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Open Innovation for Sustainability or Not: Literature Reviews of Global Research Trends

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Abstract: The demand for innovative approaches applied to productive sectors is a reality present in the circular economy and open innovation is a relatively new concept that has revolutionized the literature about innovation management. Since the concept appeared in 2003, many articles have focused on its development and application. Although some studies have connected open innovation with sustainability, the relevance of this current on the global literature about open innovation is still unidentified. In this context, this paper tries to cover this gap with a bibliometric analysis focused on the evolution of the open innovation paradigm and the relevance of sustainability in this field of research. A sample of 3087 papers published between 2003 and 2019 in the Scopus database was obtained. The analysis revealed the main topics and the most prolific journals, authors, institutions, and countries, in terms of productivity, citations, and h-indexes. Besides of these contributions, keywords analysis reveals that, in recent years, *sustainability* and *ecosystems* are decisive variables in open innovation research.

Keywords: open innovation; sustainability; keyword analysis; Scopus

Citation: Payán-Sánchez, B.; Belmonte-Ureña, L.J.; Plaza-Úbeda, J.A.; Vazquez-Brust, D.; Yakovleva, N.; Pérez-Valls, M. Open Innovation for Sustainability or not: Literature Reviews of Global Research Trends. *Sustainability* **2021**, *13*, 1136. https://doi.org/10.3390/su13031136

Academic Editor: JinHyo Joseph Yun
Received: 17 December 2020
Accepted: 19 January 2021
Published: 22 January 2021

1. Introduction

The demand for innovative approaches applied to productive sectors is a reality present in the circular economy, and open innovation is a relatively new concept that has revolutionized the literature about innovation management [1–3].

Since the introduction of the term open innovation in 2003 by Henry Chesbrough [4], it has gained increasing popularity among scholars in the field of innovation management due to the competitive and globalized environment in which innovation takes place [5,6]. Companies can no longer innovate on their own, and they have to collaborate with other parties while participating in a cocreative process. During this process, information and knowledge flow back and forth between the economic and social environment, which enables the company to gain new competitive advantages [7–9].

This idea of collaboration connects open innovation with sustainability, which calls for the need of a more coordinated and collaborative effort under the framework of open innovation [10–13]. More and more scholars are calling for further efforts to work in collaborative networks in the field of innovation, which will guide firms towards enhancing sustainability and getting positive results when facing sustainability problems [10–12,14–20]. Rupo et al. [17] believe that the innovation process must be characterized by sustainability and according to [21] (p. 476), "through OI, companies can leverage knowledge management to an asset that promotes sustainable innovation in terms of a social, environmental

(or ecological), and economic point of view." The increasing importance of the connection between open innovation and sustainability also becomes evident in the public sphere, where institutions and organizations encourage collaborative innovation by cofunding innovative projects aimed at the achievement of sustainability and competitiveness through the establishment of networks [17].

Although extensive research has helped to develop the concept and the different implications of open innovation, this field of research has just begun, specifically regarding sustainability problems. The main objective of this paper is to explore the evolution of the literature on open innovation and to analyze the relevance and growth that sustainability issues have had in this field of research over the last several years. To this end, a bibliometric analysis was carried out after obtaining a sample of 3087 publications from the Scopus database, synthesizing the available knowledge on open innovation and the subsequent appearance of sustainability issues in this literature from the first article in 2003 to the last complete year, 2019.

In this paper, Section 2 offers a review of the literature regarding the open innovation paradigm and its connection with sustainability problems. The data and methodology are presented thereafter. Section 4 shows the results and discussion of the analysis before the main conclusions are presented in Section 5.

2. Literature Review

2.1. Open Innovation Literature

Over the years, innovation has brought about increasing interest among scholars and it has been studied by different disciplines and from several perspectives [5,22–24]. In the field of business, innovation is understood, according to OECD [25], "as the implementation of a new or significantly improved product (good or service) or process, a new marketing method, or a new organizational method in business practices, workplace organization, or external relations." Innovation is considered by scholars to be an important asset for organizational construction and strategic maintenance, enhancing the competitive advantage of companies and ensuring their sustainability and economic success [12,26]. Without innovation, businesses would probably disappear [27].

With increasing competitive and globalized conditions driven by innovation [5], businesses can no longer consider innovation the result of isolated contributions, but rather of a cocreative process with knowledge circulating within the economic and social environment [8]. Organizations need to make innovation available to all active parties in the process. To do so, the collaborative side of innovation in the form of the open innovation phenomenon is used and an emerging field of research has gained popularity in innovation management as a result [5,6].

Although the concept of open innovation is deep-rooted [5], this field of research has attracted increased attention in academic fields [14] since the term open innovation was created. Henry Chesbrough conceptualized the key differences between the traditional closed model of innovation and the open innovation model in 2003 while coining the concept. Chesbrough [28] (p. 24) defined open innovation as "a paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms look to advance their technology." This definition opposes traditional "closed" innovation, where firms can rely on their internal research and development efforts [4].

Since Chesbrough's first definition of open innovation, the concept has been further described by several authors who have introduced new notions [29–34]. For instance, Chesbrough and Bogers [34] (p. 13) referred to open innovation as "a distributed innovation process based on purposively managed knowledge flows across organizational boundaries, using pecuniary and nonpecuniary mechanisms in line with the organization's business model." However, the most frequently used definition of the term is "the use of purposive inflows and outflows of knowledge to accelerate internal innovation and to expand the markets for external use of innovation, respectively" [29] (p. 1).

If companies want to make innovation open to other parties, such as firms, customers, suppliers, universities, or competitors, they cannot innovate only within themselves anymore, despite their previous efforts to do so in research and development [6,32,35–37]. In this sense, companies collaborate to have access to new knowledge and additional resources that promote endless innovation and new competitive advantages for the company [7,9].

Open innovation is a recognized and complex research field with multiple facets due to the inherently dynamic process it entails. It is also considered a multi-level phenomenon [14,38]. Open innovation research is undergoing rapid development [14], which is easily demonstrable by looking at the rising number of research publications and special issues released in journals [7]. However, in the words of Lopes and de Carvalho [5] (p. 1), it "has only just begun."

2.2. Economics Environments in Open Innovation Paradigm

A relevant issue in the open innovation literature is the context of its application and the importance it has been having in the economic environments where it is developed. Thus, the connection between open innovation processes and the economic environment where they take place plays a key role in the empirical application of the open innovation paradigm [39–44]. From the economic environments' perspective, a crucial issue is how open innovation contributes to development through efficiency improvements or increasing the value of activities, which can be generated with these practices in the economic field, in general, and the industrial field, in particular [39].

Additionally, extant research has connected this paradigm with economic environments in different ways. These works have contributed to the open innovation trend and have emphasized the importance and applicability, through its connection with the fourth industrial revolution [39], the creation and appropriation of knowledge-related open innovation with digitalization/broadband networks [40], the entrepreneurship effect and, particularly, high-tech start-ups [42], the open science with its social contract and contributions for society [43], the power of data as crucial tool for increasing the corporate profits [44], or the human ingenuity and transformation processes dedicated to sustainability [41].

2.3. Open Innovation and Its Connection with Sustainability

As mentioned before, open innovation entails that the company is more and more influenced by external stakeholders and their behavior [11]. Therefore, stakeholders transfer their ideas and knowledge inside the innovation process of the company, which generates a need for coevolution between technological innovations and social innovations [45]. This would allow to address sustainability issues beyond the firm boundaries, reaching the stakeholder's environment as they come into play [11,46]. This process innovation process would help to address other challenges such as the growth limits of capitalism [47] that suppose the necessity to explore the responsibility and cooperative model [11,48], as well as, the development of an entrepreneurial role with the environment [49], developing new business models adapted to open innovation [18].

Sustainability problems have become crucial in recent years due to the global concern about the impact that businesses can have on resources, the environment, and society [12]. Sustainability brings inherent degrees of uncertainty, complexity, and big challenges compiled by the United Nations in the Sustainable Development Goals (SDGs) [13,50].

The significance of innovation in achieving a higher sustainability of companies and environmental improvements has been widely discussed in the literature [11]. However, the focus and mechanisms of innovation have shifted to the community [51]. Thus, to face sustainability problems, many scholars have called for a more coordinated and collaborative effort to ensure business sustainability and continuity through flexible, dynamic, and open platforms [10–13]. The European Union has taken action in this direction. In 2010, the EU launched the Innovation Union as one of seven emblematic initiatives of the Europe 2020 Strategy to achieve a smart, sustainable, and inclusive economy [26]. In

2015, the European Commission set open innovation as one of the three goals for the European Union research and innovation policy, an initiative to promote new technology and business models [52].

Research has shown that working in collaborative networks efficiently distributed across different organizational functions and technical fields of expertise [53] contributes to the achievement of sustainable competitive advantages [54,55], while boosting innovation and performance [54,56]. Consequently, as Nunes and Abreu [57] stated, one of the greatest benefits of managing open innovation projects correctly is the positive impact in economic, social, and environmental sustainability [16]. That is why open innovation may play a relevant role towards an effective, strategic, and sustainable management [21]. In addition, recent research reveals the importance of developing and combining both internal and external knowledge to improve innovations related to sustainability, that is to say, green open innovation [3].

Yun et al. [19,49,58,59] added an additional vector in open innovation research known as open innovation dynamics. As they explain, open innovation leads "self-sustainable system dynamics by creating a platform through a feedback loop" (p. 2), where a new business model is constantly created during the process [60,61]. Consequently, these system dynamics can be considered the driving force of sustainable growth and development, specifically for economic systems or sector-based innovation [47,59].

3. Data and Methodology

Bibliometric analysis is a common method used to measure several aspects of scientific production by applying statistical and mathematical techniques to review scientific literature. This methodology allows the study and analysis of scientific activity through the so-called bibliometric indicators, which are measurements that provide information on the results of scientific activity in all of its expressions. Since their introduction by Garfield in the mid-20th century [62], their use has become widespread and has contributed to the re-evaluation of data in multiple scientific fields [63–70], while supplying numerous databases for researchers.

The objective of this study is to show the dynamics of the general research on the open innovation paradigm and to analyze its evolution and its relation to issues about sustainability. For this purpose, a quantitative bibliometric analysis was carried out to identify, arrange, and evaluate the trends of this topic of research.

There are currently different sources of data in the scientific literature (Google Scholar, PubMed, Scopus, and Web of Science) with different approaches in the research fields and tools for data analysis. However, Elsevier's Scopus is a multidisciplinary database that contains an extensive summary of global research. It is one of the main archives of literature that uses peer review as a method of validation of scientific research. Scopus has a simple interface and intelligent tools for the analysis and visualization of research and it helps in the process of graphing the data through software such as VOSviewer [71].

Consequently, we made an exhaustive search of all the papers published in the Scopus database prior to 2020 containing the term open innovation to scrutinize the subfields of title, abstract, and keywords in all publications available until 2020. The period sample covered 17 years from the first article published on the subject (2003) to the final year (2019). The search was carried out in July, 2020, and included research articles, books, and book chapters. A final sample of 3087 documents was obtained and more than 80% of those were research articles. We used the same criteria to conduct a search in the Web of Science to see the publications available in this database. As a result, we only obtained 2433 documents, thus reinforcing the suitability of the Scopus database to have a more reliable sample, including emerging journals with valid contributions to this field. From this sample, those articles that contained the keyword sustainab* gave us a subsample of 121 studies that discuss both the open innovation phenomenon and sustainability issues and concerns. The variables analyzed in the study were year of publication, subject area, journal, author, author affiliation, country, institution, and keywords appearing in the publication.

In this research, the indicators analyzed were the yearly distribution of published documents, as well as the productivity of the authors, countries, and research institutions. Figure 1 shows the steps followed during our research on open innovation.

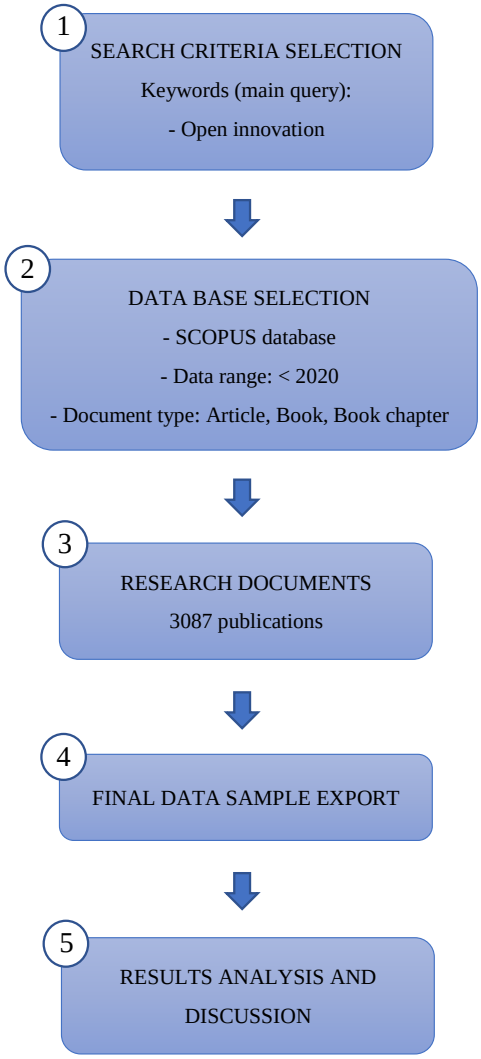

Figure 1. Methodology flow chart.

Several quality indicators were used to assess the impact of the different agents in the field of research. Among these were the h-index, which detects the most prominent authors in the field according to the citations of their scientific papers, the number of citations, and the 2019 SCImago Journal Rank (SJR) Indicator, which measures the quality of the scientific journals included in the Scopus database [72,73].

The links between authors, research institutions, and countries were measured using some network indicators, such as the analysis of coauthorship through processing tools and network maps of known reliability and suitability for bibliometric analysis. The keyword analysis detected present and possible future research topics or concerns through the analysis of co-occurrences. This is possible given that scientific papers can be reduced to a set of joint occurrences between the words appearing in each article. For the analysis of these network indicators, the VOSviewer software tool (version 1.6.10., Leiden University, Leiden, the Netherlands) was used. This tool provides data on interactions and content evaluation to measure research network activities [74,75].

The results obtained in this study are highly valuable for researchers, scholars, policymakers, and others concerned given the widespread repercussions of the scientific literature evaluated within the field of research on society.

4. Results and Discussion

This section develops an analysis of the scientific literature on the open innovation concept, its evolution, and lately the joint consideration and appearance with environmental and sustainability issues from 2003 to 2019. In addition, authors, research institutions, and countries were analyzed regarding their contribution to this field of research. Finally, an analysis of the keywords of the sample of articles is presented, allowing the detection of research lines and their evolution during the period of study.

4.1. Evolution of Scientific Production

Table 1 shows the main characteristics of the research on open innovation from 2003 to 2019. The period studied covers 17 years structured in three different periods each comprising 6 years of scientific production (except for the last one that comprises 5 years).

Table 1. Major characteristics of the scientific production from 2003 to 2019.

Year	A	AU	C	TC	TC/A	J
2003	1	1	1	1458	1458	1
2004	4	3	1	368	92	4
2005	9	12	6	1044	116	7
2006	14	31	7	3563	255	7
2007	39	55	11	1963	50	33
2008	51	89	23	2463	48	44
2009	91	192	26	5284	58	63
2010	153	309	35	7478	49	94
2011	206	444	35	7075	34	94
2012	189	412	39	3699	20	127
2013	294	753	44	5188	18	169
2014	261	606	44	4260	16	160
2015	282	767	56	3692	13	175
2016	319	781	54	2785	9	188
2017	370	917	56	4016	11	214
2018	368	952	64	1532	4	203
2019	436	1156	67	398	1	226

A: number of articles; AU: number of authors; C: number of countries, TC: total citations in articles; TC/A: total citations per article; J: number of journals.

This field of research has grown in interest since Chesbrough [4] first contribution in 2003 (In 2001, Chesbrough attended an OECD Conference where he presented the concept that would later be released on his first published article. This is actually the first reference appearing in databases [76].). Henry Chesbrough coined the term *open innovation* and laid the foundation for future developments in relevant literature. During the first period (2003–2008), 118 articles were analyzed, most of them within the last 2 years and representing 3.8% of the total production (3087). From 2009 to 2014, 1194 articles were published (38.7%), and in the last period analyzed (2015–2019), 1775 articles were registered (57.5%). This evolution of the scientific production is reflected in the average number of published articles, which goes from 20 annual publications in the first period to 199 in the second period, and 355 articles per year during the final period. Sustainability-related papers in open innovation experienced a boost over the final years studied. During the first period, just 3 articles were published, representing 2.5% of the subsample. From 2009 to 2014, 24 papers were found (19.8% of the subsample), while in the last period 94 articles were published, thus counting for almost 77.7% of all papers about sustainability and open innovation. Looking at the average number of published articles, these publications went from 0.5 annual articles published within the first period to 4 annual articles in the

second period, and 19 articles per year during the last one. This shows the evolution of sustainability-related open innovation scientific production.

Research on open innovation has burgeoned since 2009, with a variation percentage of 912% concerning articles published in the previous period. This exponential growth may have been influenced by the change in the way businesses manage innovation, which has shifted from closed innovation to the open innovation paradigm [26]. The emergence of new topics, such as management and networking and the focus on value chain stakeholders rather than on customers [38] may have also contributed to the growing interest in this field of research. Some issues on open innovation were reported in journals, such as *The R&D Journal, Research Policy*, and *Management Science* [5]. The European Union (EU) launched the Innovation Union as one of the seven emblematic initiatives of the Europe 2020 Strategy in 2010 (See more: https://ec.europa.eu/research/innovation-union/pdf/innovation-union-communication_en.pdf (Accessed 21 July 2020).) to achieve a smart, sustainable, and inclusive economy [26]. This initiative may have also contributed to the number of publications on this topic. In the last period analyzed, scientific production kept increasing mostly due to the importance of sustainability issues in the field of research and studies on environmental concerns, as will be shown in following sections.

A similar growth trend regarding the rest of analyzed variables can be observed. The articles analyzed in the sample obtained were written by 5877 authors. During the first period (2003–2008), 179 authors were identified, a number that increased in the following periods. From 2015 to 2019, this number increased to 3839, which represents 65% of the total sample of scholars contributing to the scientific production in the period of study. This increase is expressed in the average number of authors per article, which goes from 1.6 in the first period to 2.6 in the final period, demonstrating the increased interest that this phenomenon has aroused in scholars. The number of authors publishing in this field of research has increased at a higher rate during the last period analyzed than the number of published articles.

Data show that there were 94 countries involved in open innovation production from 2003 to 2019. In the first period, up to 23 countries were identified, up to 44 in the second, and up to 67 countries collaborated in the scientific production on open innovation during the final period.

In the first period studied (2003–2008), 10,859 citations were counted, mostly due to the relevant and radical contributions of the first publications on open innovation in the research field. The second period (2009–2014) counted 32,984 citations, representing almost 60% of the total citations. The previous figure shows that period of study was the most remarkable in terms of valuable and interesting developments for scholars. The final period (2015–2019) included 12,423 citations, which represents 22% of the total. The average number of citations per article decreased from 337 (2003–2008) to 32.5 (2009–2014), and then to 7.6 (2015–2019). This trend is probably a result of the first and ground-breaking publications about open innovation, which laid the foundations for subsequent publications.

The total number of journals with articles published about open innovation is 1076. The first period featured 76 journals, which represents 7.1% of the total journals. This compares to 64.6% of the 695 journals in the final period studied. The average number of articles published per journal goes from 1.2 to 1.8, again illustrating the increased interest researchers have had in this field over time.

Figure 2 shows the annual number of articles and the percentage of variation during the period studied. The blue line, which indicates the number of articles published, represents the increase in interest seen in this field of research. The first year that exceeds 100 articles is 2010, with 153 documents. This number almost doubled in just 3 years (294 publications in 2013) and reached a milestone at that point. Despite a slight decrease in 2014, the number of publications has not stopped growing and it is expected to continue, given the high interest in maintaining the development of the open innovation concept and its connection with sustainability-related issues.

The orange line represents the variation percentage in the number of articles and shows the changes experienced in scientific production throughout the period studied. The highest growth percentage of 300% was seen from 2003 to 2004 due to the four articles that came after the first groundbreaking publication about open innovation. The second-highest value took place in 2007 with a variation percentage of 179%. During this year, the number of published articles increased from 14 to 39. Finally, the year 2014 stands out for posting the greatest percentage decrease in the number of publications in the period analyzed (−11.2%).

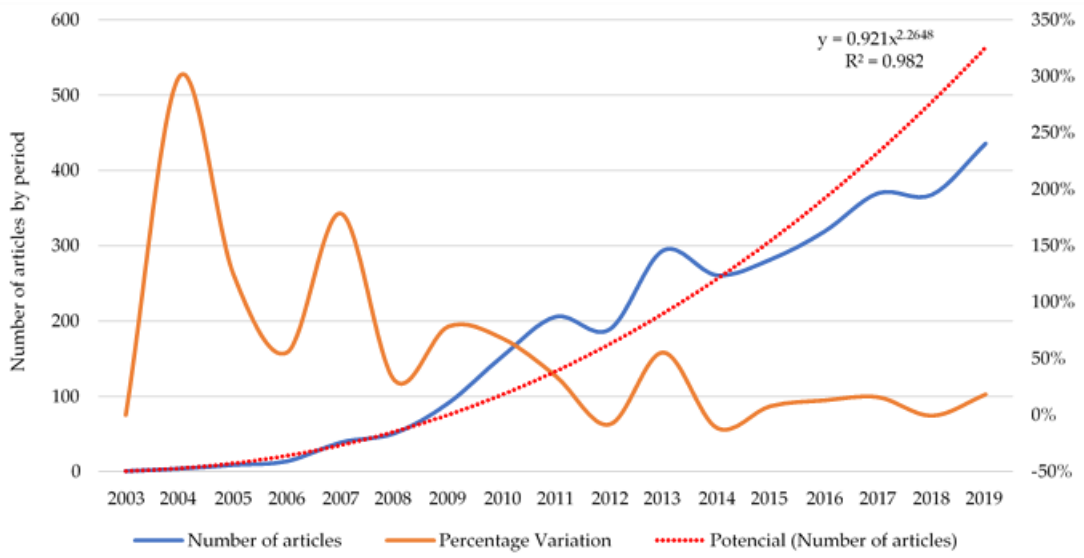

Figure 2. Comparison between the number of articles published, their variation percentage and potential function.

4.2. Analysis of Scientific Production by Subject Area

The Scopus database enables the classification of articles into different subjects according to their topic and the angles of analysis proposed. In this case, the sample of 3087 articles obtained was classified into 26 thematic areas.

Figure 3 shows the evolution of the five main categories in which the articles about open innovation (including the ones related with sustainability) are framed. The most significant subject area is Business, Management, and Accounting, which includes 2020 articles and represents 36% of the total sample. In this category, more than half of the articles are classified due to a direct relationship between the field of study and the subject area, since the open innovation paradigm has been mainly studied in relation to firms, their dynamics and the processes associated. This is also because of the main classification of the most important and prolific journals that have awakened an interest in publishing about the concept. Economics, Econometrics, and Finance occupies the second position with 638 articles (11.3%), and it was not until 2013 that it gained relevance in the field and established itself in this spot. The subject of Social Science came in third place with 618 articles while representing 11% of the total sample. Since 2017, this third-place finisher has surpassed the second-place category. This may be due to the increase of sustainability-related publications in the last several years, which are usually categorized within the subject of Social Sciences.

The Engineering (559 articles) and Computer Science (464 articles) categories hold the fourth and fifth position, respectively, and both represent 18.2% of total scientific production. These five categories include 4299 articles, which is 76.4% of the production categorized in all thematic areas identified. It is typical that the number of articles in subject areas exceeds the number of the analyzed sample (3087) since each article can be classified into one or more thematic area depending on author and journal preferences.

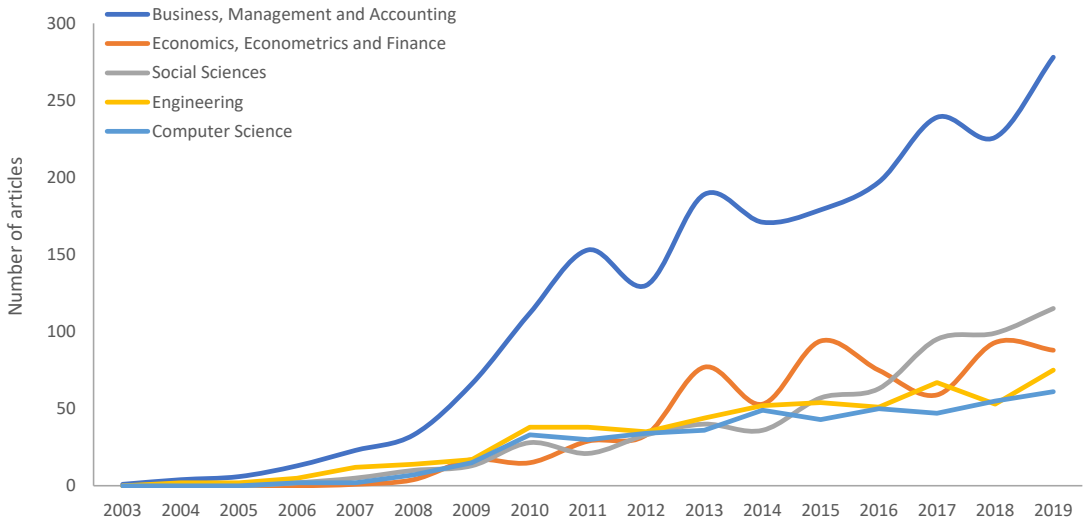

Figure 3. Comparisons of growth trends in subject areas in research by years.

4.3. Identification of the Most Prolific Journals

The articles of our sample were published by 1076 international journals. Table 2 shows the 20 most prolific journals, which comprise 855 articles and represent 27.7% of the total sample due to the high number of journals choosing at least one publication on open innovation. Additionally, some important characteristics of the journals are detailed, such as the number of articles published, the h-index of the journal [77], the quartile occupied in the SJR indicator [78], or the country. The most important characteristics of the published articles are also presented, such as the total number of citations received [79], the average number of citations per article, the h-index, or the period of publication. It is remarkable that more than half of the journals (60%) belong to the first quartile of the SJR indicator. Even though they are published in different countries, those of European origin prevail (16), standing out the journals from the United Kingdom (11). Countries with the most prolific journals in open innovation are included among global leader economies in innovation, and they are listed in The Global Innovation Index by the World Intellectual Property Organization (WIPO). In the 2019 top-three ranking per region are the United States (1st) in North America, Switzerland (1st), and the Netherlands (3rd) in Europe (Germany has the fourth position and the United Kingdom becomes the third in 2020); Singapore (1st) in South East Asia, East Asia, and Oceania; and Chile (1st) in Latin America and the Caribbean.

Table 2. The most active journals from 2003 to 2019.

Journal	A	TC	TC/A	Ha	Hj	SJR (Q)	Country	R(A)		
								03–08	09–14	15–19
Journal of Open Innovation Technology Market and Complexity	75	633	8.44	15	20	0.780 (Q1)	Switzerland	0	0	1 (75)
International Journal of Innovation Management	68	922	13.56	18	39	0.491 (Q2)	Singapore	39(1)	1(30)	4 (37)
Sustainability Switzerland	63	304	4.83	11	68	0.581 (Q2)	Switzerland	0	0	2(63)

Table 2. *Cont.*

Journal	A	TC	TC/A	Ha	Hj	SJR (Q)	Country	R(A)		
								03–08	09–14	15–19
Technological Forecasting and Social Change	62	1282	20.68	24	103	1.815 (Q1)	United States	0	11(14)	3(48)
Research Policy	58	5946	102.52	36	224	3.246 (Q1)	Netherlands	3 (6)	3 (28)	8 (24)
International Journal of Technology Management	48	1086	22.63	21	54	0.410 (Q1)	United Kingdom	8 (3)	2 (29)	16 (16)
Technology Analysis and Strategic Management	47	640	13.62	18	64	0.627 (Q2)	United Kingdom	0	9 (18)	5 (29)
R&D Management	45	5150	114.44	28	99	1.249 (Q1)	United Kingdom	2 (6)	6 (23)	17 (16)
Research Technology Management	44	1392	31.64	17	63	0.837 (Q1)	United Kingdom	1 (7)	4 (26)	25 (11)
Technovation	42	4268	101.62	29	121	2.795 (Q1)	United Kingdom	17 (2)	5 (25)	20 (15)
Creativity and Innovation Management	39	1241	31.82	20	55	0.970 (Q1)	United Kingdom	4 (5)	12 (13)	11 (21)
European Journal of Innovation Management	39	1196	30.67	18	57	0.678 (Q2)	United Kingdom	22 (1)	10 (14)	6 (24)
Journal of Product Innovation Management	32	1621	50.66	21	135	3.128 (Q1)	United Kingdom	14 (2)	16 (11)	12 (19)
Management Decision	32	625	19.53	15	91	0.862 (Q1)	United Kingdom	9 (3)	33 (5)	7 (24)
Journal of Technology Management and Innovation	31	338	10.90	11	25	0.212 (Q3)	Chile	0	8 (18)	22 (13)
International Journal of Business Innovation and Research	29	190	6.55	9	19	0.290 (Q3)	United Kingdom	0	13 (12)	15 (17)
Journal of Business Research	26	300	11.54	10	179	1.871 (Q1)	Netherlands	0	44 (4)	9 (22)
Journal of the Knowledge Economy	26	375	14.42	9	23	0.576 (Q2)	Germany	0	22 (7)	13 (19)
International Journal of Innovation and Technology Management	25	150	6.00	7	17	0.258 (Q3)	Singapore	38 (1)	18 (10)	21 (14)
Journal of Knowledge Management	24	338	14.08	13	106	1.752 (Q1)	United Kingdom	0	114 (2)	10 (22)

A: number of articles; TC: total citations for all articles; TC/A: number of citations per article; Ha: Hirsch-index in this topic; Hj: Hirsch-index in journal; SJR (Q): SCImago Journal Rank (Quartile); R: rank position by the number of articles published.

The Journal of Open Innovation: Technology, Market and Complexity leads this ranking. It is the most recent journal. It appeared in 2015 and reached the first position with the highest number of articles (75), all of them published during the final period (2015–2019). It has obtained 633 citations and an h-index of 15 in articles. Regarding quality, it is included in the first quartile with a punctuation of 0.780 in SJR. The first article published by this journal in the field of open innovation was "Demand articulation in the open-innovation paradigm" [80], in 2015.

The second most prolific journal is the International Journal of Innovation Management, with 922 citations and an average number of 13.56 citations per article. This Asian

journal, which is positioned in the second quartile, has an h-index of 39 and a SJR indicator of 0.491. Its first article on the topic was published in 2008, and since then, it has published 68 articles on open innovation. It was ranked 39 in the first period (2003–2008) when its first article was published, reaching the fourth place in 2015–2019, with 37 articles, and taking over the first position in the second period. This journal has achieved a huge success.

Sustainability (Switzerland) is the third journal in this ranking by number of articles published. This was the last journal to publish articles on open innovation and its first publication on the topic was "Open innovation in value chain for sustainability of firms" [81] in 2017. Despite this, it ranks second in the last period (2015–2019) with just 2 years of publications about open innovation (63). It is positioned in the second quartile with an SJR indicator of 0.581 and an h-index of 68. This journal has published the most papers including sustainability concerns (almost 30% of the sustainability-related articles) and is followed by Journal of Cleaner Production and Journal of Open Innovation: Technology, Market and Complexity. This subject has awakened the interest of many journals and most in this subsample have one or two publications in the matter. The fifth position is occupied by Research Policy, which stands out for having the highest values on most indicators. With 58 articles published, this Dutch journal has 5946 total citations, 102.52 citations per article on average, an h-index per article of 36, an h-index of 224 for the journal, and a punctuation in the SJR indicator of 3246 (first quartile). It is the only journal in the ranking that remained within the top 10 journals during all the three sub-periods of study.

Finally, it is worth noticing that journals that were in the first and second positions in the ranking during the first period (2003–2008), Research Technology Management and R&D Management (the second highest regarding the number of citations), now occupy very low positions in the table (25 and 17, respectively). On the other hand, journals such as Technological Forecasting and Social Change, European Journal of Innovation Management, Management Decision, or Journal of Business Research have reached higher positions during the studied periods. This may indicate that journals with higher focus on technology and research and development are giving way to journals with a multi- and interdisciplinary approach. Journals that consider social and environmental notions seem to have the highest number of publications on the topic in recent years.

It is remarkable that, by 2019 and during the last period, the second journal with the most articles published on the topic is one aptly called Sustainability. According to its site, it is "An international, cross-disciplinary, scholarly, peer-reviewed, and open access journal of environmental, cultural, economic, and social sustainability of human beings," [82] and it is completely focused on being an advanced forum for studies related to sustainability and sustainable development. This fact shows the relevance that new research that links open innovation to sustainability issues has in recent literature.

4.4. Productivity of the Most Prolific Authors

Table 3 shows the 10 most relevant authors in the scientific literature on open innovation, who have recently introduced the relation of this concept with sustainability issues. The main characteristics, such as published articles, total citations, average citations per article, or h-index [83], are also listed in the table. Authors of European origin, four of them from Italy, dominate the ranking (8 out of 10). In addition, most of the authors in this ranking have published articles in the last year analyzed (2019), and each of them have publications in the final period analyzed (2015–2019), which indicates that they continue to have great interest in this line of research.

Table 3. The most relevant authors by number of articles (2003–2019).

Author	A	TC	TC/A	Institution	Country	1st A *	Last A *	h-Index *
Lichtenthaler, U.	35	2229	63.69	International School of Management (ISM)	Germany	2006	2016	22
Chesbrough, H.	27	3491	129.30	UC Berkeley Haas School of Business	United States	2003	2019	17
Lazzarotti, V.	26	345	13.27	Università Carlo Cattaneo	Italy	2010	2019	11
Vanhaverbeke, W.	25	2005	80.20	Universiteit Hasselt	Belgium	2008	2019	15
Bogers, M.	22	672	30.55	Københavns Universitet	Denmark	2011	2019	13
Frattini, F.	22	1054	47.91	Politecnico di Milano	Italy	2009	2019	14
Pellegrini, L.	21	276	13.14	Università di Pisa	Italy	2010	2019	11
Yun, J.H.J.	20	448	22.40	Daegu Gyeongbuk Institute of Science and Technology	South Korea	2012	2019	12
Manzini, R.	19	309	16.26	Università Carlo Cattaneo	Italy	2010	2017	11
Mortara, L.	18	302	16.78	University of Cambridge	United Kingdom	2010	2018	9

A: number of articles; TC: number of citations; TC/A: number of citations per article; 1st A: first article; Last A: last article; h-index: Hirsch-index; (*): in this research topic.

The leading author is Ulrich Lichtenthaler. He is affiliated with the International School of Management (ISM) at the University of Applied Sciences in Germany. This author started publishing papers about this topic in 2006, and he has the highest number of articles (35) and h-index (22) with the second highest number of citations (2229). His most popular work is "A Capability-Based Framework for Open Innovation: Complementing Absorptive Capacity," [84] which was published in 2009 and has been cited 447 times.

Henry Chesbrough is one of the most important authors on open innovation. He is the author with the longest research career, coining the concept of open innovation in his first publication "The Era of Open Innovation" in 2003 [4]. He is affiliated with the UC Berkeley Haas School of Business and, although he is second in the ranking of the number of articles published (27), he stands out for having the highest number of total citations (3491) and average number of citations per article (129.3). This is because he has the record number of citations in a single article, 1458 with his first publication on this field of study. Chesbrough also has the second-best h-index with a value of 17. This author signs his articles with two different names (Chesbrough, H. and Chesbrough H. W.), and we unified the information of both signatures to provide accurate data about the author.

Wim Vanhaverbeke is fourth in this ranking of articles published, but he has the second highest number of average citations per article (80.2) and the third highest number in total citations (2005) and h-index (15). This author is affiliated with the Universiteit Hasselt in Belgium, and he began to get published as a contributor to this topic in 2008, near the end of the first period of study. He has ranked among the most prolific authors due, in part, to his most popular article "Open Innovation in SMEs: Trends, Motives and Management Challenges" [85] published in 2009 in Technovation, which had received 970 citations by 2019.

The rest of the authors have similar characteristics. All but one has published between 18 and 22 articles, the exception being Lazzaroti, with 26. They all have total citations in the range of 270–670, except for Frattini, who has 1054. These authors all have an h-index between 9 and 14, and they come from diverse places. Four of them are Italian, one is Danish, one is South Korean, and another is British.

Only two of the top 10 most prolific authors have publications that consider sustainability issues. The South Korean author JinHyo Joseph Yun was the first in 2016 with the article "Not Deep Learning but Autonomous Learning of Open Innovation for Sustainable Artificial Intelligence" [86]. The next most prolific author published about sustainability is the Danish Marcel Bogers. He is fourth in our ranking despite only having one article published on the topic in 2019, "Linking Stakeholder Engagement to Profitability through Sustainability-Oriented Innovation: A quantitative Study of the Minerals Industry" [87]. Of the authors in our sample with publications about the relationship between open innovation and sustainability concerns, the most prolific is Kyung Bae Park (collaborator of Yun, J.H.J.), with 6 articles published between 2016 and 2019. These articles were published in the journals ranking first and second in the last period studied. These include Journal of Open Innovation: Technology, Market, and Complexity, and Sustainability (Switzerland) [86,88–92].

Figure 4 was made with the VOSviewer tool. It represents the collaboration network between the main authors. Authors in close proximity within the diagram have closer collaboration and the size of the bubble indicates the relevance of the author within the network of collaboration. Four main collaborative groups have been found, each one led by one of the four most relevant authors per number of papers and citations. These authors are presented in Table 3, Vanhaverbeke (purple), Chesbrough (red), Frattini (blue), and Yun (green). In some of the groups, the country or region of origin appears to determine the collaboration. For instance, most of the authors of the green network are from South Korea and those of the blue network are from Italy.

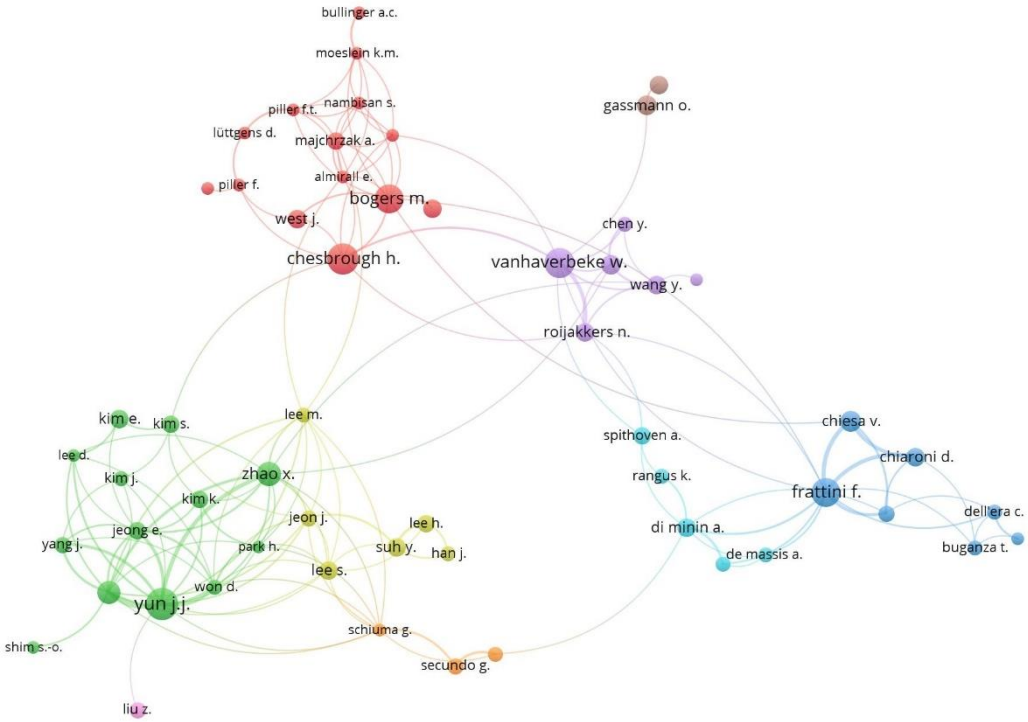

Figure 4. Network of cooperation based on coauthorship of the main authors.

Lichtenthaler, despite being the most relevant author in our ranking, does not appear in Figure 4 because he works primarily on his own. He rarely collaborates with other authors, but when he does, they are usually from the same institution. It can be noted that Chesbrough has collaborated with Vanhaverbeke on several occasions. Vanhaverbeke has also worked with Frattini, which illustrates that authors in this field of research collaborate and connect within networks. Bogers is another important author within the red network,

and he is one of the most recognizable authors (after Chesbrough) for its research focused on open innovation.

4.5. Identification of the Main Research Institutions

Out of more than 3000 identified institutions, Table 4 illustrates the 10 research institutions with the highest scientific production in this field of research. Most of these institutions are in Europe, with two in Germany and one each in Finland, Italy, the Netherlands, and the United Kingdom. Two institutions are in the United States and one is in South Korea. The table also shows some data related to citations and collaboration parameters for each of the institutions.

Lappeenrannan Teknillinen Yliopisto (LUT University) [93] is the institution that heads this ranking. Although it has the highest number of articles (48), it does not have the best values regarding the rest of the parameters. The collaboration rate of this Finnish institution is 35.4%, meaning that it has had 17 articles published in collaboration with institutions from other countries. It has more citations in national articles than in those with international coauthorship (13.45 and 9.71, respectively).

Politecnico di Milano, due to its high number of articles (46) and other good numbers, occupies the second position. This Italian institution has 1596 citations, the fourth highest value, and an average of 34.7 citations per article, and the highest h-index (19). In addition, it has a collaboration index of 32.61%, and it has more citations in international articles (35.2) than those produced nationally. Federico Frattini, one of our top 10 most prolific authors, is affiliated with this institution. His projects and papers may have influenced these metrics for the Politecnico given his collaboration capacity (see Figure 4 above) and citations in relevant articles.

Table 4. Characteristics of the most outstanding institutions.

Institution	Country	A	TC	TC/A	h-Index	IC (%)	TCIC	TCNIC
Lappeenrannan Teknillinen Yliopisto	Finland	48	582	12.125	14	35.42%	9.71	13.45
Politecnico di Milano	Italy	46	1596	34.70	19	32.61%	35.20	34.45
University of California, Berkeley	United States	33	2040	61.82	17	69.70%	11.70	177.10
Wageningen University & Research	Netherlands	32	634	19.81	14	34.38%	16.09	21.76
Technical University of Munich	Germany	31	2225	71.77	17	38.71%	77.42	68.21
University of Cambridge	United Kingdom	31	645	20.81	14	38.71%	14.92	24.53
Aalto University	Finland	30	505	16.83	13	53.33%	24.06	8.57
UC Berkeley Haas School of Business	United States	29	2137	73.69	16	62.07%	16.33	167.55
Daegu Gyeongbuk Institute of Science and Technology	South Korea	29	510	17.59	13	27.59%	10.63	20.24
Friedrich-Alexander-Universität Erlangen-Nürnberg	Germany	28	391	13.96	10	46.43%	24.08	5.20

A: number of articles; TC: total citations for all articles; TC/A: total citations per article; h-index: Hirsch index in this research topic; IC: percentage of articles made with international collaboration; TCIC: number of citations in articles with international collaboration; TCNIC: number of citations in articles without international collaboration.

The University of California, Berkeley, and the Haas School of Business (the United States) stand out for having the highest index of international collaboration at 69.7% and 62.07%, respectively. Both have the highest values in average citations in national articles at 177.1 and 167.5, respectively. Regarding total citations, they are close to the top with 2040 and 2137 citations in their 33 and 29 respective articles published. In addition, UC Berkeley Haas School of Business has the highest value of average citations per article with

73.7 citations. It must be noted that Henry Chesbrough is affiliated to this institution, thus influencing its high numbers.

Finally, the Technical University of Munich occupies the fifth position in the ranking. This German institution stands out for having the highest value in total citations with an average of 71.8 citations per article. Its collaboration rate is around 39% with 12 articles published in collaboration with other countries and an average of 77.42 citations in articles with international coauthorship, which is higher than those citations on national articles (68.21).

Of the 10 institutions analyzed, six have the highest average number of citations in articles prepared nationally. This indicates that, at the institutional level, most of the relevant studies and important contributions to literature on open innovation are created without international collaboration.

Although not among the most outstanding institutions on open innovation research, the institution that has more publications about open innovation in joint consideration with sustainability concerns is Sangji University (South Korea) with 6 articles. This is because, it is the academic institution of Kyung Bae Park, the most prolific author in this subject mentioned in the previous subsection. This institution is followed by Yonsei University (South Korea), the National Institute of Advanced Industrial Science and Technology (Japan), Hanbat National University (South Korea), and the Daegu Gyeongbuk Institute of Science and Technology (South Korea), which have 4 articles each.

4.6. Characteristics of the Most Relevant Countries

Table 5 shows the 10 most prolific countries in relation to the number of articles published. The main characteristics defining the productivity of these countries are collected, such as the articles published, the total citations, the h-index, or the period of time in which the articles were published. Of the 92 countries identified in the sample, the scientific production of the first 10 countries accumulates 2469 articles, which represents 80% of the sample analyzed. Only 80 papers were published during the first period (2003–2008), increasing to 953 articles in the second period and reaching 1436 publications over the last 5 years.

Table 5. The most relevant countries by number of articles (2003–2019).

Country	A	TC	TC/A	h-Index	R(A)		
					2003–2008	2009–2014	2015–2019
The United States	450	14,761	32.80	55	1 (28)	1 (183)	1 (239)
The United Kingdom	357	9650	27.03	47	3 (17)	3 (157)	3 (183)
Germany	353	8664	24.54	47	2 (22)	2 (157)	4 (174)
Italy	322	5275	16.38	42	8 (3)	4 (104)	2 (215)
Spain	221	4114	18.62	36	0	5 (84)	5 (137)
Netherlands	160	5312	33.20	36	5 (5)	6 (83)	10 (72)
South Korea	160	2828	17.68	25	0	13 (34)	6 (126)
Sweden	153	3599	23.52	30	10 (3)	7 (70)	9(80)
China	150	837	5.58	16	0	14 (33)	7 (117)
France	143	1775	12.41	21	14 (2)	9 (48)	8 (93)

A: number of articles; TC: total citations for all articles; TC/A: number of citations by article; h-index: Hirsch index in this research topic; R: rank position by the number of articles published.

Of the top 10 countries of our sample, the United States is the most productive with 18.2% of the relevant articles, and it has remained at the top during the whole period analyzed with 28, 183, and 239 articles published in each subperiod, respectively. This country also has the best numbers in total citations (14,761) and h-index in the researched topic (55). The two most prolific institutions, University of California, Berkeley, and UC Berkeley Haas School of Business, as well as the most productive author, Chesbrough, in the researched field are from the United States (see above). This may have influenced the

results for the country. In addition, the United States stands out for having published the articles with the highest number of citations in each one of the periods analyzed.

During the first period (2003–2008), Chesbrough's article "The Era of Open Innovation" [4] was published, and it obtained the record of citations in a single paper with 1458. The article "How Open is Innovation?" [32] was released during 2009–2014, and it received 1150 citations. The article "Smart Tourism: Foundations and Developments" [94] was published during the final period (2015–2019) and reached 344 citations.

The United States is followed by the United Kingdom (14.5% of the scientific production in this field), Germany (14.3%), Italy (13%), and Spain (9%). In fact, the top 10 countries in open innovation research comprise mostly European countries (7), which makes this the leading region in open innovation research. Its dominance could have been influenced by the introduction of the Innovation Union in 2010 as one out of seven emblematic initiatives of the EU Europe 2020 Strategy [26] to achieve a smart, sustainable, and inclusive economy. In 2015, the European Commission promoted open innovation as one of the three main policy goals for EU research and innovation [52]. As a result, four of the five most prolific countries in this field of research are European.

Although the United Kingdom is second in our ranking of article volume (357) and of total citations (9650), it must be noted that it is the third country by average number of citations per article (27.03) and by number of articles in each of the periods analyzed. Germany surpassed the United Kingdom in the first two periods, with 22 and 157 articles, while Italy did the same between 2015 and 2019, with 215 publications.

The case of Italy deserves some attention. This country stands out for having the best trajectory throughout the periods analyzed, despite being in the fourth position in the general ranking with 322 publications, 5275 total citations, 16.38 average citations per article, and an h-index of 42, very close to the top 3 countries. Italy was in the eighth position from 2003 to 2008, climbed to the fourth position from 2009 to 2014, and reached second in the final period, going from three articles to 215 by 2019, at a growth rate of 7067%. National Italian incentives to create beneficial conditions for the creation and development of innovative start-ups launched between 2012 and 2016 may have influenced this trajectory [26].

The Netherlands occupies the sixth position, standing out for having the highest average number of citations per article at 33.2. However, it has been losing position in the rankings over the years, descending from the fifth (2003–2008) to the tenth position (2015–2019) despite an increase in the number of articles published (from 5 to 72, respectively).

South Korea and China are in the top 10 most prolific countries worldwide in open innovation research. South Korea accounts for 6.5% of the production in this ranking (160), having published most of its articles in the last period (126). The South Korean government has supported R&D since the 1980–1990s to produce technology and science capacity by developing industrial cities and technology and science parks [95]. This situation, along with significant investment from the private sector in collaborative research projects [25] may justify South Korea's position in the top 10 countries in the field of research.

China ranks ninth in Table 5, with a 6.08% of the production (150), and it published most of its articles between 2015 and 2019 (117). China's position could be due to its global aspirations to develop an innovative economy, which is featured by efforts to improve businesses innovation, such as technology patents [96], alliances [97], and outward FDI [98].

Regarding the articles treating sustainability issues, the most productive country is Italy with 16 publications, although South Korea holds the first position in the ranking of institutions. Instead, this country occupies the second position with 15 articles published, followed by the United States with 13 contributions, Germany with 12, and the United Kingdom with 10 publications. In the top 10 of sustainability-related papers on open innovation, we can also find Australia, Brazil, and Spain with 6 publications each. These countries do not appear in the top 10 most productive countries on open innovation research.

The 10 countries from Table 5 have contributed to scientific production via partial collaboration with other countries and articles with domestic and international coauthorship. Therefore, Table 6 shows the main figures on collaboration between countries. The United Kingdom has the highest percentage of collaboration with 55.74%. It is followed by France (53.2%), the Netherlands (48.1%), and the United States (47.8%). The countries listed in Table 6 have the highest average number of citations in those articles produced with international collaboration. The one exception is the United States, which has a higher number of average citations in national articles (32.2 and 33.3, respectively).

Table 6. The most prolific countries and the international collaboration (2003–2019).

Country	NC	Main Collaborators	IC (%)	TC/A	
				IC	NIC
The United States	37	United Kingdom. Germany. Sweden. Spain. Italy.	47.78%	32.23	33.33
The United Kingdom	42	United States. Italy. Germany. Spain. France.	55.74%	28.21	25.55
Germany	39	United States. United Kingdom. Switzerland. Netherlands. Austria	38.24%	26.13	23.56
Italy	29	United Kingdom. Spain. United States. France. Sweden.	31.68%	24.15	12.78
Spain	32	United Kingdom. Belgium. United States. Italy. Netherlands.	42.08%	32.61	8.45
Netherlands	35	Germany. Belgium. United Kingdom. Spain. United States.	48.13%	33.49	32.93
South Korea	19	United States. United Kingdom. Australia. Malaysia. Germany.	23.13%	28.89	14.30
Sweden	27	United States. United Kingdom. Germany. Italy. Switzerland.	46.41%	29.39	18.44
China	22	United Kingdom. United States. Hong Kong. Taiwan. Australia.	36.00%	10.87	2.60
France	36	United Kingdom. Germany. Italy. United States. Canada.	53.15%	17.20	6.99

NC: number of collaborators; IC (%): percentage of articles made with international collaboration; TC/A: number of citations by article; IC: number of citations by articles with international collaboration; NIC: number of citations by articles without international collaboration.

The United Kingdom is also first regarding the number of collaborators (42). The United States, Italy, Germany, Spain, and France are the main countries that cooperate with the United Kingdom in scientific production.

The countries closest to the United Kingdom, regarding the number of collaborators, are Germany (39), the United States (37), France (36), and the Netherlands (35). Germany has 39 collaborators, the second highest number, and a collaboration rate of 38.24%. It shares authorship mainly with the United States, the United Kingdom, Switzerland, the Netherlands, and Austria.

Spain stands out with the greatest difference between the average number of citations in national articles (8.45) and international articles (32.61) and for having a relatively high percentage of collaboration (42.08%). Its main collaborators are the United Kingdom, Belgium, the United States, Italy, and the Netherlands.

With the exception of the United States, which is the most relevant and productive country in open innovation research, European countries collaborate mainly within themselves.

Figure 5 shows the international collaboration and interaction between the most prolific countries. The colors of the circles differentiate the collaboration groups and its size represents the scientific production of each country. In addition, the closer the countries appear in Figure 5, the more frequent their collaboration. There are 52 countries shown in the cooperation map based on the coauthorship of their writers, having taken into account only the countries that have a minimum of five publications on open innovation. VOSviewer software has grouped them into nine clusters, in various sizes.

The United States, the United Kingdom, and Germany are the three most productive countries regarding the number of publications, citations, and collaborations. They also appear as the most frequent partners in open innovation research and fall in the center of the map. These three countries lead their own collaborative network. Spain, Italy, and South Korea have their own group of collaboration.

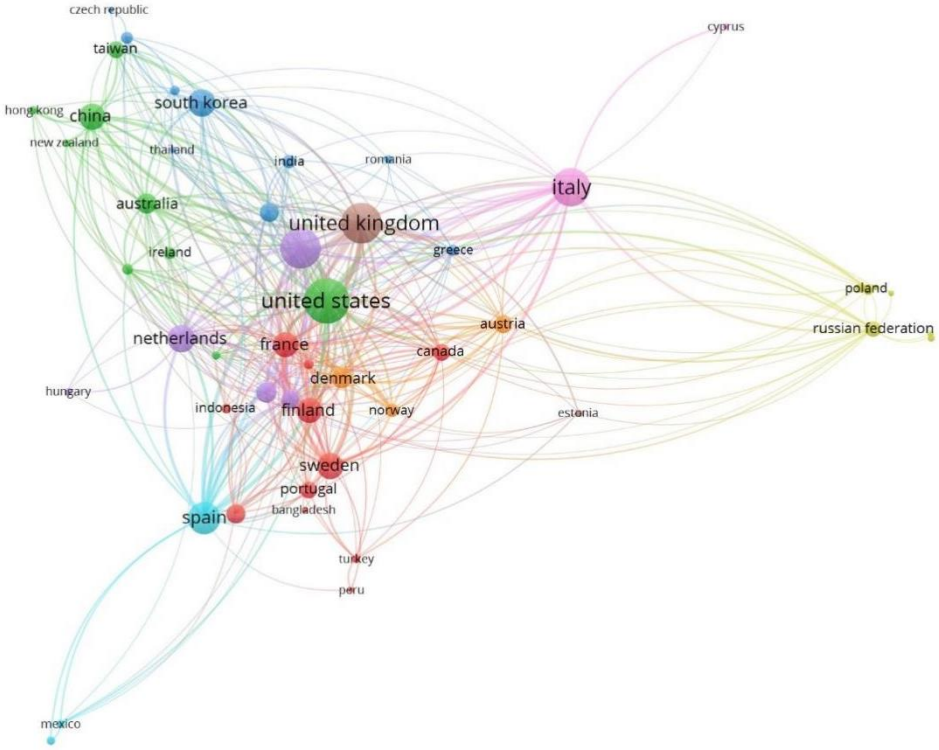

Figure 5. International cooperation based on coauthorship between countries from 2003 to 2019.

The first cluster (red) is the biggest group and it comprises 11 collaborating countries. Sweden, France, and Finland lead this group. It also includes Bangladesh, Brazil, Canada, Indonesia, Luxembourg, Peru, Portugal, and Turkey. The three leading countries boast the scientific production of 642 articles, which represent 20.8% of the sample analyzed.

The second cluster (green) is led by the United States. This group includes Australia, China, Hong Kong, Ireland, Israel, New Zealand, Singapore, and Taiwan. They account for 793 articles, which represent 25.7% of the sample.

The third cluster (blue) is led by South Korea and includes the Czech Republic, Greece, India, Japan, Malaysia, Romania, Thailand, and the United Arab Emirates. The countries in this cluster have produced 365 articles, which represent 11.8% of the total research activity.

The Russian Federation leads the fourth cluster (yellow), which includes Iran, Latvia, Poland, Serbia, Slovenia, South Africa, and Ukraine. This group accounts for 139 articles, which represent 4.5% of the total sample.

The fifth cluster (purple) is led by Germany. This collaborative group includes only European countries: Belgium, Hungary, the Netherlands, and Switzerland. These five countries have published 634 articles, which represent 20.5% of the research activity. This is one of the strongest groups as all of its members are in the center of the map with heavy relation with other clusters.

Spain is the leader of the sixth cluster (cyan), which also includes Colombia and Mexico. This group is composed of Spanish-speaking countries that have contributed to the field of study with 249 publications representing 8% of the sample.

The following cluster (orange) has three members. It is led by Denmark and includes Austria and Norway. These three European countries account for 183 articles, which represent 5.9% of the total production.

The last two groups are the smallest in our study with only two members each. The eighth cluster (brown) is led by the United Kingdom, which collaborates with Estonia. This group has published 365 articles that represent 11.8% of the total research activity. Finally, cluster nine (pink) is made up of Italy and Cyprus, the former leading the group. The two of them have published 324 articles, which represent 10.5% of the total scientific production.

It is noteworthy that, despite being in the smallest clusters, the United Kingdom, Spain, and Italy have been very productive and they have collaborated with two countries or less. They have led the scientific production with the most publications in their respective groups.

4.7. Analysis of Keywords

The sample of 3087 articles contains 9856 keywords. Table 7 shows the 24 most used keywords in open innovation research. Keywords indicate the subject of study in a given article and help to gather information about the line of research. The keyword *open innovation* has not been included in the sample as it could distort the interaction between the rest of the keywords and could lead to incorrect interpretations.

Table 7. Main keywords from 2003 to 2019.

Keyword	2003–2019		2003–2008		2009–2014		2015–2019	
	A	%	R (A)	%	R (A)	%	R (A)	%
Innovation	823	26.66%	1 (27)	22.88%	1 (351)	29.40%	1 (445)	25.07%
Knowledge management	137	4.44%	9 (7)	5.93%	3 (61)	5.11%	3 (69)	3.89%
Crowdsourcing	133	4.31%	0	0.00%	5 (47)	3.94%	2 (86)	4.85%
Research and development	105	3.40%	35 (3)	2.54%	4 (48)	4.02%	7 (54)	3.04%
Industry	91	2.95%	16 (4)	3.39%	2 (78)	6.53%	168 (9)	0.51%
Product development	88	2.85%	3 (11)	9.32%	6 (41)	3.43%	17 (36)	2.03%
Innovation management	87	2.82%	65 (2)	1.69%	10 (31)	2.60%	6 (54)	3.04%
Knowledge	84	2.72%	19 (4)	3.39%	20 (23)	1.93%	5 (57)	3.21%
Technology transfer	83	2.69%	8 (8)	6.78%	7 (41)	3.43%	20 (34)	1.92%
Collaboration	77	2.49%	46 (2)	1.69%	12 (30)	2.51%	10 (45)	2.54%
New product development	76	2.46%	32 (3)	2.54%	9 (35)	2.93%	14 (38)	2.14%
Absorptive capacity	74	2.40%	40 (2)	1.69%	17 (24)	2.01%	9 (48)	2.70%
Innovation performance	71	2.30%	0	0.00%	46 (14)	1.17%	4 (57)	3.21%
Innovation process	69	2.24%	17 (4)	3.39%	8 (36)	3.02%	26 (29)	1.63%
Competition	65	2.11%	15 (4)	3.39%	14 (27)	2.26%	19 (34)	1.92%
Commerce	61	1.98%	25 (3)	2.54%	16 (25)	2.09%	21 (33)	1.86%
Intellectual property	60	1.94%	11 (6)	5.08%	15 (26)	2.18%	28 (28)	1.58%
Cocreation	59	1.91%	45 (2)	1.69%	29 (17)	1.42%	12 (40)	2.25%
Sustainable development	54	1.75%	37(3)	2.54%	79 (11)	0.92%	13 (40)	2.25%
Technological development	52	1.68%	0	0.00%	30 (17)	1.42%	18 (35)	1.97%
Entrepreneurship	52	1.68%	57 (2)	1.69%	45 (14)	1.17%	15 (36)	2.03%
External knowledge	51	1.65%	26 (3)	2.54%	35 (15)	1.26%	22 (33)	1.86%
Open-source software	51	1.65%	76 (2)	1.69%	13 (28)	2.35%	44 (21)	1.18%
Sustainability	50	1.62%	442 (1)	0.85%	123 (8)	0.67%	11 (41)	2.31%

A: number of articles; R: rank position by the number of articles published; %: percentage over the total articles of the period.

Innovation is the most frequent keyword in the general ranking and in all the three periods of study. It appears in 823 articles, almost 27% of the total. Most of the articles containing the word innovation were published in the last two periods analyzed, 351 in the second and 445 in the third, which represent 29.4% and 25.07% of the scientific production in each respective period. This high number of occurrences can be explained because the search carried out in Scopus using open innovation as the main identifier already includes the word innovation.

Knowledge management ranks second while appearing in 137 publications, 4.4% of the total scientific production from 2003 to 2019. This term has been noted throughout the three periods analyzed, and it has climbed from the ninth position in 2003–2008 to the third position in 2009–2014, maintaining this position in the last period with 69 publications. These numbers are the result of the need to manage knowledge when collaborating with parties that are external to the company. Thus, within the open innovation process, the need to manage both internal and external knowledge becomes crucial [99].

Crowdsourcing, the third keyword in the list by number of occurrences (133), did not emerge until 2009–2014, when it occupied the fifth position. It was the second most used keyword in the period 2015–2019, appearing in 86 articles. It accounted for 4.85% of the total production in those years, the second highest percentage of articles in the last period analyzed. Along with crowdsourcing, the keywords collaboration and co-creation have also experienced an upward trend. Both started in the 46th and 45th positions, respectively, in the first period analyzed, jumping to the 10th (45 articles) and 12th positions (40 articles) in the ranking during the final period. These three keywords refer to the openness of the companies and the different forms of cooperation between partners needed to achieve the open innovation goals of a company. Their increasing use could be due to the boom experienced in communication and internet technology [26]. Through internet-based technology, firms can develop the interconnectivity needed to enhance the interactions with some external players, such as customers, partners, or the general public (crowdsourcing) [100,101].

Innovation performance is another keyword that emerged in the second period (2009–2014). It began in the 46th position (14 articles) and stepped up to fourth in the 2015–2019 ranking, appearing in 57 publications, 3.2% of the scientific production in this period. This increasing interest in researching the relationship between innovation performance and open innovation may be due to the fact that interacting with other firms and using external knowledge (consequence of open innovation processes) affect the innovation capability of companies [4].

Another keyword seeing escalated usage during the period of study is research and development. This keyword ranks fourth in the general classification, appearing in 105 articles, which represent 3.4% of the total. It started in the 35th position during the first period, stepping up to the fourth position in the second period, and ending in seventh place by 2015–2019 when it appeared in 54 publications.

Something similar happened with innovation management, absorptive capacity, and entrepreneurship, which occupied the 7th, 12th, and 21st positions in the general ranking, respectively. These keywords started in the 65th, 40th, and 57th positions in 2003–2008, appearing in just two papers each. They finished in the 6th, 9th, and 15th positions by the end of the period of study while being used in 54 (3%), 48 (2.7%), and 36 (2%) published papers. The three keywords are related and they refer to the innovation capacity of the firm [18]. They are also related to the previously mentioned concept of innovation performance. The study of these keywords has increased along with open innovation due to the importance of assimilating and acquiring external knowledge in this environment and applying it to internal technology and processes [102]. Absorptive capacity started to be used as a lens to analyze how firms could look for and integrate outside knowledge for open innovation [38,84]. Entrepreneurship brings about a culture of searching for new opportunities in technology or marketing, while generating the informational and collaborative climate needed in open innovation [103].

On the other hand, some keywords with a downward trend in research interest have been found throughout the years. This is the case of industry, product development, and technology transfer. Although they occupy the 5th, 6th, and 9th positions in number of occurrences, they have fallen from the 16th, 3rd, and 8th positions in the first period analyzed to the 168th, 17th, and 20th in the final period, respectively. In the case of industry, it is different because it improved to second in the ranking during 2009–2014, but it then plunged to the 168th position, while appearing in only nine articles during the final period. This may be due to the fact that research during the second period was mostly industry-oriented, while authors have focused more recently on knowledge and the materialization of collaboration. The infrequent use of product development and technology transfer may be due to the strong emphasis of old-school research on the firm-centric aspects of open innovation focusing on technology and its development as a strategic instrument enabling the inflow and outflow of knowledge [38].

It is remarkable how the keyword sustainability, despite being last in the general ranking and appearing in only 50 articles, has been climbing from the 442nd to the 123rd

position in the second period and to the 11th position by 2015–2019. It went from being in just one article, 0.85% of the scientific production in 2003–2008, to appear in 41 papers (2.3% of production). Likewise, sustainable development experienced significant improvement. It started in the 37th position in 2003–2008, appearing just in 3 articles, then dropped to the 79th position in the second period with 11 articles, and finally stepped up to the 13th position by 2015–2019, while being used in 40 publications representing 2.25% of the scientific production.

This shows that sustainability, sustainable development, and related issues have consistently increasing weight in open innovation literature and they are an important and relevant topic to consider when applying open innovation research. In this sense, the most relevant publication on open innovation and sustainability issues is the article by Lee, Hancock, and Hu "Towards an Effective Framework for Building Smart Cities: Lessons from Seoul and San Francisco" [104] released in 2014, which has achieved 285 citations.

Figure 6 shows the main keywords used throughout the period studied from 2003 to 2019, represented in four clusters that refer to different research lines in the field of study.

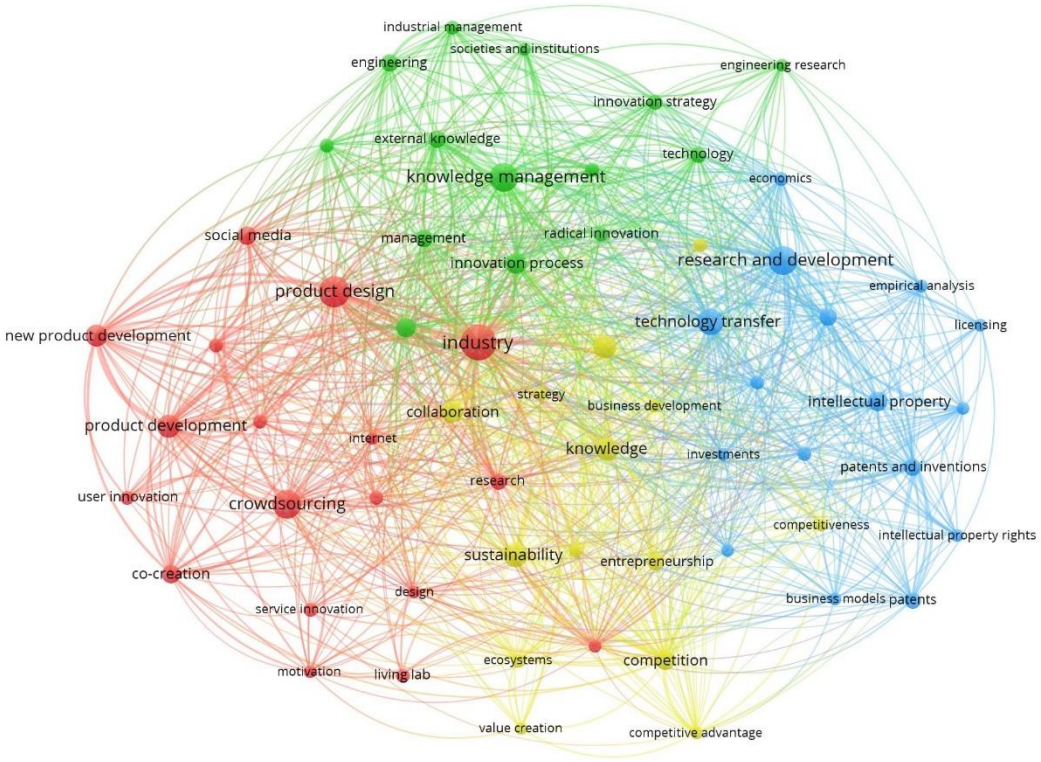

Figure 6. Main Keywords network based on co-occurrence from 2003 to 2019.

The first cluster (red) represents the keywords industry, product design, and crowdsourcing. This line of research is oriented on the analysis of product development within the firm and the different forms of collaboration with a special focus on industry analysis. Some of the most frequently used terms in this group are product development, co-creation, social media, new product development, and research and design. This cluster includes more than 500 publications (558). The most relevant authors within this trend are Frattini, F. (7), Bogers, M. (6) Majchrzark, A. (6), Brem, A. (5), and Chiesa, V. (5). The countries leading this line of research are the United States (103), the United Kingdom (70), and Germany (63). At a distance, Italy (58) and Spain (51) can be found. The most cited studies in this cluster can also be found among the most cited in the other clusters. This is the case of the article published in 2009 by Leimeister et al. [105], with 472 citations and appearing in the red and yellow clusters. The papers by Terwiesch and Xu [1] and Laursen and Salter [106] have been cited 438 and

337 times, respectively, and they appear in the green cluster as well. Finally, Henkel's 2006 article [107] appears both in the red and blue clusters with 401 citations.

The keyword knowledge management, which brings together terms such as innovation process, external knowledge, engineering, innovation strategy, and management, among others, leads the second cluster (green). This group is linked to the innovation capacity of companies, their absorptive capacity, and the management of knowledge from inside and outside the firm. This cluster includes more than 500 articles (503). The most relevant authors in this line of research are Lichtenthaler, U. (9), Bogers, M. (6), Enkel, E. (6), Frattini, F. (6), and Spithoven, A. (6). The countries leading this trend are the United States (71), Germany (69), and the United Kingdom (65), followed by Italy (53) and Spain (37). The most cited articles in this group, besides those shared in the red cluster, are "How Open Is Innovation?" by Dahlander and Gann [32], with 1169 citations, "Managing Open Innovation" by Chesbrough [108], cited 313 times and also appearing as among the most cited in the blue cluster, and article in 2008 by Tether and Tajar [109], with 296 citations, which also appears in the yellow cluster.

The third cluster (blue) is led by the term research and development. The fact that concepts such as technology transfer, intellectual property, patents and inventions, or investments are grouped illustrates the focus of this cluster on technology and intangible assets that firms can access and develop when collaborating with partners. This cluster is composed of more than 300 articles (312). The most relevant authors within this trend are Lichtenthaler, U. (11), Frattini, F. (6), Vanhaverbeke, W. (6), Bianchi, M. (4), and Cammarano, A. (4). The leading countries are the United States (66), the United Kingdom (48), Italy (33), Germany (32), and Spain (26). In addition to those articles shared with the red and green clusters, some of the most cited articles in this group are those of Lichtenthaler [33] and Chesbrough and Schwartz [110], with 345 and 240 citations, respectively. This cluster also includes the article by Schaffers et al. [111], which appears among the most cited articles of the yellow cluster, while being cited 573 times.

Finally, in the fourth cluster (yellow), the keywords knowledge, sustainability, collaboration, competition, and ecosystems are the most widely used. This cluster focuses on a wider research line that takes into account the relational nature of the firms with their surroundings where sustainability issues are key while dealing with partners and the environment. This cluster includes more than 300 articles (340). The most relevant authors within this trend are Bogers, M. (7), Park, K.B. (5), Majcchrzak, A. (4), Shim, S.O. (4), and Chesbrough, H. (3). The countries leading this trend are the United States (55), the United Kingdom (36), Germany (35), Italy (34), and Spain (24). The most cited articles in this cluster, besides those previously mentioned, are "Open Innovation in SMEs: Trends, Motives and Management Challenges" [85] and "Regionally Asymmetric Knowledge Capabilities and Open Innovation: Exploring "Globalization 2—A New Model of Industry Organization" [112], with 981 and 295 citations, respectively.

It must be noted that the most cited article of all time, written by Chesbrough in 2003 [4], does not appear in any of our clusters by keywords. This is due to the absence of keywords in this article in the Scopus database, which makes it impossible to be classified in any group.

To know the first concepts used in open innovation research and its evolution and to analyze the maturity in the period of 2003–2019, Figure 7 is presented below. Three periods can be distinguished: 2003–2013, 2014–2015, and 2016–2019. The color blue indicates the older terms used in literature, while yellow shows the most recent keywords that have appeared in the research field. Thus, research was focused on industrial management and the use and development of technology from 2003 to 2013 [92,93]. In this period, a great deal of attention was paid to companies, licenses, product development, and research and investments made inside the firm.

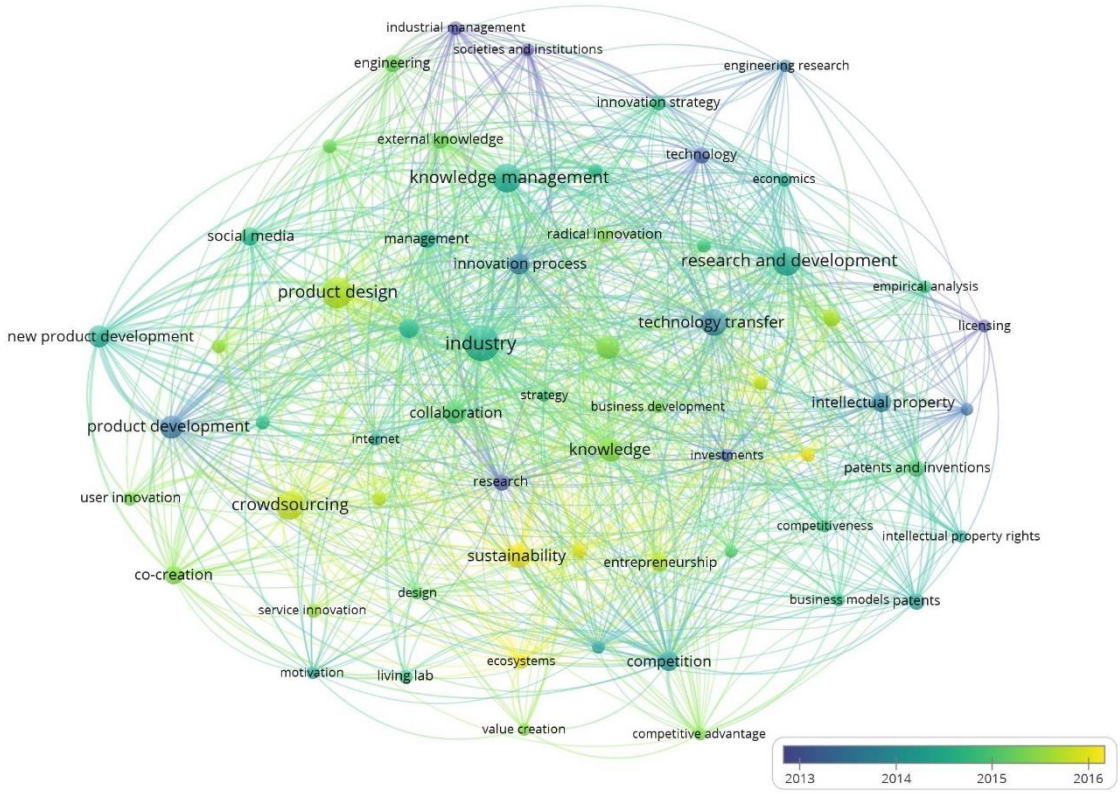

Figure 7. Evolution of main keywords network based on co-occurrence (2003–2019).

Articles were mostly industry-oriented and focused on knowledge management, research and development, innovation process, technology transfer, social media, and competition and new product development between 2014 and 2015. This was motivated by the emergence of communication and internet technology and the new emphasis on the outside environment of the firm for new product development and collaboration in R&D processes [106,113,114].

Finally, from 2016 to 2019, articles have featured new areas of study within the open innovation framework, such as crowdsourcing and product design that introduce other external elements fundamental to the strategies of firms [115,116]. Additionally, the latest concepts introduced (yellow) are sustainability and ecosystems, which indicate the recent concern about the environment and the environmental responsibility of the firm when collaborating in open innovation processes, thus becoming decisive variables to consider the improvement of current and future scenarios [12,117].

5. Conclusions

The main objective of this paper is to analyze and explore the evolution of open innovation literature and its relation with environmental studies while highlighting the relevance and evolution that sustainability issues have had in this field of research over the years. A bibliometric analysis of a sample of 3087 articles published between 2003 and 2019 was carried out using the Scopus database. To perform the analysis, some agents contributing to the field of study have been identified, such as the most relevant authors, institutions, journals, and subject areas where the articles are classified.

Since the first article published in 2003 by Henry Chesbrough, who coined the term open innovation, the number of scientific publications has increased, as illustrated in the study. This field of research has burgeoned since 2009, which caused a variation percentage of 912% with respect to the articles published in the previous period. More than half of the articles were published in the final 4 years analyzed (1775). This boost in production may be linked to changes in the researched topics, the appearance of new themes connected to

open innovation, the arrival of special issues related to open innovation, and efforts made by the European Union in 2010 and 2015 at the policy level.

The main subject area is Business, Management, and Accounting, grouping 36% of total production, followed by Economics, Econometrics, and Finance with 11.3%, and Social Science with 11%. The most productive journals on open innovation research are the Journal of Open Innovation: Technology, Market and Complexity, the International Journal of Innovation Management and Sustainability, with 75, 68, and 63 articles published, respectively. More than half of the journals analyzed (60%) belong in the first quartile (Q1) of Scopus.

The German author Ulrich Lichtenthaler, from the International School of Management (ISM) (University of Applied Sciences) is the author with the highest number of articles published (35) and with the highest h-index (22). However, it is Henry Chesbrough, with 27 publications, the author with the longest research career on open innovation, the highest values in citations (3491) and average citations per article (129.3). The most prolific institution in this field of research is the Lappeenrannan Teknillinen Yliopisto (LUT University) with 48 articles published, although the one with the most impact is the Technical University of Munich with 2225 total citations and an average of 71.8 citations per article. The most productive countries, ranked in order of importance, are the United States, the United Kingdom, and Germany. The United Kingdom is the most collaborative country in the production of scientific papers in this topic of research with the highest collaboration rate (55.7%) and number of collaborators (42).

Finally, these results reinforce recent papers that have focused on the potential contribution of open innovation to produce knowledge related with both environmental strategy and environmental performance [3,21]. Specifically, the results of the keywords analysis reveal four lines of research during the period of 2003 to 2019. These are (1) product development and collaboration with a special focus on industry; (2) innovation capacity, absorptive capacity, and knowledge management; (3) technology and intangible assets accessible within the collaboration; and (4) the relational nature of companies where sustainability issues are fundamental when dealing with partners and the environment.

The main contribution of this paper has been the identification of work studying sustainability concerns in open innovation research, highlighting its relevance and contributions for the field of study. Sustainability-related studies have strongly entered in this discipline in the last several years with almost 80% of the articles being published from 2015 to 2019, thus becoming one of the most relevant elements in today's research on open innovation. This increase has been mostly influenced by the boost experienced with the appearance of the journal Sustainability (Switzerland), that mainly focuses on publishing sustainability and environmental related papers about open innovation. Its first publication on the topic was in 2017, and in only 2 years it published 63 articles. It is the third journal in the general ranking by number of articles published, but became the second in the last period studied (2015–2019). Other important journals in this matter are Journal of Cleaner Production and Journal of Open Innovation: Technology, Market and Complexity. However, Technological Forecasting and Social Change is the journal that has published the most relevant publication, an article by Lee, Hancock, and Hu released in 2014 that has achieved 285 citations.

The main subject area is Social Sciences, due to the fact that business management sustainability-related publications are usually categorized within this subject. The most productive author on open innovation and sustainability concerns is the South-Korean Kyung Bae Park, with six articles published between 2016 and 2019. Among the top 10 authors in open innovation, JinHyo Joseph Yun, also of South Korea, was the first to publish articles considering sustainability issues in 2016. Yun is followed by Marcel Bogers of Denmark with his work in 2019. The most prolific institution in sustainability-related issues in the field is Sangji University, the institution of Kyung Bae Park in South Korea, while the most productive countries are Italy and South Korea.

This research has some limitations, which could set the basis for future work. The bibliometric analysis applied in this study is of a quantitative nature, so it could be extended with other qualitative or quantitative tools to look for different scenarios of this research line. Additionally, in future bibliometric analyses, some research could be made focusing on the different areas to which this discipline can be associated, studying the relations between the open innovation concept and other lines of research and key points for business management.

Another important line of research to be developed in the future would consist of deepening the context in which open innovation correctly works and favors business performance. In the same vein, previous works have already highlighted the important role that Collaborative Open Innovation Networks (COIN) can play [20], improving the knowledge transfer received by firms [20], stakeholder integration [46,118], and the satisfaction of the stakeholders of those organizations closer to open innovation practices.

Author Contributions: All authors have equally contributed to this paper (conceptualization, methodology, formal analysis, and writing). All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data sharing not applicable.

Acknowledgments: This paper has been developed during the following research stays: Luis J. Belmonte-Ureña: Visiting Scholar in Newcastle University (London) (February–August 2020). Jose A. Plaza-Úbeda: Visiting Scholar in the Faculty of Business and Law in Portsmouth University (UK); (March–September 2020).

Conflicts of Interest: The authors declare no conflict of interest.

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