



# Eco-innovation in SMEs: a scientometric review

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Received: 7 September 2021 / Accepted: 2 May 2022 / Published online: 16 May 2022  
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## Abstract

In recent years, the research of SMEs' eco-innovation (EI) has gained attention on an international scale. However, only a few studies provide a global research panorama. This study attempts to bridge this knowledge gap by utilizing the scientometric tools. A total of 749 articles from ISI web of science core collection were collected and analyzed to generate the result, which demonstrated a wealth of useful new conclusions in this domain. The results show that (i) the research topics on SMEs' EI are changing dynamically and become more diversified from 1997 to 2021, especially from 2014 to 2021. (ii) The newest research frontiers are logically consistent with the previous knowledge base, while reflect the novelty of the research, which shows more correlation and adaptation to the newest development situation. (iii) The innovation paradigm in this field has not yet formed, and correlational studies are still in the early stage and a paradigm of open innovation is strongly recommended for researchers. And the barriers, category, process, outcome, and more similar subdivided themes of SMEs' EI are worthy to be further explored. For research methods, inter-regional, inter-institutional, and interdisciplinary perspectives are hopeful to contribute to future research avenues. Some useful inspirations are also provided for practitioners to develop SMEs' EI.

**Keywords** Eco-innovation · Small and medium-sized enterprises · Scientometric analysis · Diversified trends

## Introduction

With concerns about global warming, ecological problems have increasingly become the focus of scholars and practitioners. Since the Brundtland Report in 1987 highlighted the importance of sustainable development (World Commission on Environment and Development 1987), an ongoing debate on ecological innovation has gradually focused on the sustainability of enterprises. Furthermore, the three-pillar models of sustainable development, which balance economic, social, and environmental needs and goals, were

defined by the Brundtland Report. However, this has been accompanied by a growing understanding of ecosystems and their responses to stressors and the inherent limitations of this understanding; the notion of sustainable development is reclaimed from the plethora of economically focused to prioritize the ecological dimension because of limited natural resources (Santillo 2007).

In this context, the theme of eco-innovation (EI) is getting more and more attention from academic research and policy circles (Hojnik and Ruzzier 2016). Eco-innovation can be divided into micro-, medium, and macro-dimensions, and enterprises, industries, and countries are the subjects of eco-innovation on these three dimensions respectively (Dong and Shi 2010).

The role of SMEs is particularly important as one of the micro-level subjects. According to OECD (Organization for Economic Co-operation and Development 2010a), SMEs in the OECD region are trying to align themselves with sustainable practices in manufacturing and services and are therefore seen as key to large-scale adoption of green growth models (OECD 2010a). In other words, the role of SMEs is becoming more and more important in both society and economy. While providing employment opportunities, they also promote economic growth and

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Responsible Editor: Philippe Garrigues

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play a critical role in the well-being of local and regional governments. Nevertheless, along with them come the externalities of their business activities, about 60% of carbon dioxide emissions and 70% of pollution are blamed on them (Parker et al. 2009). Considering that SMEs face other environmental pressures, such as response to corporate social responsibility (CSR) (Schoenberger-Orgad and McKie 2005; Chen and Ma, 2021), requirements for a low-carbon economy (Quintás et al. 2018), and public expectations for its sustainable development (Malik and Jasinska-Biliczak 2018). The combination of SMEs and EI is not only forced by the situation but also a necessary measure to improve its own competitive advantage (Segarra-Ona et al. 2016). Besides, innovation activities are essential to guide the allocation of enterprise resources and ensure the optimization of industrial policies (Chen et al., 2022).

Furthermore, compared with large companies, SMEs face many particular challenges, including insufficient financing, difficulties in technology development, limited management capacity, and regulatory burden (OECD 2000), which might prevent them from actively participating in the innovation process (Del Brío and Junquera 2003). From this perspective, most studies agree that SMEs are “reactive” to environmental and social problems (Klewitz and Hansen 2014). Moreover, literature also shows that SMEs have their own unique advantages, such as flexible organizational capacities and CSR opportunities in niche markets (Bos-Brouwers and Bos-Brouwers 2010; Jenkins 2009). As a result, small companies may be better placed to take on EI in niche markets than large companies (Schaltegger and Wagner 2011). Besides, innovation in SMEs will be different from that in large companies because of their disparate organizational structures and capabilities for EI (Klewitz and Hansen 2014; UNEP et al. 2003).

In summary, the problem of eco-innovation of SMEs has become an important branch of EI research, which has received continuous attention from academic research to industry circles and produced a considerable number of relevant literature. Del Brío and Junquera (2003) reviewed references based on the research progress at that time, formed an earlier research review in this domain. But it is too early to reflect current progress. Klewitz and Hansen (2014) systematically reviewed the sustainability-oriented innovation (SOI) of SMEs, which has been widely cited and affirmed by peers. However, their comments did not include a discussion of the existing literature, as SMEs’ EI was a newly emerging research branch. He et al. (2018) makes a systematic review of the corporate eco-innovation, proposes the research framework of “DSPP,” and discusses the subject of EI and its relationship. However, their research is not specific to SMEs, so there are some limitations. Similarly, the study of De Jesus Pacheco et al. (2018), which is

specifically targeted at EI drivers of small and medium-sized manufacturing enterprises, also has certain limitations.

To conclude, only a few studies provide a comprehensive literature review on SMEs’ EI. Through these literature reviews, we know that a large number of existing research which uses different methods from different perspectives have carried on the beneficial exploration for SMEs’ EI on a lot of subdivided fields. However, with the changing and dynamic development in the field of the research, it is necessary to seek a new way to summarize development status and track the hot research topic and the frontier, we believe that a scientometric review approach, which is inspired by a large number of bibliometric methods, can help us to give a more intuitive and comprehensive solution. Also, there is limited study including aspects such as co-citation analysis, and co-author analysis to analyze its research corpus in such a deep way.

Therefore, the SMEs’ EI is studied by using the software “Citespace”-based scientometric analysis to provide a global research literature foundation and frontier trends for future research so that potential research and practice directions are referential. This paper primarily solves the following three questions:

- (i). What consist of the knowledge bases on SMEs’ EI before 2018?
- (ii). What is the research focus in the domain of SMEs’ EI? What are the characteristics of the research on these different themes? How do these themes change dynamically? What are the limitations and gaps in existing research?
- (iii). Based on the scientometric analysis, what research frontiers of SMEs’ EI can be summed up? And finally, what are potentially valuable research directions?

To answer those above questions, the research framework of this article is as follows. The research questions and reasons are put forward in the introduction. “**Defining terminology**” mainly involves the research of SMEs and eco-innovation. The source of the data and research method is included in “**Research methodology.**” “**Scientometric analysis and discussion**” expounds the co-citation analysis and co-author analysis on SMEs’ EI. And finally, “**Conclusions and limitations**” interprets and summarizes the above results, and summarizes the deficiencies of the article.

## Defining terminology

### SMEs

SMEs, which account between 96 and 99% of all enterprises, are an important part of the global economy and

affect the environment dramatically (OECD 2002; Bras 2006). However, environmental considerations are not a priority for a SME, which is struggling to meet its financial objectives and obligations. Furthermore, SMEs are a diverse group in terms of size and industry diversity and there is no global version of the definition of SMEs (Hillary 2006; Degong et al. 2018). One definition from the USA is “a business with fewer than 500 employees” (Parker et al. 2009). EUC further divided SMEs into small enterprises and medium-sized enterprises, which have less than 250 staffs (EUC 2003).

Since different countries, or regions, use different criteria for definition (e.g., employment, sales, turnover), it will take time to work out the definition of SMEs (Berisha and Shiroka Pula 2015). However, SMEs are mainly defined by the number of employees, with a top and bottom limitation from 1 to 500 (OECD 2010b).

In view of the above situation, this paper selects the three terms that appear most frequently in the literature as the retrieval keywords: SMEs, small and medium-sized enterprises, and small and medium-sized businesses.

## Eco-innovation

The notion of eco-innovation was first proposed by Fussler and James (1996), which refers to a dual effect that significantly lower negative impacts on the environment and bring business value to enterprises. EI can be accomplished in the level of technology or organization (Kemp and Arundel 1998), which refers to eco-product, or eco-organizational (Horbach 2008; Triguero et al. 2013). However, most papers define eco-innovation in the same way as the OECD concept (OECD 2009), this definition not only relates to technology, but also extends to new organizational approaches, products, services, and knowledge-driven innovations that executives can also benefit from practice (Antonioli et al. 2013).

Other definitions of EI are constantly supplemented and updated. These concepts are interdisciplinary substantially, because interdisciplinary perspective from economics or management is involved in this domain (He et al. 2018).

In many literatures, EI is often substituted with some other terms, such as environmental innovation, green innovation, or sustainable innovation (Bossle et al. 2016); this paper chooses these four terms as retrieval keywords.

## Research methodology

In recent years, scientometric analysis has been widely used and has become one of the commonly used methods to assess the research status quo of different regions,

institutions, and individuals (Konur 2012). And it is described as a technique to capture and map knowledge fields more broadly and accurately by identifying knowledge bases, research focus (Chen et al. 2010), and visualizations to track outstanding research frontiers (Olawumi and Chan 2018).

This paper mainly adopts three scientometric techniques. (i) Co-citation analysis. The co-cited documents, co-cited authors, and co-cited journals are included. (ii) Co-author analysis. It includes co-authorship networks, network of faculties or countries. These two techniques are executed for exploring the knowledge bases. (iii) Co-word analysis. This mainly identifies co-occurring keywords, which mainly disclose the research focus. (iv) Co-citation Clusters analysis. It includes document clusters analysis and author clusters analysis, and it can uncover the frontiers to a great extent (Chen et al. 2010). These four kinds of scientometric techniques and their visualizations can be achieved through the “Citespace” software developed by Chaomei Chen. The research design of this study is shown in Fig. 1.

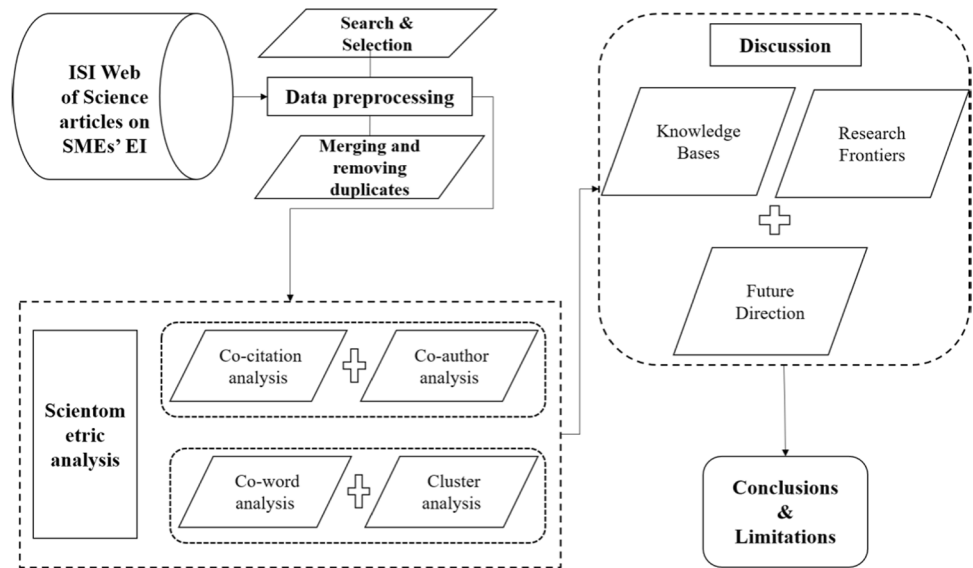
## Database construction

The ISI web of science and Scopus database have become the main resources for scientific investigation and research in recent years. Considering that records which may be duplicated in Scopus have little effect on the results (Valderrama-Zurián et al. 2015), this paper chooses ISI web of science core collection which is a massive online database and provides readers with a way to get specific information about papers published cross over 12,000 of the world’s leading journals (Liu 2017).

## Search strategies and selection of papers

About the covered timeframe, this paper searches articles from 1997 to 2021 mainly reasoned for the following: (i) The concept of EI was proposed in 1996 (Fussler and James 1996). (ii) This study aims to explore the research status, research frontiers, and potential research directions of SMEs’ EI. Retrieval terms are designed as two groups of terms defined as described above. They are Term A: “SMEs,” “small and medium-sized enterprises,” and “small and medium-sized businesses.” And Term B: “eco-innovation,” “environmental innovation,” “green innovation,” and “sustainable innovation”; Term A and Term B are searched together one by one, which means the retrieved papers need to match more than one term in both two groups. This search was executed in the ISI web of science core collection on

**Fig. 1** Outline of research design



the date of March 13, 2022, after merging and removing duplicates in Citespace, resulting in a total of 749 articles listed below in Table 1.<sup>1</sup> And the growth in the yearly number of articles in this domain is presented in Fig. 2. In the first two-thirds of the total 24 years (1997–2013), the annual number of publications remained stable at less than 10. From the last one-third (2014–2021), the annual output increased year by year, especially in the last three years (2019–2021), the output exceeded half of the total quantity, which is close to Price’s model of scientific growth (Price 1956). This reflects the amount of attention this area has received in recent years. Specific research will be further analyzed and discussed below.

## Scientometric analysis and discussion

This section executes the scientometric analysis of the procedures in the research design (Fig. 1). And the above three scientometric techniques including co-citation analysis, co-author analysis, and co-word analysis are executed based on the database of 749 articles. The time slicing is set for 1 year per slice commonly but can be tailored according to specific research needs, so it is with the pruning function. And the nodes selection criteria are top 50 per slice by default.

### Co-citation analysis

Co-citation research is one of the most frequently used methods in science a scientometric analysis, especially for author

co-citation analysis and document co-citation analysis. The co-citation analysis is carried, out and the results are visualized in the figure below. And the meaning of a line, its thickness, and color can be referred to Chen’s paper (Chen et al. 2010).

### Document co-citation analysis

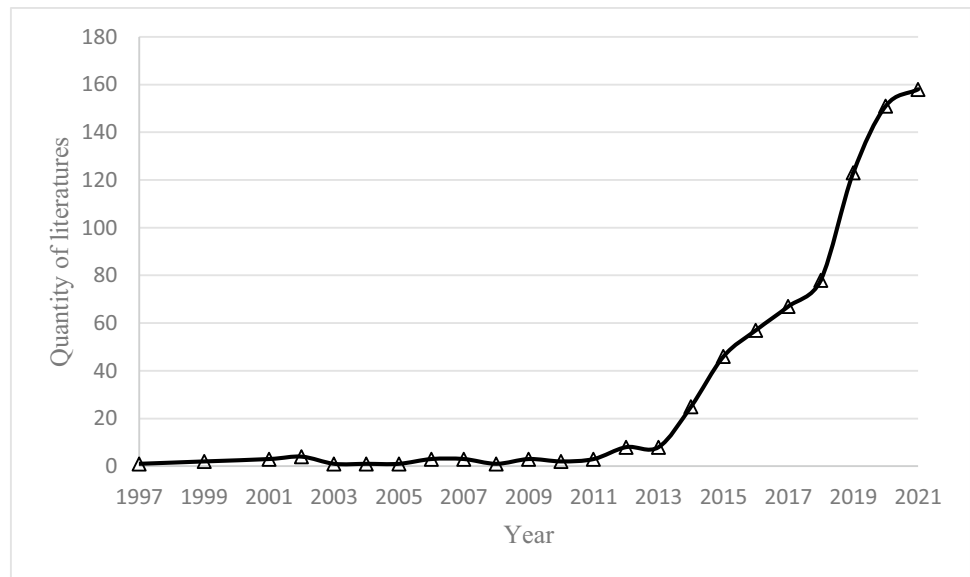
Document co-citation analysis is executed to analyze the references in the 749 retrieved records to understand the knowledge structures of SMEs’ EI domain. And this analysis of the document co-citation analysis reveals that Klewitz’s article (Klewitz and Hansen 2014), which is cited by 87 local records and published in the Journal of Cleaner Production, is the most cited one and the most important intellectual base. Considering that it is a literature review,

**Table 1** Results of SMEs’ EI search

	Eco-innovation	Environmental innovation	Green innovation	Sustainable innovation
SMEs	109	450	202	360
Small and medium-sized enterprises	60	257	118	207
Small and medium-sized businesses	25	133	41	122
Total				749

Note: The total quantity removes duplicate references after each item is retrieved

<sup>1</sup> This paper focuses on peer-reviewed papers in the English language.

**Fig. 2** Number of yearly articles published on SMEs' EI

it means that many of the studies that cite it may have been inspired by one of its ideas, and we will discuss it in conjunction with the other analysis in the discussion section. The second-ranked article is “Drivers of different types of eco-innovation in European SMEs” by Triguero et al. (2013), which is based on the data of SMEs in 27 European countries and analyzes the drivers of EI. The third-ranked article adopts a business model to promote sustainable innovation by Boons and Lüdeke-Freund (2013). Next, the fourth to tenth cited topics are, drivers of green innovation in SMEs (Cuerva et al. 2014), environmental innovation driven by environmental regulations (Horbach 2008), firms' R&D cooperation strategies to introduce environmental innovations (De Marchi, 2012), factors that affect the transformation of SMEs' sustainable innovation (Bos-Brouwers, 2010), review to develop sustainable business model archetypes (Bocken et al. 2014b), determinants of eco-innovation in manufacturing SMEs (Pacheco et al. 2017), and success factors for environmentally sustainable product innovation (de Medeiros et al. 2014). These top ten highly cited articles have two things in common. First, they are all related to drivers of eco-innovation in SMEs more or less, which indicates that the knowledge base in this domain is concerning the drivers of eco-innovation utmostly. Second, most of these publications were published around 2014, when large pieces of literature emerged in that period as we can see in Fig. 2, and we will further discuss it next.

The documents co-citation network is illustrated in Fig. 3, which shows that the overall distribution of scholars' achievements is relatively concentrated. From the perspective of the centrality index, several articles ranked at the top of the centrality index are more centered in the figure and have more connections with other nodes. It shows that these

highly cited works are often cited at the same time, and the papers that cite them may also focus on this field.

#### Author co-citation analysis

Author co-citation analysis refers to author groups who were cited together in the relevant literature, aiming to identify the fundamental specialties in a domain (Chen et al. 2010). And an author co-citation analysis representatively concentrates on the network of cited authors whose co-citation links are highlighted.

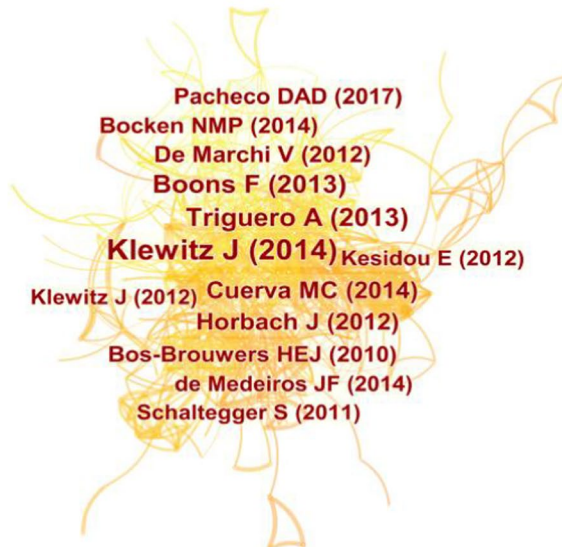
A network of co-cited authors is presented in Fig. 4a. In general, the cited author group is in a state of overall dispersion and regional aggregation. Table 2 shows the specific cited situation of the author. In terms of ranking, Porter Me, who is the No. 1 author cited by 151 times in the local database, has become one of the scholars frequently cited in the study of EI, especially in the drivers of SMEs' EI due to his well-known “Porter hypothesis” (Porter and van der Linde 1995). In particular, the second author on the list is ANONYMOUS, who is not the same author but a collection of anonymous authors whose documents may be state documents, laws, etc. after manually verified by us. Something similar happened with the OECD (123 times), which ranked third, and the European Commission (119 times), which ranked fifth. As these agencies promoting EI research and practice, they have published numerous relevant laws and standards, which have attracted continuous attention from academic circles for many years.

In fourth place, it is Fornell and Larcker (1981), whose paper on SEM (Structural Equation Model) published in 1981 was cited in 120 local articles. Given that this paper is intended to SEM, it indicates that SEM as a research tool

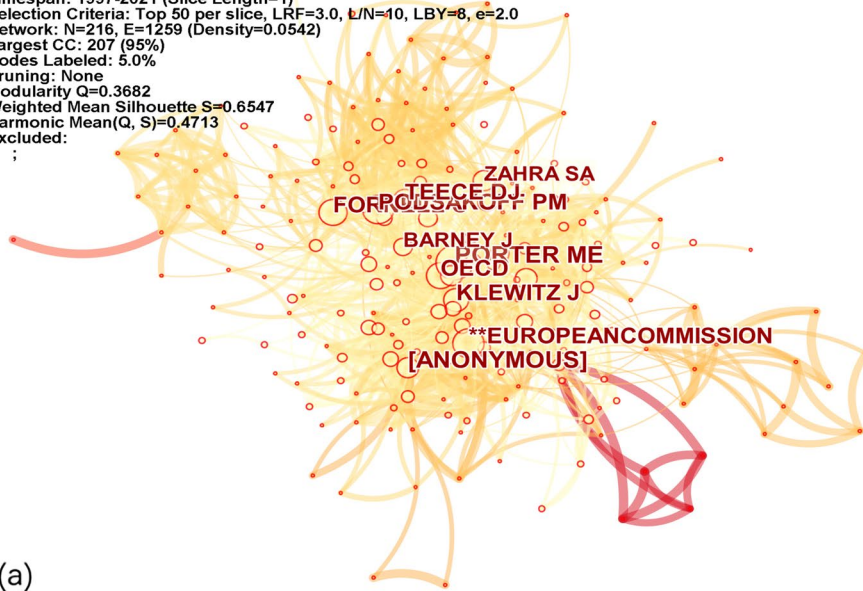


**Fig. 3** Documents co-citation network

CiteSpace, v. 5.8.R3 (64-bit)  
 March 14, 2022 3:02:15 PM GMT+08:00  
 WoS: C:\Users\HPI\citespace\Examples\Data  
 Timespan: 1997-2021 (Slice Length=1)  
 Selection Criteria: Top 50 per slice, LRF=3.0, L/N=10, LBY=8, e=2.0  
 Network: N=379, E=1604 (Density=0.0224)  
 Largest CC: 329 (86%)  
 Nodes Labeled: 5.0%  
 Pruning: None  
 Excluded:

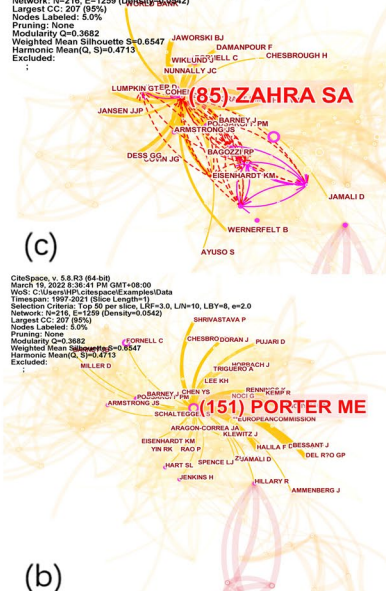


CiteSpace, v. 5.8.R3 (64-bit)  
 March 19, 2022 9:16:33 PM GMT+08:00  
 WoS: C:\Users\HPI\citespace\Examples\Data  
 Timespan: 1997-2021 (Slice Length=1)  
 Selection Criteria: Top 50 per slice, LRF=3.0, L/N=10, LBY=8, e=2.0  
 Network: N=216, E=1259 (Density=0.0542)  
 Largest CC: 207 (95%)  
 Nodes Labeled: 5.0%  
 Pruning: None  
 Modularity Q=0.3682  
 Weighted Mean Silhouette S=0.6547  
 Harmonic Mean(Q, S)=0.4713  
 Excluded:



(a)

CiteSpace, v. 5.8.R3 (64-bit)  
 March 19, 2022 9:36:41 PM GMT+08:00  
 WoS: C:\Users\HPI\citespace\Examples\Data  
 Timespan: 1997-2021 (Slice Length=1)  
 Selection Criteria: Top 50 per slice, LRF=3.0, L/N=10, LBY=8, e=2.0  
 Network: N=216, E=1259 (Density=0.0542)  
 Largest CC: 207 (95%)  
 Nodes Labeled: 5.0%  
 Pruning: None  
 Modularity Q=0.3682  
 Weighted Mean Silhouette S=0.6547  
 Harmonic Mean(Q, S)=0.4713  
 Excluded:



(c)

(b)

**Fig. 4** Authors co-citation network: **a** overall network; **b** network of Porter; **c** network of Zahra

often appears in this field. In addition, it is worth mentioning that Podsakoff's citation times rank only the sixth, but the actual citation times are not far from the top author, and he gets a centrality of 35 and ranks the third, indicating that his related research has been mentioned many times in related

literature of different research directions (Podsakoff and Organ 1986).

Another noteworthy result, which is obtained by structural variation analysis, can be compared in Fig. 4b and 4c, shows the difference between the rank 1st and 10th authors, namely, Porter and Zahra. To be detailed, though

**Table 2** Top 10 cited authors

Citation	Centrality	Author
151	36	Porter Me
129	-	[Anonymous]
123	-	OECD
120	-	Fornell C
119	-	European Commission
111	35	Podsakoff Pm
102	38	Klewitz J
98	-	Teece DJ
86	-	Barney J
85	-	Zahra Sa

“-” indicates no such item or no report

Porter’s works got highest citation, which is almost twice as Zahra’s. The latter’s work contributes to a relative high centrality to the author co-citation network, which can be measured by the red dashed lines in Fig. 4c, indicating that he got a relative high co-citation ratio.

**Journal co-citation analysis**

Journal co-citation analysis is mainly used to reflect important journals and their status in the field. The network of high-cited journals is presented in Fig. 5. As a whole, it presents a centralized distribution state. Besides, the overall gap between the top ten journals is not so obvious, which reflects that the competition of literature published in this field is relatively concentrated and each journal has certain competitiveness. Journal of Cleaner Production (430 citations) ranked first, and its centrality index was 44, ranked secondly, reflecting that this journal is in a relatively more acute and prominent scientific position in the field of SMEs’



**Fig. 5** Journals co-citation network

EI. Besides, its citation burst strength is 3.69, which shows that its citations increase within a short time more obviously in the top 10 journals.<sup>2</sup>

From second place to fifth place, the journals are Strategic Management Journal (334 cited times), Research Policy (299 cited times), Academy of Management Review (289 cited times), and Academy of Management Journal (274 cited times). The remain five journals have contiguous cited times (256 to 272), with a similar centrality index (0.08 to 0.12) except Sustainability.

The top 18 cited journals with the strongest citation bursts are presented in Fig. 6.<sup>3</sup> It is worth mentioning four of them which are “Energy Policy,” “International Journal of Innovation, Management and Technology,” “Procedia-Social and Behavioral Sciences,” and “Psychometric Theory.” Although their cited times are only 28, 25, 27, and 25, which are relatively low. Their burst strengths are all over 10, which is relatively high. Considering that they are founded between 2017 and 2019, they are relatively new and still in the enhancement trend. It reflects that they may become a “Dark Horse” coming from behind. In addition, the sigma index of “Harvard Business Review,” “Mis Quarterly,” and “Psychometric Theory” are above average level, indicating that their published papers were more novel.<sup>4</sup>

**Co-author analysis**

**Co-authorship network**

Author co-citation analysis charts the relationship diagram between cited authors in the same publication (Olawumi and Chan 2018). Considering the research cooperation period, the length of time slice was adjusted to 2 years (slice length = 2); that is, the observation interval was 2 years. The network of co-authorship is presented in Fig. 7.

Overall, there is a poorly difference in the amount of cooperation between different authors. However, many authors may have formed stable partnerships. Such as Samuel, Joseph, and Albert, who are the authors that our analysis shows most collaboratively.<sup>5</sup> Most of their co-authored articles are two or three. In addition, the actual

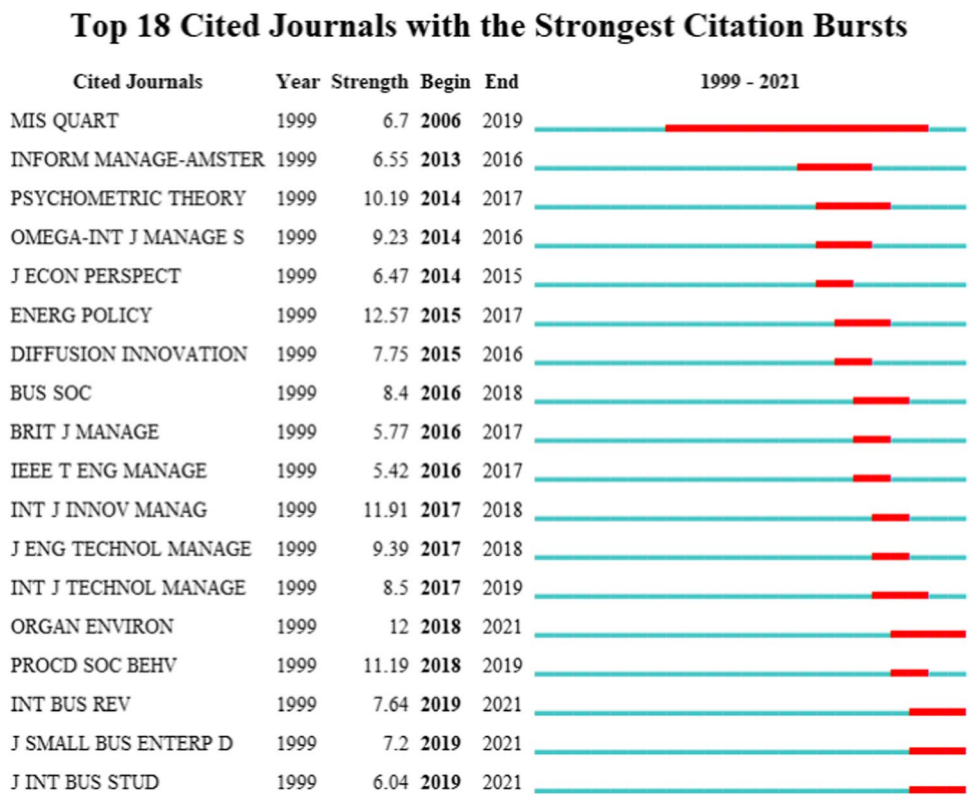
<sup>2</sup> Burst detection is derived from Kleinberg’s algorithm, and it determines whether there are statistically significant fluctuations over a short period. It is valuable to examine whether and when a particular article’s citation rate has spiked (Chen, Ibekwe-SanJuan, et al., 2010).

<sup>3</sup> Twenty-seven cited journals have citation bursts; due to space constraints, we chose the first two-thirds of the results for display.

<sup>4</sup> Sigma is an introduced standard for measuring research novelty. It identifies literature that may represent new ideas based on two criteria of innovative discovery (Chen et al., 2010).

<sup>5</sup> In fact, these three authors are co-authors of four papers, the same number as the next three authors. But Samuel published two independently, so they rank higher.

**Fig. 6** Top 18 cited journals with the strongest citation bursts



**Fig. 7** Co-authorship network (slice length = 2)





number of signatories in most articles is higher than the number shown in Fig. 7, indicating that the authors’ research relies heavily on intellectual contributions from researchers outside their collaborative network. In other words, we may think of the research results in this field as dependent on “open innovation.” Of course, some authors have done their own research independently, and their publications rank lower than those of their co-authors.

Considering the length of the collaboration period may have diverse effects on collaboration between the authors. And the longer the cooperation period is, the more likely the potential cooperation relationship will be converted into a real one. As mentioned above in “Search strategies and selection of papers,” most of the literature in this field is published in the last 8 years (2014–2021), so we mainly compare the difference during this period.

Therefore, this paper chooses to investigate the impact of the longest cooperation period by setting slice length to 8, which means to investigate the cooperation between authors in 8 years from 2014 to 2021. The results are presented in Fig. 8.

Compared to the results of Fig. 8, the number of nodes increased from 104 to 212, while the number of connections increased from 84 to 193, indicating that the 8-year cooperation period seems to get more co-authorships than the 2-year period. So, we summarized and counted all the co-authorships in Table 3, which shows a significant increase in all the number of co-citations, especially in 5 times and 2 times. However, the network density decreased from 0.0157 to 0.0086, which indicates less connection between nodes. With a track of some stable partners, such as Samuel, Joseph, and Albert, their numbers of co-authorships remained; however, Joseph published a paper in this field in collaboration with other authors. In consequence, it can be concluded that

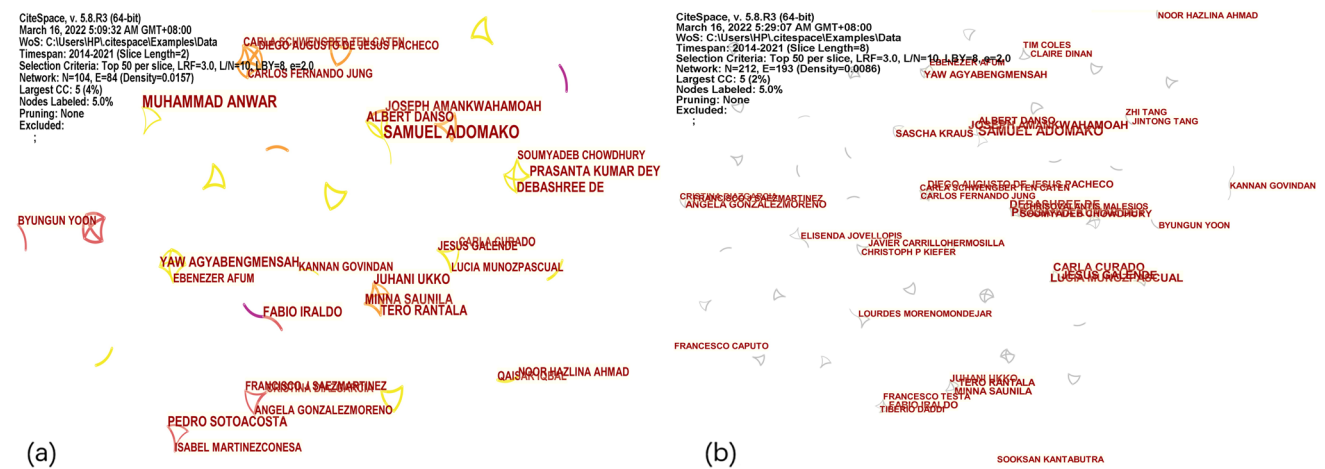
**Table 3** Change of co-authorships in different cooperation period

	Cooperation period	
	2 years	8 years
Number of co-citations	7	1
	6	1
	5	0
	4	10
	3	16
	2	76
Total	104	212

the extension of the cooperation period cannot increase the number of cooperation significantly, but for a single author, longer cooperation can increase his research output in this field.

**Network of institutions/faculties and countries/regions**

This section examines the analysis of institutions/faculties and national/regional network to the stock of knowledge in this domain. Considering that one institution may have multiple authors in the field, the probability of cooperation between institutions is greater than the probability of cooperation between authors, the slice length is set to 1 firstly, then it is set to 2 for a comparison of longer cooperation. Results as presented in Fig. 9. In Fig. 9a, The number of nodes increased from 98 to 131, while the number of connections increased from 49 to 76, indicating that the 2-year cooperation period seems to get more cooperation between institutions than the 1-year period. Again, we summarized and counted all the cooperation in Table 4, which shows a significant increase in most of the number of cooperation, especially in 4 times and 3 times. However, the network



**Fig. 8** Co-authorship network of 2014–2021: **a** slice length=2; **b** slice length=8



**Fig. 9** Network of institutions/faculties: **a** slice length = 1; **b** slice length = 2

density decreased from 0.0103 to 0.0089, which indicates less connection between nodes. With a track of some stable institutions, such as the University of Castilla-La Mancha, published more papers with other institutions in this field when the cooperation period extends. So, again, it can be concluded that the extension of the cooperation period cannot increase the amount of cooperation between institutions significantly, but for a single institution, longer cooperation can increase its research output in this field.

Similarly, there has been a significant increase in published quantity by institutions, and a change in institutions' ranking due to their inconsistent increases, though there was no correlation between the published quantity by specific institutions and the number of their cooperation.<sup>6</sup>

A similar situation occurs again when analyzing the network of countries/regions. When slice length is 1, that is, when the observation interval is 1 year, the cooperation between most countries/regions is formed (see Fig. 10a), which is not much different from the result when the observation interval is 25 years (see Fig. 10b). It is not difficult to understand that the micro-basis of cooperation among countries/regions is the cooperation between authors and institutions. When extending the cooperation period of the latter cannot increase the cooperation opportunities, the former is likewise the same.

On the other hand, it must be mentioned that the ranking of centrality index in top ten countries changes obviously. Except for Spain, Italy and P. R. China decrease, while USA, France, and Denmark increase; it reflects that with the extension of the cooperation period, the intermediation of research results of the former category decreases,

while that of the latter category increases. The reason for this change may be that the thesis themes of the former category are more concentrated, while the latter category is more diversified.

Take Denmark as an example. When slice length increased from 1 to 25, Denmark published three more papers but ranking increased from 9 to 4th, in contrast to P. R. China, eight more papers were published, but centrality decreased from 3rd to 5th, indicating that in the long run, compared with the research results from China, the research of Denmark helped to connect more different research communities in this field (Freeman 1977). However, the research results in China are relatively focused on fewer subjects.

Besides, it is worth keeping an eye on countries that are low on the ranking of centrality but have a relative-large literature output (e.g., Romania, Slovenia, Slovakia in Fig. 10b) because their research may serve as a knowledge base for expanding new research directions.

**Table 4** Change of cooperation between institutions in different cooperation period

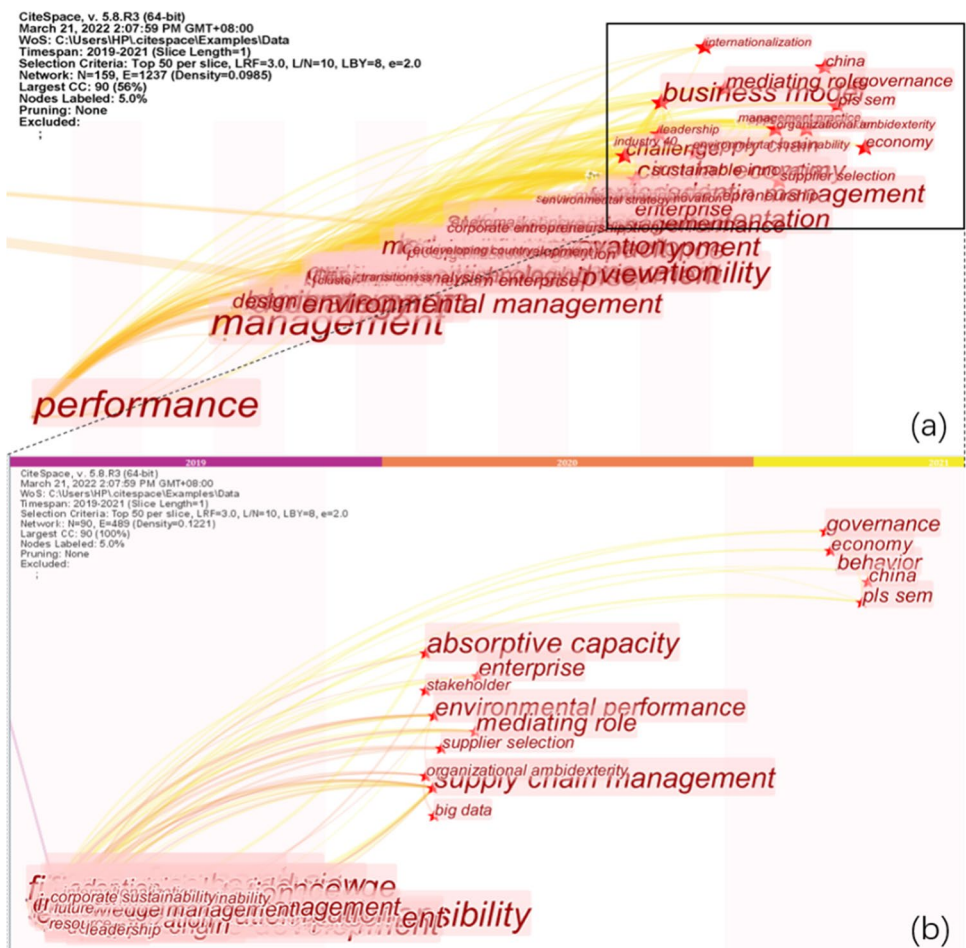
		Cooperation period	
		1 year	2 years
Number of cooperation	12	0	1
	11	1	0
	8	1	3
	7	1	5
	6	4	6
	5	7	13
	4	12	26
	3	19	53
	Total	43	103

<sup>6</sup> Still take the University of Castilla-La Mancha for example, its ranking ascends from 2 to 1 when the cooperation period extends from 1 to 2 years.





**Fig. 12** Timezone of co-occurring keywords: **a** 1997–2021; **b** 2019–2021



the top two, showing strong burst and novelty, which are hot keywords in this field.

It is worth noting that the centrality index of “Performance” is 0.12, ranking second, which shows a high degree of intermediation, indicating that a considerable part of literature touches on the theme of “Performance.” Also, what is worthy of attention in terms of intermediation

are topics such as “Implementation,” “Corporate Social Responsibility,” “Financial Performance,” “Model,” and “Firm Performance.” In particular, “Performance” is also a hot topic in traditional innovation research, and various research communities in this field are connected by it.

This paper notices two keywords of “performance” and “firm performance.” They may be confusable but have

**Fig. 13** Network of co-occurring subject categories





**Table 6** Top 18 co-occurring subject categories in publications

Burst	Centrality	Sigma	Category	Year
9.64	0.49	45.41	Business and Economics	2013
7.99	0.01	1.1	Management	2007
4.56	0	1	Environmental Sciences	1997
4.52	0.07	1.38	Information Science and Library Science	2006
	0.73	1	Social Science Citation Index	2007
	0.09	1	Environmental Sciences	1997
	0.03	1	Science and Technology—Other Topics	2007
	0.01	1	Green and Sustainable Science and Technology	2002
	0.01	1	Environmental Sciences	2007
	0	1	Environmental Studies	1997
	0.37	1	Engineering	2002
	0.05	1	Business	2013
	0	1	Engineering, Environmental	2014
	0.01	1	Environmental Studies	2014
	0.01	1	Engineering, Industrial	2015
	0.03	1	Economics	2015

essential differences. The former may be closer to the concept of “innovation performance,” while the latter is more similar to “organizational performance.” Obviously, for SMEs, the most important organizational performance indicator is still the profit, which has been recognized as one of the goals of firm performance since Adam Smith proposed it (Smith and Stewart 1963). Therefore, this paper believes that “firm performance” is “organization performance” for SMEs, and whether the “innovation performance” is equal to the “performance” mentioned above need to be studied and checked further. After our manual reading and analysis of relevant literature one by one, we found that there were not many single types of research on the eco-innovation performance for SMEs, and they were often carried out at the same time with other topics (such as innovation mechanism). However, papers with keywords including “firm performance” are indeed on the organizational performance (such as company revenue, profit, growth rate) (Zeng et al. 2011).

Through the time-zone map of co-occurring keywords, we can capture the evolution of research hotspots at different time stages (see Fig. 12a), especially what topics constitute

the research frontier in the past two years (see Fig. 12b). Research frontiers for 2020 include “absorptive capacity,” “supply chain management,” “environmental performance,” “mediating role,” which reflects a logical relationship with its knowledge base in this domain. And for 2021, they include “China,” “Governance,” “Behavior,” “Economy,” which indicates more themes correlated with the newest status. For example, co-occurring keywords of “China” and “economy” show more relationship with global economic trends amid the spread of COVID-19.

**Co-occurring subject categories**

The result of co-occurring subject categories analysis is presented in Fig. 13 and Table 6. According to the ranking of the burst index, it is found that SMEs’ EI research has a relatively high burst degree in “business and economics,” “management,” “environmental sciences,” and “information science and library science.” In particular, the average year of the literature on “management” and “information science and library science” is 2014, indicating that the burst time is

**Table 7** Document co-citation clusters of SMEs’ EI research

Cluster ID	Size	Silhouette	Mean year	Cluster Label (LLR)
#0	56	0.81	2013	Sustainable business model
#1	56	0.713	2012	Environmental innovation
#2	49	0.802	2016	Green product innovation
#3	38	0.891	2009	Sustainability-oriented innovation
#4	38	0.67	2010	Environmental protection intensity
#5	24	0.945	2010	Indian industries
#6	16	0.953	2016	Circular economy
#7	15	0.993	2012	Green electricity
#8	14	0.944	2012	Green innovation performance

relatively close, which reflects the rapid growth of relevant research on SMEs' EI from the perspective of management and information science in recent years.

On the other hand, for “business and economics,” its sigma index of 45.41 is far beyond all other subject categories, indicating that its research is more innovative than previous research. In addition, from the perspective of centrality index, “business and economics,” “management,” and “environmental sciences” rank top three, which proves that research based on these three subject categories is most closely related to research from the perspective of other disciplines. On the whole, “business and economics,” “management,” “environmental sciences,” and “information science and library science” are the major subject categories involved in this field, and this conclusion is consistent with the existing relevant research on SMEs' EI by He et al. (2018).

### Co-citation cluster analysis

Cluster analysis, which can be used as a data mining tool exploratorily, is used to define and analyze the significant terms and context in this study, their development trends, and interrelationships within the SMEs' EI research field. Cluster labels selected from the references to the cluster are often more targeted than those selected by human experts. The intellectual base of a certain field is defined by the cited members of a cluster, whereas the research frontier is formed by citers to the cluster (Chen et al. 2010).

Cluster analysis in this study are adopted in three aspects: (i) document cluster analysis (DCA), which is established on search terms in cited references; (ii) author cluster analysis (ACA), which is established on search terms in cited authors; and (iii) keyword cluster analysis (KCA), based on the category of the author names and the journal index terms.

### Document cluster analysis

12 document clusters (ID #0 to #11) were originated from the DCA based on WoS citation metric; there are 9 clusters of larger size among them, as presented in Table 8. Silhouette scores of all clusters (from 0.713 to 0.996) were above 0.5, reflecting a robust and meaningful result (Lee et al., 2016).<sup>7</sup> The modularity Q is 0.6, and the weighted mean silhouette score is 0.8342 (see Fig. 15), which means a well-structured network with clear boundaries (Chen et al., 2010).<sup>8</sup>

<sup>7</sup> The quality of a cluster is measured by its homogeneity and consistency, reflecting its robustness and meaning by silhouette score.

<sup>8</sup> The Modularity Q, ranging from 0 to 1, measures the degree to which a network can be grouped into clusters with distinct boundaries.

**Table 8** Author co-citation clusters of SMEs' EI research

Cluster ID	Size	Silhouette	Mean year	Cluster Label (LLR)
#0	60	0.875	2015	Environmental dynamism
#1	47	0.755	2014	Sustainable business model
#2	46	0.825	2015	Open innovation
#3	24	0.7	2019	Fuzzy multi-criteria analysis
#4	15	0.935	2014	Adoption determinant
#5	12	0.959	2013	Evidence
#6	3	0.958	2012	Production

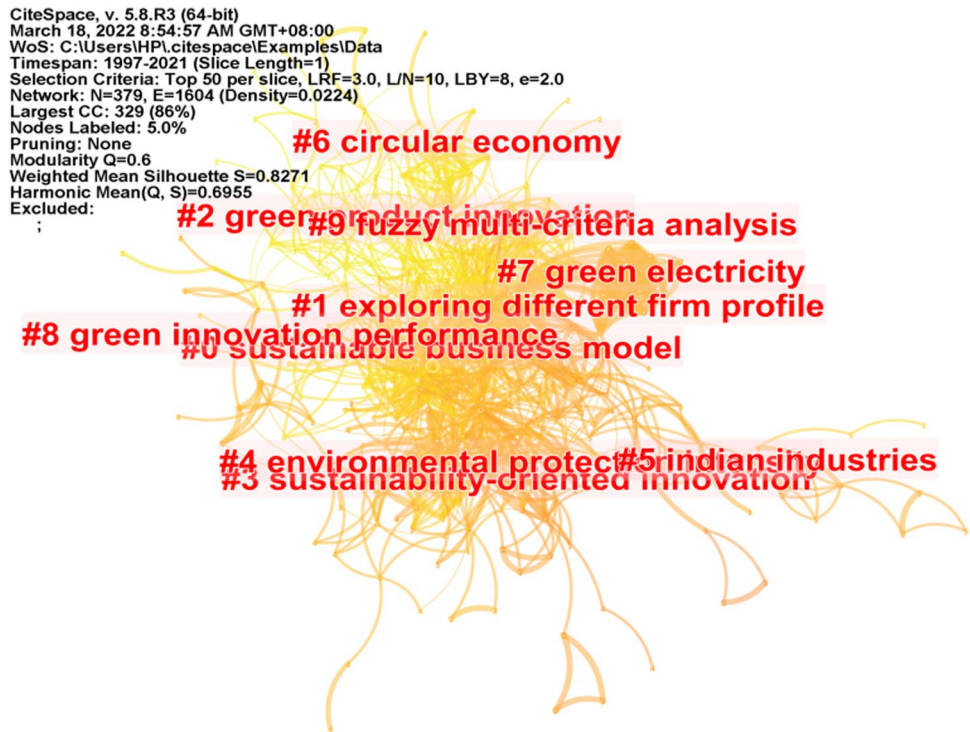
Cluster #0 “Sustainable business model” with 56 cited articles and 53 citing articles is the biggest cluster, and the latest cluster for the mean year of cited references is 2013. Cluster #7 “Green innovation performance,” which is based on 14 articles, is also the latest cluster. The time span of all clusters in Table 7 is from 2009 to 2016, reflecting that the focus time span of this field is not large and is very recent.

In Fig. 14, Cluster #6 “Circular economy (CE)” is further away from other clusters. The representative work is the article of Garrido-Prada et al. (2021). This article mainly focused on the key drivers of SMEs' implementation of CE activities. Although it can also be regarded as the research on determinants of SMEs' CE activities, it is still quite different from other clusters' focused topics focused on eco-innovation. The representative paper of Cluster #5 “Indian industries” is the paper of Singh et al. (2015), which tries to identify the main motivational factors and firms' characteristics that determine the adoption of environmental management system practices by firms. So, it is also distinct from other topics. The other seven clusters mainly focus on SMEs' EI and its practice. Finally, the average years of cited references of these 9 clusters are also very close, reflecting that their knowledge bases are also very close.

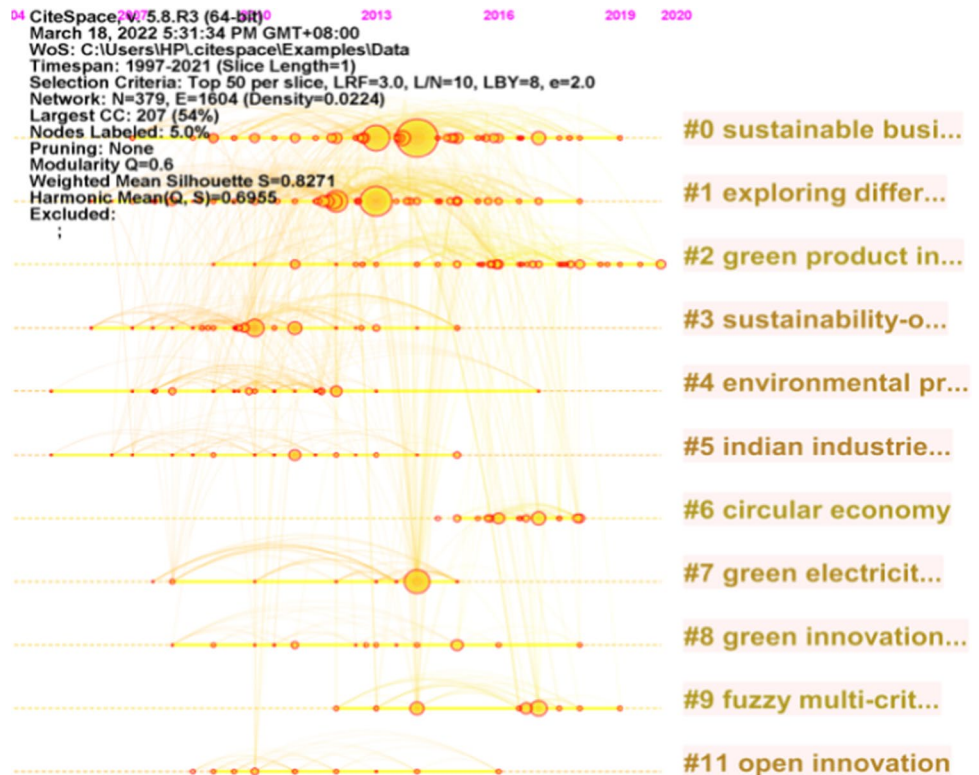
Figure 15 presents the timeline of document co-citation clusters from 1997 to 2021. Cluster #0, Cluster #1 and Cluster #2 are the most active clusters, whose active time span is more than ten years, accompanied by several obvious citation burst intervals, which can be verified from the large-sized circle and red thick ring.<sup>9</sup> This proves that “Sustainable business model” and “Exploring different firm profile” are the most active and lasting themes in EI research. In comparison, Cluster #4 and Cluster #5 formed and became active later, but the trough time came earlier. It can also be considered that the research heat on “Environmental protection intensity” and “Indian industries” of SMEs has been

<sup>9</sup> A circle with a citation ring is used to indicate the cited reference or author. The color and thickness of each ring should correspond to the amount of heat and reference of the time slice. Therefore, a thick red circle indicates the corresponding reference or the author's high citation (Chen et al., 2010).

**Fig. 14** Document co-citation clusters network



**Fig. 15** The timeline of document co-citation clusters from 1997 to 2021



reduced. While Cluster #2 and Cluster #6 are formed lately, they keep active in the whole period. Besides, the literature of Cluster #7 is cited by other clusters (there are a lot of connections with other clusters in Fig. 16, reflecting its

characteristics of cross-subject research hot spots. It can be inferred that “Green product innovation,” “Circular economy,” and “Green electricity” are three hot topics in this field. Although there are not many previous studies on open

innovation (OI) represented by Cluster #11 combined with SMEs' EI, besides they last for a short time and seem to be fading now. However, considering that OI is a major focus of innovation theory in recent years, and that the traditional research objects of OI are mainly large enterprises rather than SMEs (Chesbrough 2006; Laursen and Salter 2006), it can be considered that OI still has the potential to be combined with SMEs' EI in the future. Just as OECD (2010c) claimed that EI could break through the boundaries of traditional innovative organizations involves a wider range of social arrangements, thus triggering changes in existing social and cultural norms and institutional structures.

### Author cluster analysis

Results of author clusters analysis are presented in Fig. 16 and Table 8 below. Based on the author clusters analysis, this paper has the potential to examine the frontier of relevant research from another perspective. Except for some clusters directly related to this domain, the largest ones are Cluster #0 and Cluster #4, which represent “Environmental dynamism” and “Adoption determinant,” respectively, and are related to the drivers of SMEs' EI. Even though many themes seem to break through the scope of traditional EI, Cluster #6 referred to open innovation, which proves the above judgment that SMEs' EI can be combined with OI from another perspective.

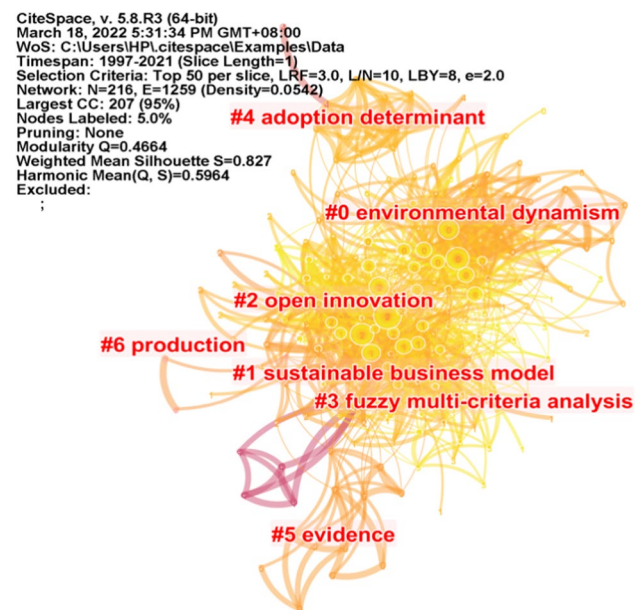


Fig. 16 Author co-citation clusters network

**Table 9** Keyword co-citation clusters of SMEs' EI research (1997–2018)

Cluster ID	Size	Silhouette	Mean year	Cluster Label (LLR)
#0	33	0.725	2015	Environmental innovation
#1	31	0.454	2016	RFID adoption
#2	27	0.681	2015	Corporate social responsibility
#3	25	0.655	2016	Entrepreneurial orientation
#4	17	0.678	2015	Sustainable growth
#5	16	0.564	2017	Green innovation
#6	10	0.853	2016	Green electricity

### Keyword cluster analysis

As presented in Table 9 and Fig. 17 below, there are 7 keyword co-citation clusters, and each cluster, with its label, ranking and size are worthy of attention in the same way as the DCA and ACA mentioned above. For example, Cluster #2, ranked first and labeled as “Corporate social responsibility (CSR),” covers the objectives, methodology, and short- and medium-term outcomes of the transboundary network project, which aims to clarify the complicated relationship between CSR, innovation, and performance in SMEs. However, this theme is still consistent with the concept of drivers to SMEs' EI. Similarly, Cluster #4, whose themes include “Sustainable growth,” also falls within the category of drivers.

Besides, Cluster #6 is concerned with “Green electricity,” which demonstrates a fundamental role in SMEs' EI. In addition, it is noteworthy for Cluster #1, whose label is “RFID adoption.” Compared with the above ACA and DCA themes, they have made breakthroughs, indicating that the existing literature expands the focus of SMEs' EI to the fields of technological innovation.



Fig. 17 Keyword co-citation clusters network



**Table 10** Main results of knowledge base, research frontiers, and future directions in SMEs' EI

	Theme	Method	Characteristics
Knowledge bases	Drivers, performance, financial performance...	SEM, other statistical test method...	Strong burst around 2014
Research frontiers	Absorptive capacity, supply chain management, environmental performance, China, economy...	PLS-SEM...	More correlation and adaptation to the newest status
Future directions	Innovation barriers, innovation paradigm, innovation category, measurement, process and output...	Inter-regional, Inter-institutional, Inter-disciplinary	

## Discussion

Concluded from the above results from the scientometric analysis, an abundance of new findings in this domain have been drawn, which are hard to find in previous reviews, but are helpful to discuss the questions mentioned in the “Introduction” section more objectively.

We can get quite rich and diversified scientometric results, which reflect that since the concept of EI was put forward by Fussler and James (1996), its combination with SMEs has been increasingly expanded and deepened, and relevant research is still developing and deepening. To be easily understood for our readers, we summarized them in three dimensions in Table 10, namely, the research theme, research method, and research characteristics in the knowledge base, research frontiers, and future research directions in SMEs' EI.

For a better understanding of answers made for the three questions mentioned in the Introduction by our scientometrics analysis, we answer by interpreting knowledge base, research frontiers, future research directions, and so on in Table 10 one by one.

### (i) Knowledge bases

An inference can be drawn about the content and method of EI research according to the co-citation analysis of documents, authors, and journals in this paper; findings reveal that there are a diversified of themes on the intellectual base of SMEs' EI, which includes drivers of EI, Porter hypothesis, and performance for research theme, structural equation model (SEM), and other statistical test methods for research method. There was a strong burst in the amount of literature around 2014, which can be seen in Fig. 2, and this can be explained by the co-citation analysis of authors in Fig. 4 and Table 2, which indicates that researches of Porter Me and Klewitz draw so much attention around 2014. So, this made a milestone contribution to the knowledge bases in this field.

According to the co-authorship network of countries (regions), institutions, and authors, the European and American countries, research institutions, and authors are major contributors in this domain, since the top ten countries and

their rankings have little change. But at the same time, a growing number of academics from developing countries are entering this field with samples and papers from their regions. As a result, the research topics on SMEs' EI are more diversified than before, which in turn attracts more scholars' attention and makes future research directions more possible.

### (ii) Research frontiers

A research frontier is inspired by its knowledge bases and conducted by the research object from all the time. We can draw a panorama by the timezone of co-occurring keywords to track the hot research topic dynamically in past 25 years. The newest research frontiers in recent 3 years are, on the one hand, reflect the novelty of the research. For example, “China” and “Economy” as co-occurring keywords in 2021 are responses to the newest status under the COVID-19 pandemic. And the PLS-SEM method is an improved research technique to expand theoretical research by exploring existing theories to better understand its increasing complexity (Hair et al., 2019). Consequently, as an improvement of research methods, it can adapt to the rapid growth of SMEs' EI.

On the other hand, the research frontiers are logically consistent with the previous knowledge base. It can be seen from the above analysis that the knowledge bases in this field mainly focus on practical issues such as drivers (especially environmental regulation proposed in Porter hypothesis) and performance of EI. Today, these topics remain important research directions in this field and continue to expand horizontally into adjacent fields. As Cecere et al. (2020) focused on the interaction between public funding and the internal and external lack of funding, which can be regarded as a new way of driving the ability of SMEs to introduce EI. As for the performance, it can be incorporated into practical actions together with concepts such as CE (Circular Economy), and the in-depth research on its threshold effect is also advancing (Demirel and Danisman 2019). Researches of environmental performance are recent frontiers following performance (S. K. Singh et al., 2020; Zhang and Wei, 2021), and literature concerned on absorptive capacity and

supply chain management are responses to the circumstance of open innovation accordingly (Arora et al., 2020; Miroshnychenko et al., 2021).

### (iii) Future research directions

As mentioned above, drivers and performance are typical research focus in this domain, which can be subdivided into more subdomains, and a growing number of research methods are being applied in this field, driving the depth of the research to become more sophisticated. However, according to the analysis results of this paper, barriers, as an important factor hindering SMEs from carrying out ecological innovation, seem to have not received enough attention from existing research. Therefore, it will be a direction worthy of further exploration. Besides, a single type of research on the eco-innovation performance for SMEs is scarcely executed as we noted in “Co-occurring keywords,” so it is noteworthy to put more eyes on this subdomain.

We also perceived a general lack of reflection on the innovation paradigm through the scientometric analysis, and a paradigm is a recognized model or pattern which is shared by the research community (Kuhn 1962). Due to this shortcoming, this paper believes that the future development of EI needs to pay more attention to the innovation paradigm, which has been focused substantially in some kinds of literature.

For example, empirical research on open innovation of SMEs is still lacking (Popa et al. 2017). Since longer cooperation can increase the research output of a single author or institution in this field as mentioned above, it is suggested that researchers focus more on open innovation which has a variety of choices to combine with SMEs' EI. One solution might be to extend the collaboration period between institutions and increase the number of partners. However, future research directions on SMEs' EI are still worthy to be further explored, but cannot be completely and explicitly inferred by the scientometric analysis.

As for the upcoming research framework in this field, future studies may concentrate more on the category, process, and outcome of SMEs' EI, which are concluded from our manual review but not typically in **co-occurring keywords** analysis above. Take the category of SMEs' EI for instance. Kemp and Arundel (1998) firstly declaimed that eco-innovations can be implemented from three aspects: technology, organization, and marketing. Since then, there have been very few studies on the definition, comparison, and integration of the category of SMEs' EI. Only a few pieces of literature on the specific category of innovation can be retrieved.<sup>10</sup> In consequence, directions for future

research are suggested to consider the application of sustainable product development (Bocken et al. 2014b), eco-design (Santolaria et al. 2011), environmental management (Gonzalez-Moreno et al. 2016), green practices throughout the supply chain, and cleaner production (Gupta and Barua 2017; van Hoof and Lyon 2013), which can be performed by SMEs from different countries and regions.

Furthermore, we can also make further exploration from the front end to the terminal end of SMEs' EI, which logic is based on the innovation process. Up to the front end first, there are a lot of existing researches on the drivers of SMEs' EI. Studies show that many factors play an important and special role in promoting eco-innovation, and these factors can be divided into the national level (Cecere and Mazzanti 2017), industry (or market) level (Bozic and Botric 2017; Saez-Martinez et al. 2016), and corporate level (Bliesner et al. 2014; Bocken et al. 2014a; Cecere et al. 2020). The future research direction can do further in-depth research on the mechanism and interrelationship of these levels of drivers. Besides, research on obstacles mainly focuses on the enterprise levels. There are few studies from the industry and government level. Future research can focus more on these two aspects.

Last but not least, the research on the outputs of EI also has a lot to learn. De Jesus Pacheco et al. (2018) pointed out the important role of EI in the circular economy (CE), and characterize CE-inducing EI in terms of targets, mechanisms, and impacts. Following this train of thought, the impact and mechanism of SMEs' EI on circular economy is a direction worthy of in-depth study.

In terms of research methods, many quantitative research tools are used to study the problems in a specific innovation field. However, through our scientometric analysis, it is suggested that cross-regional and cross-disciplinary research perspectives should be given priority to promote the future advancement of research methods. It is also reasonable to expect that this kind of research will promote the progress of related research methods in this field.

Inter-regional and inter-institutional collaborative research is an important driving force for the continuous expansion and renewal of research results in this field. This point is verified by our specially designed co-authorship analysis listed above. To be detailed, as shown in “Network of institutions/faculties and countries/regions,” changes in the centrality rankings suggest that researchers can consider two different directions. If they want to get more attention for their research in this field, they should consider more co-authorships in top-ranked countries or regions (such as England, France, and the USA) and carry out research with them. On the contrary, if researchers want to broaden their visions and look for underperformers, they should incorporate the knowledge of authors from low-ranking countries

<sup>10</sup> For instance, research on the “industrial symbiosis” of small and medium-sized enterprises, can be classified as SME's organizational innovation.

(e.g., Romania, Slovenia, Slovakia), which can be the basis for new research directions.

At the same time, researches based on different disciplinary backgrounds make it possible for research of SMEs' EI to produce more fruitful results in the future. With the increasing diversity of research topics, interdisciplinary research will undoubtedly be more valuable and easier to produce breakthroughs. Past studies in this field are mainly based on limited disciplines, and this can be concluded from the analysis of co-occurring subject categories. So, scholars may consider more in-depth research from an interdisciplinary perspective. For example, Innovation Geography is based upon geography and concerned with the spatialities of economic novelty (Boschma & Martin, 2010). And spatial econometrics can be used to deal with things of specific spatial characteristics, such as spatial dependence and spatial heterogeneity (Anselin, 1988; Lesage and Pace, 2009). Consequently, they are all new interdisciplinary perspectives in this domain, which were hardly seen in the past.

Finally, our research also provides some important inspirations for the development of eco-innovation strategies by the management of SMEs. The first practical meaning is that the EI strategy of SMEs should encourage the development of knowledge management towards a more open direction, that is, open innovation. Second, some themes in this domain need a further step, such as innovation performance, which could be measured and improved in practice to improve the relevant study in the future. Third, the practical field of SMEs' EI is extended more than before as the service sector is included; however, a further attempt to more domains is certainly to be encouraged.

## Conclusions and limitations

In this paper, based on the scientometric method of "Citespace," we use the scientometric techniques, including co-citation analysis, co-author analysis, and co-word analysis, to explore the 749 articles collected from the WoS core collection for a comprehensive and deep interpretation of the current and trend in this domain.

Based on the above analysis, main results are drawn, concluded, and suggested to reply to three questions mentioned in "Introduction," which are a beneficial revelation and research enlightenment to government departments, international organizations, academic institutions, and enterprises, thus allowing them to systematically exploring future research and practical paths.

However, there are still some limitations in this study worth exploring. First, cognition of SMEs' EI and the definition of related concepts are still in development. The retrieval terms in this paper may be omitted, which may

result in the failure of the relevant literature to be included (false negative) or the selection of irrelevant literature with low correlation (false positive). Second, selected literature is mainly based on the WoS core collection database, which may cause the omission of important literature (Halme and Korpela, 2014).

**Acknowledgements** We would be grateful for any helpful comments, and any remaining errors are the joint responsibility of the authors.

**Author contribution** Yongzhe Yan: methodology, software, funding acquisition, writing — original draft. Yufeng Chen: conceptualization, data curation, funding acquisition, writing — review and editing. Jiafeng Miao: visualization, methodology.

**Funding** This study was supported by National Natural Science Foundation of China under grant nos. 72174180 and 71673250, Zhejiang Provincial Natural Science Foundation for Distinguished Young Scholars under grant no. LR18G030001, Major Projects of the Key Research Base of Humanities Under the Ministry of Education under grant no. 14JJD790019, Zhejiang Provincial Philosophy and Social Science Planning Project under grant nos. 22QNYC13ZD and 21NDYD097Z, Ningbo Soft Science Research Project under grant no. 2021R027, and research project of College of Science and Technology, Ningbo University, under grant no. YK202005.

**Data availability** Available.

## Declarations

**Ethics approval and consent to participate** All content is subject to ethical approval and consent to participate.

**Consent for publication** We all agreed to publish this manuscript.

**Competing interests** The authors declare no competing interests.

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