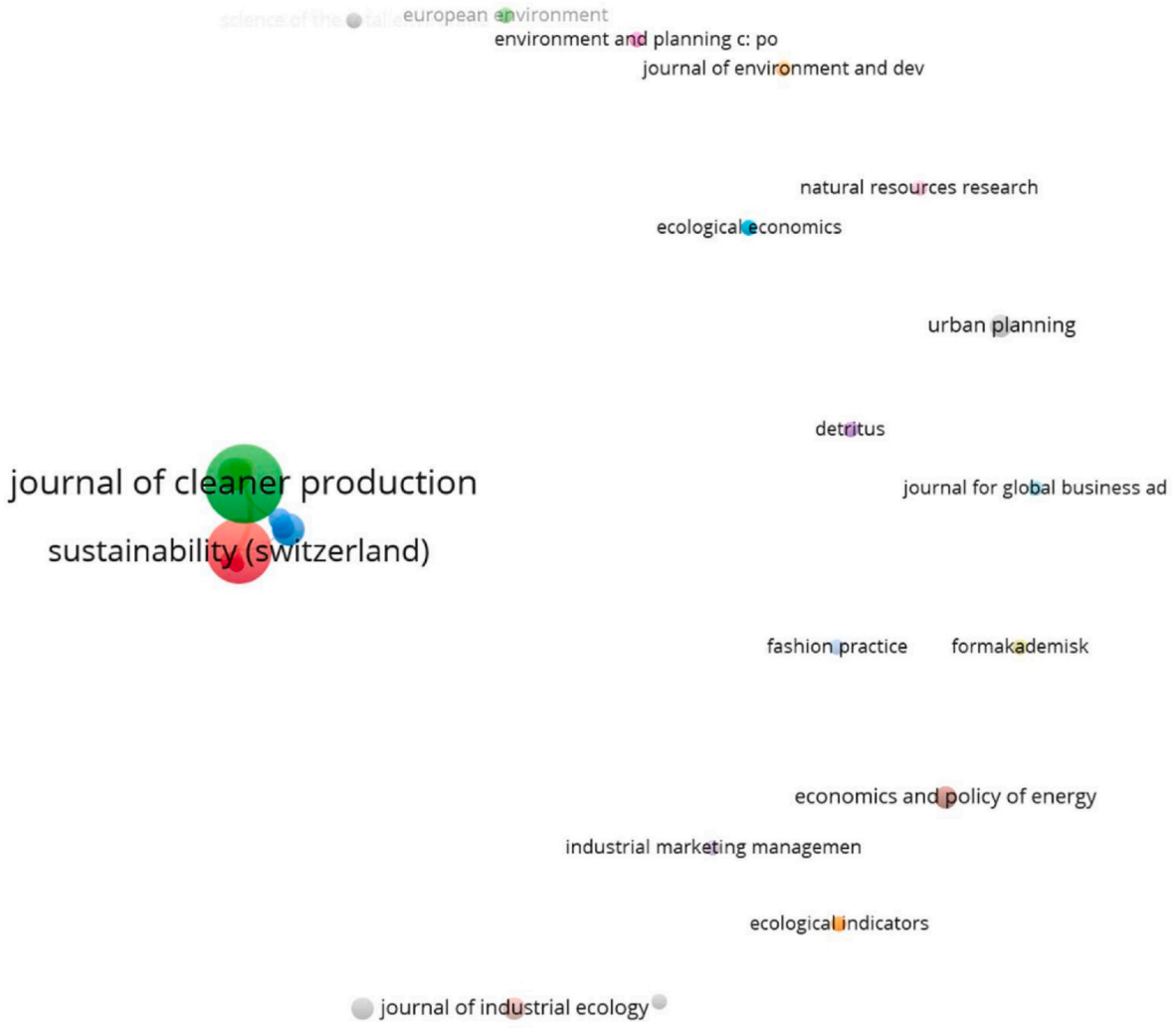

Fig. 9. The network visualisation of sources citation (minimum number of documents of a source – 1).

research outputs in only several publishing sources, a further analysis of the top three cited papers was performed and presented in **Appendix B**. These results, complemented with the ones from **section 3.1.2** which showed that 48% of the papers were published in the two journals – Journal of Cleaner Production and Sustainability, prove that a considerable amount of the research output in the field is being concentrated in these publishing sources. Moreover, a self-referencing phenomenon can be observed, a finding that also emerged in **section 3.2.4**, which could imply that the impact of the research outputs is only on the tangent disciplines. However, Marra et al. (2018), reckon that a factual implementation of CE can be guaranteed only by multidisciplinary approaches. More precisely, in a quest to assess the level of multidisciplinarity of the CE literature, they show that multidisciplinarity in the CE research field is low, with heterogeneous distribution of research outputs across subject areas.

3.3. Content analysis

3.3.1. Theories underpinning the circular economy

The CE concept was initially introduced more than 50 years ago, in the work of Boulding (Cramer, 2020; Avdiushchenko, 2018). Early schools of thought began shaping the theoretical foundations of this inevitable transition from a linear economy to a new economic model. According to Scarpellini et al. (2019), the main schools of thought associated with CE are those of the functional service economy, natural capitalism, and 'cradle-to-cradle' principles (Aranda-Usón et al., 2020; Barbero and Pallaro, 2018). The work of Pearce and Kerry Turner (1990) has been flagged as pivotal in the introduction of CE, with the concept used to explicate the functioning of the economy while taking into account the implications of the environment-economy nexus (Scarpellini et al., 2019). Nevertheless, as Avdiushchenko (2018) points out, opponents of this early notion of establishing CE on closed loops argue that, *'the economy of nature is based on an open system, not a closed system, that nature operates using short cycles, not extended lifetimes, that nature is sub-optimal, not optimal, and that nature is eco-inefficient, not eco-efficient'* (Skene, 2018). In more advanced phases, CE is situated within the field of industrial ecology (IE) (Gonçalves et al., 2021; Henrysson and Nuur, 2021; Aranda-Usón et al., 2020; Cramer, 2020; Van den Berghe and Vos, 2019; Scarpellini et al., 2019; Barbero and Pallaro, 2018), industrial symbiosis (IS) (Cramer, 2020; Barbero and Pallaro, 2018; Lombardi, 2017), ecological economics (Gonçalves et al., 2021; Henrysson and Nuur, 2021), and environmental economics (Henrysson and Nuur, 2021).

Moreover, Nohra et al. (2020) claim the notion of eco-effectiveness, originating from the cradle-to-cradle principle and industrial ecology, has been engrained in the CE paradigm. Van den Berghe and Vos (2019) revisited the pivotal work of Wachsmuth (2012) on the three ecologies of urban metabolism, namely, the human ecology, the (urban) industrial ecology and the (urban) political ecology, and ultimately are situating the operational concept of circularity within the industrial ecology. According to Banaite and Tamošiuniene (2016) the CE concept, initially put forward by the EC in a report of 1976, is perceived as an outcome of

Table 7
Top 10 cited papers.

	Title	Authors	Source	Year of Publication	Total Citations
1.	Experiences from early stages of a national industrial symbiosis programme in the UK: Determinants and coordination challenges	Mirata (2004)	Journal of Cleaner Production	2004	219
2.	Industrial symbiosis networks and the contribution to environmental innovation: The case of the Landskrona industrial symbiosis programme	Mirata and Emtairah (2005)	Journal of Cleaner Production	2005	187
3.	Towards a sustainable industrial ecology: Implementation of a novel approach in the performance evaluation of Italian regions	Arbolino et al. (2018)	Journal of Cleaner Production	2018	58
4.	Shared responsibility at the regional level: The building of sustainable industrial estates	Brand and De Bruijn (1999)	European Environment	1999	39
5.	Industrial symbiosis, networking and innovation: The potential role of innovation poles	Taddeo et al. (2017)	Sustainability	2017	37
6.	Circular economy strategies in eight historic port cities: Criteria and indicators towards a circular city assessment framework	Gravagnuolo et al. (2019)	Sustainability	2019	33
7.	Barriers and challenges to plastics valorisation in the context of a circular economy: Case studies from Italy	Paletta et al. (2019)	Journal of Cleaner Production	2019	27
8.	Forest sector circular economy development in Finland: A regional study on sustainability driven competitive advantage and an assessment of the potential for cascading recovered solid wood	Husgafvel et al. (2018)	Journal of Cleaner Production	2018	25
9.	The development of regional collaboration for resource efficiency: A network perspective on industrial symbiosis	Zhu and Ruth (2014)	Computers, Environment and Urban Systems	2014	25
					25
10.	The experience of the first industrial symbiosis platform in Italy	Cutaia et al. (2015)	Environmental Engineering and Management Journal	2015	24

implementing sustainable development globally, while Drejerska et al. (2020) claim the theoretical basis of the CE is founded on the material cycles idea.

3.3.2. *Mapping the studies based on NUTS classifications*

This study draws on the NUTS classification – more specifically the NUTS 2 level regions – as a unit of analysis for regional CE implementation. To map the final dataset against the three levels of NUTS regions, **Appendix C** was created and populated with a quantitative content analysis.

The 'indicated region(s)' categorisation includes papers which clearly specified an existing region or territory, regardless of the context in which it was stated. For instance, Henrysson and Nuur (2021) brought up the following regional examples of CE initiatives across the EU - Päijät-Häme - Finland (NUTS 3), Brussels-Capital Region (NUTS 2), Malopolska - Poland (NUTS 2) and Extremadura - Spain (NUTS 2). Other contributions falling under this category are Whicher et al. (2018), referring to the UK's NUTS 1 region – Scotland; Barbero and Pallaro (2018) mentioning the Italian NUTS 2 region of Piedmont; and Virtanen et al. (2019) pointing out to the Finnish NUTS 3 region of Päijät-Häme.

In the second category of "considered as region(s)', the authors are primarily referring to large cities that Eurostat does not regard as NUTS regions, but which for the purpose of this research are considered to belong to one of the five proposed levels, solely based on their population. One of these cases is the study of Dąbrowski et al. (2019), which looks at the Amsterdam and Naples metropolitan areas. These are not NUTS regions, but based on their population, they could be considered NUTS 2 and NUTS 1 regions, respectively.

On some occasions, Eurostat data indicate that an area could represent more than one NUTS level, as is the case with the French region of Pays de la Loire which is both NUTS 1 and NUTS 2 level in the paper of Vanhamaki et al. (2019). Another example is the study of Alonso-Almeida and Rodríguez-Antón (2020), where some of the Spanish regions the authors are analysing according to Eurostat are both NUTS 2 and NUTS 3 levels (i.e. Asturias, Cantabria, Ceuta, Melilla and Murcia). This fourth category is represented by the green triangle in the category of 'multiple levels'.

The 'suggested level' category indicates that the author(s) proposed a specific NUTS level, though exact regions/territories were not named. For example, Avdiushchenko (2018) proposes that NUTS 2 regions are the most suitable one for implementing CE but makes no reference to any specific region.

Finally, five papers were generic and did not specify any region or territory, though they had regional considerations; hence, they were grouped in the 'N/A' category (Bezama et al., 2019; Marra et al., 2018; Lombardi, 2017; Banaite and Tamošiuniene, 2016; Zhu and Ruth, 2014).

Most of the analysed paper were mapped in the NUTS 2 region (thirty-five papers), followed by NUTS 3 region (twelve papers) and NUTS 1 region (six papers). Nineteen papers mentioned multiple regions belonging to at least two categories, like Nohra et al. (2020) reporting on the results from the RETRACE Project, which involved partners from Piedmont (NUTS 2), Basque Country (NUTS 2), Nouvelle Aquitaine (NUTS 1), Northeast Romania (NUTS 2) and Slovenia (NUTS 1). The results from this quantitative content analysis presented in **Appendix C** show the tendency of scholars to focus on the NUTS 2-sized regions, which supports the argument of this research to base the sub-national implementation of CE precisely on the NUTS 2 level regions.

3.3.3. *Pillars of CE: industrial ecology (IE), industrial symbiosis (IS) and Eco-Industrial Parks (EIP)*

IE, presented in the literature as both policy tool and academic theory (Daddi et al., 2016) concerns the impact of industry, technology and related changes in society and economy on the biophysical environment (Taddeo et al., 2017; Taddeo, 2016). The IE discipline, according to Mirata and Emtairah (2005) encourages new ways of tackling environmental issues at regional and local level. Two main place-based approach are vital within the IE, Eco-Industrial Parks (EIPs) and IS (Mirata, 2004).

According to Taddeo (2016) IE offers sustainable approaches for local development, mostly manifested through establishing EIPs, which are the global referential models for delivering IE locally. In terms of establishment, EIPs can arise spontaneously from bottom-up initiatives or top-down planned approach, the former being more resilient and having greater chances of success (Taddeo, 2016).

IS denotes synergetic activities between companies where the waste of one company can be considered an input to another company,

entailing materials, energy, services and facilities (Henrysson and Nuur, 2021; Yu et al., 2021; Patricio et al., 2018; Lombardi, 2017; Taddeo et al., 2017; Taddeo, 2016; Iacondini et al., 2015). According to Savini (2019), prototypes that precipitated recent models of CE originate from the late 1970s, when industrial manufacturing groups started investing in IS and successful industrial design. Nonetheless, the literature on IS is deemed to be theoretically fragmented (Aranda-Usón et al., 2020).

Despite the already presented theoretical links between the concept of CE and IS, scholars perceive the nexus between these two concepts differently. For instance, IS is presented as: one of the most effective enablers for the CE transition; a mechanism to develop the CE (Yu et al., 2021); one of the dominant strategies for the establishment of a CE (Patricio et al., 2018, 2020); a very beneficial tool for the exchange of waste and formation of networks for developing CE (Poponi et al., 2020; Lombardi, 2017; Iacondini et al., 2015); territorially-bound enabler (Gravagnuolo et al., 2019); an early prototype of circular production (Savini, 2019); a mechanism for implementing the CE at the regional level, along with Eco-Industrial Parks (Scarpellini et al., 2019) and an approach which strengthens the idea of CE (Vanhamaki et al., 2019).

Last but not least, scholars established the bond between IS and CE in terms of implementation levels. More specifically, the IS is predominantly considered as a meso-level approach for implementing the CE transition (Vanhamäki et al., 2020; Avdiushchenko and Zajaç, 2019; Marra et al., 2018).

The crucial role of the IS within the European CE strategy is also acknowledged in the literature (Compagnoni, 2020; Patricio et al., 2020; Husgafvel et al., 2018; Husgafvel et al., 2018a; Lombardi, 2017; Iacondini et al., 2015). According to Lombardi (2017) from local, regional, national to EU level, IS is perceived as a strategic tool contributing to the CE; however, less than 0.1% of the 26 million active companies in Europe are acknowledged as operating within a symbiotic partnership.

Several studies in the final dataset were exploring the link between existing or potential IS networks and the CE in different European regions (Yu et al., 2021; Aranda-Usón et al., 2020; Cappellaro et al., 2020; Avdiushchenko and Zajaç, 2019; Husgafvel et al., 2018; Smol et al., 2018). Iacondini et al. (2015) evaluated existing opportunities and ongoing projects in the Emilia-Romagna region envisioned to apply IS and implement CE. Overall, this paper revealed that both industrial and academic ecosystems are supportive and interested in IS, but regulatory and cultural issues are the main obstacles observed.

3.3.4. Circular economy policy-making

According to Scarpellini et al. (2019), the contribution of local and regional authorities to the introduction of and transition to a CE is vital; hence, the CE should be translated into environmental regional planning. The progress towards a CE in a territory, however, depends on various aspects, including its industrial structure, regional business, level of innovation, and legislative profile at the regional and local level. Nevertheless, the integrated nature of planning – involving environmental, social, and economic factors – can result into cases where economic aspects take precedence over local development (Datta, 2012; Pickvance, 2000).

The crucial role of regional authorities in initiating and promoting the CE implementation, as argued by Bacova et al. (2016) consists of establishing framework conditions or directly encouraging local and regional actors (Silvestri et al., 2020). Moreover, according to Bacova et al. (2016), "… *since CE implementation is affected by geographic, environmental, economic and/or social factors, the diversity of territorial contexts translates into different needs and opportunities that any CE approach should address …*". Lechner et al. (2021) adds that even though policy-making is perceived as mainly (trans)national way to address sustainability issues on large scale, local authorities have important influence on climate mitigation activities. More specifically, Cramer (2020) and Vanhamäki et al. (2020) claim that national governments started engaging in the CE transition, but the adoption of the CE in cities and regions is still in infancy phases hence related research is also meagre. Christis et al. (2019) recommends a shift of environmental policies to the consumption side in territories with high consumption and limited production activities and resources, e.g. Brussels Capital Region, in order to improve circularity metrics and mitigate climate change effects.

When developing macro-level CE policies, a systematic and ample understanding of the multifaceted relationships between the different systems (natural, social, and economic) must be ensured. However, the results of the study of Marra et al. (2018) reveal a fairly homogenous knowledge base on CE, inadequate for alleviating cross-disciplinary sharing. This could be the cause of significant challenges to successful cooperation between diverse fields. Murray et al. (2017) argue that the multifaceted knowledge base that policy-makers require remains in the development phase. Similarly, Dąbrowski et al. (2019) claim the CE field cannot be considered mature and experience and knowledge of CE implementation in spatial strategies remain insufficient. Likewise, McDowall et al. (2017) highlight the scale and place aspects do not receive the required attention.

Real et al. (2020) refer to the work of Manzini (2013) related to the concept of cosmopolitan localism, in which the CE is delineated as a network of smaller circular economies. This is closely linked to other concepts, among which are degrowth (Demaria et al., 2013), diseconomies of scale and opposition to bigness (Kohr, 1957) or conviviality (Illich and Lang, 1973), all of which require change-makers to create socio-technical transitions in small territories such as cities or regions (Real et al., 2020).

The policy review performed by Stanojev and Gustafsson (2021) uncovered that CE should be perceived as a wider sustainable development strategy which should also "support *Member States and regions to strengthen innovation for the circular economy through smart specialisations (S3*[2]*)*". They add that the S3 approach will be a primary tool for detecting regions' opportunities for progress, development and CE. Similarly, Compagnoni (2020) concludes that the most holistic instrument used by Italian regional authorities to introduce the CE principles at the regional level is the S3, providing a multi-faceted policy mix based on medium-long run regional development ambition shared by many actors, which influences the innovation course of main economic areas.

3.3.5. Approaches for regional circular economy implementation: top-down vs bottom-up

Implementing CE at a large scale requires a hybrid approach that is impelled both from the top-down public institutions interventions and bottom-up industry activities (Vanhamäki et al., 2020; Poponi et al., 2020; Sánchez Levoso et al., 2020). The top-down initiatives are the ones stimulated by institutions and linked with strategy and policy decisions, like environmental regulations or economic incentives. Bottom-up interventions are emerging from social movements and business initiatives, such as community-led digital platforms or sharing economy initiatives (Prendeville et al., 2016).

The policies and legal frameworks stimulating CE are differing across the world (McDowall et al., 2017), conditional on the political system and governance structure (Cramer, 2020). China on one hand is promoting the CE as a top-down national political objective, while, on the other hand, Japan, the USA and EU countries are more reliant on devising bottom-up environmental and waste management policies (Vanhamäki et al., 2020; Gravagnuolo et al., 2019; Ghisellini et al., 2016).

Paletta et al. (2019) focused on the barriers and challenges to plastics valorisation in the European CE context. They stress the inability of the present approach to meet the projected recycling target of 55% by 2025 without bottom-up support from industry and the community (Winans

[2] An innovative approach aiming to boost growth and jobs in Europe, by enabling each region to identify and develop its own competitive advantages.

et al., 2017). They suggest a radical transformation of the complex value chain of plastics, which includes integrative collaboration; innovative solutions; and significant efforts by key decision-makers, industry (plastics waste sorters, recyclers, retailers), and consumers. Sánchez Levoso et al. (2020), Vanhamäki et al. (2020) and Aranda-Usón et al. (2018) call for a balanced approach, combining both bottom-up and top-down initiatives, and the equal commitment of all stakeholders. The transition towards a CE requires both the support of the government via top-down policy instruments (e.g. subsidies and tax incentives) and encouragement from the bottom in response to changing social preferences (Vanhamäki et al., 2020; EEA, 2016). The foundation of the policies should be on flexible and innovative governance model able to consider new structures of rules and actors capable of combining top-down and bottom-up processes (Nohra et al., 2020).

Alonso-Almeida and Rodríguez-Antón (2020) are characterising as a top-down transformation the general approach EU is adopting to deploy legal instruments, i.e. directives, policies and recommendations, implying initially national regulations are adjusted and then lower regulations which are impacted. Other studies are focusing on the roles of counties and municipalities in the design of policies in Nordic countries (Ortega Alvarado et al., 2021;Lidström, 2018; Sjöblom, 2018).

Similarly, Sutcliffe and Ortega Alvarado et al. (2021) are acknowledging the protagonist role of the subnational authorities in EU policy and regulative implementation (Borghetto and Franchino, 2010), but claim that adaptations of the EU policies to national policies is happening following a locally adjusted top-down approach (Alasuutari, 2015). Therefore, the concept of policy diffusion is inadequate, and the role of locality and cultural context in implementing global policies could be explored through the mechanisms of the domestication framework (Sutcliffe and Ortega Alvarado, 2021). The spatially centric nature of the systemic change entailed by the CE adoption requires more profound understanding of place-specific bottom-up route formation (Henrysson and Nuur, 2021). However, the authors are portraying the CE as a top-down transformational approach within the regional development context of the natural resource-based sector, and they point to the need for research in terms actor-centered interventions design to target key actors of change which have been overlooked (Henrysson and Nuur, 2021).

3.3.6. Drivers and barriers in relation to regional circular economy implementation

Most of the papers tackle the issue of drivers and barriers in relation to CE implementation (Sani et al., 2021; Nohra et al., 2020; Dąbrowski et al., 2019; Obersteg et al., 2019; Paletta et al., 2019; Lombardi, 2017). **Appendix D** summarises the relevant studies on specific drivers of CE implementation, as well as barriers and challenges to the introduction and transition. It is evident that most papers identify barriers and challenges, and some of the most frequently cited are lack of policies, regulations, funding, and awareness. Policies and funding instruments are among the most commonly identified drivers. It is important to note that CE implementation differs in each region or city, depending on geographic, environmental, economic, and social factors. Therefore, each region must consider the region-specific processes affected by CE, as well as taking into account the barriers and challenges (Avdiuschchenko, 2018). According to Compagnoni (2020) the regional authorities have fundamental role in developing policies for CE transition, because local driving forces and challenges linked with CE are very specific. For example, agricultural regions can concentrate on diffusing bioeconomy practices, the urban territories can focus on practices like "product as a service" while manufacturing regions on facilitating product innovation via eco-design. In their proposed methodological framework for developing regional CE roadmaps, Sánchez Levoso et al. (2020) argue that potential barriers for implementing CE practices shall be analysed and included in the final roadmap, as well as solutions for overcoming them.Sánchez Levoso et al. (2020)

Despite the endorsement of the CE paradigm by the EU, the actual adoption is restricted, mainly due to cultural barriers (Kirchherr et al., 2017), though De Jesus and Mendonça (2018) claim "harder" obstacles are also hampering the transition towards the CE because even when CE practices are viable technically, there are still economic and market restraints (Sanchez Levoso et al., 2020).

Henrysson and Nuur (2021) state the institutional environment can be found on both sides, as a driver and a barrier for the CE transition, and institutional factors are main driving forces for outlining potential pathways for transformation. Moreover, they postulate three determinants for endogenous and directed shift towards the CE in the regional context: proximity of knowledge of physical flows and material assets, maturation and diversity of market networks and inherent values and patterns of cooperation. As claimed in their study *"emerging regional industrial CE practices are shaped by systems and networks of markets defined by inherent values and modes of cooperation that depend on the interplay between institutional and material circumstances, technology, and spatial industrial dynamics"*.

Alonso-Almeida and Rodríguez-Antón (2020) explored the role of institutional pressures in the diffusion and application of CE from the central government to the regions. The findings showed coercive pressures are the most effective ones for advancing the CE in the Spanish regions, though normative pressures are not so relevant. Nevertheless, suggestions to reinforce some coercive instruments were made, in the shape of laws, sanctions or support for adopting CE practices. Mimetic pressures also appeared as relevant for the CE transition in the Spanish regions, probably attributable to the selection of performance or proximity traits.

3.3.7. Policy mechanisms for regional circular economy implementation

A more ample and overarching comprehension of the CE mechanisms is vital for better integration of the CE paradigm within national and regional policies (Vanhamaki et al., 2019). **Appendix E** summarises the policy mechanisms and measures for CE implementation proposed in the literature. The work of Aranda-Usón et al. (2018) is pivotal in this regard, where the authors suggest several measures policy-makers can introduce to support the CE transition. Towa et al. (2021a) calls for cohesive approach for all CE interventions, taking into regard inputs of resources, outputs of waste and related emissions, therefore ensuring the systemic dynamics are considered and the adoption of any CE practice will not imperil a change of environmental issues.

In this context, regions play a vital role, and policy-makers are perceived as drivers of the adoption of CE at the regional level, since they are supporting companies to close their material loops and adopt CE-related practices. Additionally, the regional scale is deemed to be vital for application of waste management policies taking into regard that regions and municipalities are accountable for separate collection systems, as well as founding and overseeing treatment facilities (Gardiner and Hajek, 2020).

Gonçalves et al. (2021) and Arbolino et al. (2020) stress the prominence of an adequate institutional and political framework for the deployment of eco-innovation and sustainable activities, like waste treatment plans and green energy configurations (Ilic and Nikolic, 2016). In contrary, the lack of policy instruments or unfitting provision of such tools could obstruct the attainment of the targets (Geng et al., 2009). Place-specific norms and values, along with instruments and policy mechanisms imposed by local and regional institutions also proved to be crucial in local eco-innovation projects, and in a smart development context, prevailing technological advances and local industrial structure proved to be vital for project initiation (Gonçalves et al., 2021). Scarpellini et al. (2019) propose key measures to be incorporated into regional environmental plans, grouped into scenarios according to the intensity with which the CE practices are introduced within the region.

In the case of the regional CE implementation in the Malopolska region, Avdiushchenko and Zajaç (2019) pinpoint the green public procurement and public-private partnerships as the main public policy

instruments used by the regional authorities. Sutcliffe and Ortega Alvarado et al. (2021) focus on the Norwegian experience for CE adoption, more specifically the case of the Trøndelag county. Regional policy-makers reveal that looking at best practices which can be implemented in the county helped considerably, along with the learning by doing approach of implementation and the scientific perspective represented by the local research communities. On sub-national levels, regional (county) and local (municipality) level, the CE concept was initiated via EU projects and international collaboration. The Finnish case is completely the opposite, where the regional CE roadmap for the Päijät-Häme, serving as a strategic instrument for CE implementation, was being inspired by the Finnish national road map. The Finnish experience show that in order to close biological loops systemic changes are need, implying a combination of regional policy interventions and practice-based business activities with longer vision (Vanhamäki et al., 2020).

Arbolino et al. (2020) cross-country analysis shows the discrepancies between the Italian regions in terms of CE adoption in the chemical sector. The need for a proper planning of the funds and effective recalibration of policy goals in the Southern regions is also noted. In light of that, the adequate planning and efficient institutions, as essential factors for public investment effectiveness, are pinpointed as fundamental for having greater benefits from the investments. Alonso-Almeida and Rodríguez-Antón (2020) investigate the link between institutional theory and the adoption of environmental practices. The results of the study highlight coercive pressure followed by mimetic as the most effective ones for the adoption of CE practices in the Spanish regions, while low normative pressure is noted.

3.3.8. Regional circular economy measurement systems

According to Scarpellini et al. (2019), few studies focus on CE implementation at the regional level, and methodologies that can measure the establishment of CE in a specific territory remain under examination. The importance of an available monitoring framework is also an issue tackled in several studies (Vanhamäki et al., 2020; Alaerts et al., 2019; Avdiushchenko and Zajaç, 2019; Avdiushchenko, 2018). The primary aim of a monitoring framework is to assist governments at various levels with assessing the effects of CE policy interventions and identifying the actions required to direct the economy (Reichel et al., 2016). A monitoring framework should enable stakeholders to identify ways of contributing to a CE, taking into account the wider economic, environmental, and societal factors (Alaerts et al., 2019).

Moraga et al. (2019) and Iacovidou et al. (2017) underline the lack a single indicator or methodology able to monitor every aspect of the CE. Moraga et al. (2019) argue this could be due to the lack of a commonly agreed concept of what CE should encompass is still missing, and Vanhamäki et al. (2020) adds the difficulties in defining and setting CE targets as a reason. Saidani et al. (2019) on the other hand argue that CE indicators exist though all-inclusive indicators and comprehension on the usability of the various types of indicators is still scarce. Vanhamäki et al. (2020) claims the monitoring of the direction of change can *"make the change more manageable from the regional development and policy point of view"*. However, their recent study revealed that for the majority of regions the monitoring and evaluation of the CE strategies and action plans are in the development stage, indicating that regions have different approaches to monitor and assess the CE implementation.

Avdiushchenko and Zajaç (2019) and Alonso-Almeida and Rodríguez-Antón (2020) draw attention to the national focus of the EC CE monitoring framework and the limited focus on monitoring procedures for regional and local policies. This results in a gap between policy-making and practical implementation, which affects regional actors. This is a critical omission, as regions are the most significant administrative units for devising and implementing major EU policies. Furthermore, Avdiushchenko and Zajaç (2019) refer to the expected rebound effect of the CE transformation, and the support that monitoring procedures can offer to policy-makers in the form of adjusting and revising strategies and actions. Towa et al. (2021a) tackled the issue of assessing the circularity of regions and claimed that current studies disregarded the trade of waste for treatment among regions when assessing the regional circularity.

Avdiushchenko (2018) took the first step in proposing a CE-based regional development monitoring framework and Avdiushchenko and Zajaç (2019) built upon this conceptual study to suggest a wide range of specific indicators for each of the pillars. Arbolino et al. (2020) suggested a composite index - Circular Economy Index (CEI) aiming to assess the regional performance of the chemical sector and tested it in 20 Italian regions. D'Adamo et al. (2020) developed a socio-economic indicator for the bioeconomy (SEIB) in order to assess the socio-economic performance of the regional bioeconomy and tested it on 20 Italian regions. Arbolino et al. (2018) proposed a novel index to assess ecological industrial policy - Industrial Environmental Sustainability Index (IESI) with the use of Principal Component Analysis and applied in 20 Italian regions. Silvestri et al. (2020) constructed two composite indicators - the Circular Economy Static Index (CESI) and the Circular Economy Dynamic Index (CEDI), allowing both static and dynamic assessment of the CE performance of EU NUTS 2 regions. An interesting line of inquiry the authors are suggesting is to identify the reasons for diversity and/or similarity in CE performance in trans-border to neighboring regions within one country, in order to investigate the role of national and regional institutions for promoting the CE practices (Silvestri et al., 2020).

Municipal waste has been highly debated topic in the EU, despite being only 10% of the total waste created in the EU. As a result, many studies have focus on this area (Boffardi et al., 2021; Foschi et al., 2021; Towa et al., 2021b; Agovino et al., 2019, 2020; Banias et al., 2020; Compagnoni, 2020; Gardiner and Hajek, 2020; Patricio et al., 2020; Mihai and Grozavu, 2019; Sastre et al., 2018). Gardiner and Hajek (2020) advocated the regional scale as the most significant for adopting waste management policies, since regions and municipalities are accountable for separate collection systems and managing treatment facilities. Agovino et al. (2019) addressed the issue of separate waste collection (SWC) in Italy, on municipal levels (NUTS 4). Findings revealed that the quality of local institutions are the main driving force of SWC in Italy, though the morphological features of the area, the consumption of cultural goods and income level are also crucial.

3.3.8.1. Data availability issues. The issue of a lack of data and challenges in terms of data availability were encountered in several studies (Tazi et al., 2021; Towa et al., 2021; Towa et al., 2021a; Towa et al., 2021b; D'Adamo et al., 2020; Arbolino et al., 2020; Banias et al., 2020; Bianchi et al., 2020; Gardiner and Hajek, 2020; Mihai and Grozavu, 2019; Patricio et al., 2020; Silvestri et al., 2020; Agovino et al., 2019; Christis et al., 2019; Virtanen et al., 2019; Volk et al., 2019; Arbolino et al., 2018; Avdiushchenko, 2018; Sastre et al., 2018).

Arbolino et al. (2018) pointed out to the fact that the regional level represents a challenging territorial level for analysis, simply due to dearth of data, which was also corroborated by Bianchi et al. (2020) and Towa et al. (2021b). Aranda-Usón et al. (2018) noted the limited number of data sources, as well as the absence of a common methodology for measuring CE. Avdiushchenko and Zajaç (2019) reported difficulties with data accessibility, which restricted their opportunities to monitor CE in their study region. Towa et al. (2021) stressed the incomplete and reliable information both for country and regional levels for Belgium. Volk et al. (2019) communicated uncertainties in the data, while Mihai and Grozavu (2019) encountered lack of available data on rural municipal level (commune) concerning waste collection coverage. Virtanen et al. (2019) listed numerous challenges that they faced during their data collection process, such as an inability to find regional-level data, inconsistency between sources and the specifics of their study region. The latter prevented the use of national figures, as these do not necessarily reflect the reality and the regional disparities.

4. Main research findings

This section of the paper critically discusses the main findings of the review and underlines the emerging research gaps.

4.1. General findings related to the field of regional CE

Overall, the **adoption of the CE at the regional level is underexplored and in infancy stage.** A dearth of relevant research was detected at the beginning of the process, indicated by the low number of related papers identified during the SLR process (**section 2.1**). As shown in **section 3.1.1**, 30% of the papers were published in 2020 and 20% in 2021 (from January 1, 2021 until May 13, 2021 when the data was extracted). This indicates that academic interest in the RCE domain has only just begun to emerge. Additionally, as argued by Murray et al. (2017), the CE school of thought has developed from legislation rather than scholars, explaining why there is not yet a journal, editorial board, or group of faculties. These findings were also corroborated in **section 3.2.3** where the analysis revealed rather individualistic approach for researching this field, with very few links for co-authorship and citations among the authors in the dataset, but also very lose citations links among sources (**section 3.2.4**). These fragmented results can be rationalized by the novelty of the field. Towa et al. (2021b) attribute the slow progress of studies at the subnational level to the unavailability of detailed information but emphasise the importance of having related studies considering that they contribute local and national decision-makers to take into account regional specifics.

A missing regional element and lack of multidisciplinarity was also observed. The absence of regional science journals was noted (**section 3.1.2**), as well as a lack of representativeness concerning subject areas pertinent to regional development (**section 3.2.1**). The combination of a research outputs concentrated in few publishing sources and subject areas along with the self-referencing phenomenon identified (**section 3.2.5**) could imply that the impact of the research outputs is only to the tangent disciplines. This research gap is corroborated by the findings of a recent study (Marra et al., 2018). Moreover, Bezama et al. (2019) highlighted the need for bonds between different scientific disciplines, technology fields and sectors to *"implement value chains into regional value cycles as a sustainable management of regional resources"*.

The **close links between IS and CE** are well documented in the literature (**section 3.3.3**) (Compagnoni, 2020; Patricio et al., 2020; Husgafvel et al., 2018; Husgafvel et al., 2018a; Lombardi, 2017; Iacondini et al., 2015). According to Lombardi (2017) from local, regional, national to EU level, the IS is perceived as a strategic tool contributing to the CE. The keywords co-occurrence analysis (**section 3.2.2**) confirmed these findings, showing the most dominant keywords after 'circular economy' are 'industrial symbiosis', 'environmental policy', 'regional development' and 'waste management' and the overlay visualisation situated these studies dealing with IS to be one of the earliest (also reported in **section 3.1.1**).

4.2. Findings related to the implementation level

The **macro-, meso- and micro-level divisions need to be reconsidered**, as the macro-level is considered very broad in the current literature (Vanhamaki et al., 2019). Additionally, the term 'region' in the context of CE implementation embodies a multitude of geographic territories and is not used consistently (**section 3.3.2**). The **majority of the papers were focused on NUTS 2 regions** (**section 3.3.2**), supporting the argument of this research to base the sub-national implementation of CE precisely on these regions, as also suggested by Avdiushchenko (2018). CE activities are impacted by geographical proximity because the accessibility of activities at local and regional levels contribute to cost reduction in relation with broader circuits including greater number of transactions (Stahel, 2013). Regional resource loops despite for being preferred for their sustainability potential, they also contribute to supporting the regional business activities (Sutcliffe and Ortega Alvarado, 2021).

4.3. Policy-related findings

The challenges of translating higher level policies into regional and local arrangements and policies – and then implementing them – were also highlighted (**section 3.3.4**). Cramer (2020) and Vanhamäki et al. (2020) claim that national governments started engaging in the CE transition, but the **adoption of the CE in cities and regions is still in infancy phases,** while Murray et al. (2017) argue that the multifaceted knowledge base that policy-makers require remains in the development phase. Dąbrowski et al. (2019) claim that, despite the growing number of policies and strategies at different levels, the CE field cannot be considered mature. Furthermore, experience and knowledge of CE implementation in spatial strategies remains insufficient, and the **scale and place aspects do not receive the required attention** (McDowall et al., 2017).

Sutcliffe and Ortega Alvarado et al. (2021) suggest that policies defined at national level shall avail some flexibility so that subnational authorities will have enough room to perform in a transformative manner considering the local context. According to Scarpellini et al. (2019), **the contribution of local and regional authorities to the introduction of and transition to a CE is vital**; hence, the CE should be translated into environmental regional planning. Henrysson and Nuur (2021 call for policy actions directed towards **local factors being crucial for establishing** and maintaining institutional environment supportive of CE-based transformations.

4.4. Findings related to the approach of implementation

The need for a balanced approach to implementation was acknowledged (**section 3.3.5**), combining both bottom-up and top-down initiatives, and the equal commitment of all stakeholders (Sánchez Levoso et al., 2020; Vanhamäki et al., 2020; Aranda-Usón et al., 2018). The transition towards a CE requires both the support of the government via top-down policy instruments and encouragement from the bottom in response to changing social preferences (Vanhamäki et al., 2020; EEA, 2016). The foundation of the policies should be on flexible and innovative governance model able to consider new structures of rules and actors capable of combining top-down and bottom-up processes (Nohra et al., 2020). Moreover, Bezama et al. (2019) point to the necessity of **regional clusters and networks**, where all relevant actors will be integrated and will then serve as **platforms for discussion and knowledge exchange**. The need for a common repository/knowledge base collection of experiences and knowledge was also reported (Sutcliffe and Ortega Alvarado, 2021).

4.5. Findings related to drivers and barriers for implementation

Considering **that local drivers and barriers linked with CE are very specific**, regional authorities have a fundamental role in developing policies for CE transition (**section 3.3.6**). It is important to note that CE implementation differs in each region or city, depending on geographic, environmental, economic, and social factors among others, and that is why Avdiuschchenko (2018) reminds on the importance of taking into account the region-specific drivers and barriers, along with the region-specific processes affected by CE. Henrysson and Nuur (2021) state the **institutional environment can be found on both sides, as a driver and a barrier for the CE transition**, and institutional factors are main driving forces for outlining potential pathways for transformation.

4.6. Findings related to mechanism for implementation

Additionally, as argued by Vanhamaki et al. (2019), **more**

comprehensive understanding of the CE mechanisms for implementation are vital for CE to become an integral component of national and regional policies (**section 3.3.7**). Many policy instruments and industry practices were linked to waste management and recycling, which certainly are fundamental for the CE transition, but this approach is inappropriate to bring the structural and systemic change towards the CE, because it is focusing on the end-of-life phase (Compagnoni, 2020). In light of that, the adequate planning and efficient institutions, as essential factors for public investment effectiveness, are pinpointed as fundamental for having greater benefits from the investments (Arbolino et al., 2020). Sastre et al. (2018) pointed to a weak enforcement mechanism cascading downwards from the national strategies to the practical regional application of the foreseen measures in the Spanish regions. Additionally, they called for a harmonised regulatory framework on CE-related matters which will ensure homogeneous approach across all regions in the country. Hence, it is vital to further explore the types of mechanisms available to different regions and determining the correct combination of mechanism that should be introduced in different regions.

4.7. Findings related to monitoring and measurement systems

Finally, the **lack of a regional monitoring framework and measurement system** was identified (**section 3.3.8**), supporting the findings of other recent studies (Avdiushchenko and Zajaç, 2019; Scarpellini et al., 2019; Avdiushchenko, 2018). The fact that only 27% of the papers were from quantitative nature (and additional 17% mixed studies) in way alluded to the underdevelopment of this side of the discipline (**section 3.1.3**). The recent study of Vanhamäki et al. (2020) revealed that for the majority of regions the monitoring and evaluation of the CE strategies and action plans are in the development stage, **indicating that regions have different approaches to monitor and assess the CE implementation.** The **underrepresentation of the social and environmental dimension** was also noted. Furthermore, Avdiushchenko and Zajaç (2019) refer to the expected rebound effect of the CE transformation, and the support that monitoring procedures can offer to policy-makers in the form of **adjusting and revising strategies and actions**. This adjusting mechanism for regular update was noted in the Päijät-Häme region, where the road map was designed as a process rather as a report (Vanhamäki et al., 2020; Vanhamäki et al., 2020), but also in Satakunta region and Basque Country (Vanhamäki et al., 2020). Towa et al. (2021a) claim that current studies disregarded the trade of waste for treatment among regions when assessing the regional circularity. The **lack of regional data** issue **and challenges in terms of regional data availability** were encountered in many studies (**section 3.3.8.1**).

5. Conclusion and future research agenda

The present study was designed to determine how scholars approach the implementation of regional circular economy. For that purpose, the academic literature relevant to this study was critically reviewed using the systematic literature review method. Descriptive and bibliometric analysis has been performed initially, followed by in-depth content analysis of the current body of academic knowledge. Emphasis has been placed on several structural dimension which were selected by the researchers as the most significant ones to be further explored. Overall, the importance of regions as an implementation level for adopting circular economy practices has been acknowledged. Nevertheless, the related research is still in an infancy stage, despite the increased interest of scholars in the recent period. A number of knowledge gaps in the academic literature have been revealed and are used to articulate the agenda for the future lines of inquiry in the field.

This study is not free of limitations, primarily due to the type of review chosen. In particular, this is due to the use of scientific databases and the methodological decisions around search strings, filters, and inclusion/exclusion criteria. Relevant materials not listed in one of the selected databases may have been inadvertently excluded, alongside grey literature that could have offered a significant contribution. Another limitation was the manual data handling and screening process, which could have resulted in relevant content being overlooked and excluded. Finally, although the process was well documented, transparent, and structured, the analysis of the content and the classification of information was inevitably influenced by researcher bias.

Limitations related to the performed analysis should also be acknowledged. The ranking of articles, journals and authors are founded on local and global citations. Hence, the latest published articles did not make it to the top rankings yet, since certain period (2–3 years) must pass for a paper to gain a reasonable number of citations (Goyal et al., 2021). It could be inferred those outstanding contributions published in 2020 and 2021 (comprising 50% of the total articles for analysis) did not appear in the most cited ranking due to this constraint. Last but not least, the content analysis might generate interpretation bias, however, the systemic multi-method approach which was applied (descriptive, bibliometric and content analysis) contributes to mitigating these limitations.

These limitations can serve as a baseline for refining and encouraging future research on the topic. A fundamental consideration to be taken into account is the expansion of the scope of research from academic literature to grey literature, which according to Merli et al. (2018) in the context of an emerging research field has a vital role. This will contribute to defining the concept of RCE with its conceptual boundaries and associated practices, and ultimately serve as a yardstick for building up the knowledge base in the RCE field. In order to reach a global functional CE, a systemic shift must happen affecting every activity of our ecosystem, implying changes impacting all actors in the value chain. In order to ensure that, a multidisciplinary approach must be taken not only to study but to implement the CE, at all levels including the regional level as well. There is a window of opportunity for further and more thorough investigation of all structural dimensions mentioned in **section 3.3**, in order to have a better understanding of how we can design and implement circular economy at the regional scale. This study offers important contributions to both theory and practice. It is the first attempt to provide a holistic systematic literature review in the regional circular economy domain, therefore it presents an important initial contribution in the direction of establishing robust conceptual frameworks which involve the constructs of regional circular economy and laying the groundwork for future studies in this field. The study is also providing preliminary findings which could be of interest for policy-makers at different levels, in terms of decision-making and devising regional policies, as well as for practitioners for encouraging bottom-up actions for future implementation of the CE at the territorial level.

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CRediT authorship contribution statement

Sanja Arsova: Conceptualization, Investigation, Methodology, Visualization, Writing – original draft, preparation, Writing – review & editing, All authors have read and agreed to the published version of the manuscript. **Andrea Genovese:** Conceptualization, Funding acquisition, Writing – review & editing, Supervision, All authors have read and

agreed to the published version of the manuscript. **Panayiotis H. Ketikidis:** Conceptualization, Funding acquisition, Supervision, Writing – review & editing, All authors have read and agreed to the published version of the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2022.133117.

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