A Bibliometric Map of Intellectual Communities in Frugal Innovation Literature

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***Abstract*—Frugal innovation is the process of innovating to respond to severe resource constraints with products that have cost advantages compared with existing solutions. The philosophy behind frugal innovation can be applied to both products and services from different sectors, as shown by academia and managerial applications. In this article, the purpose is to examine the intellectual structure of the developing domain of frugal-innovation research in order to identify the most active and influential communities, as well as the most seminal works and the most active scholars. Therefore, we conducted a bibliometric analysis of the literature on frugal innovation. The outcomes of our analysis allow us to offer an objective and scientific mapping of the development of this field. Four distinct intellectual communities have been identified: strategic challenges, inclusive development, sustainability, and industrial application. We, herein, provide insights into the commonalities between these distinct communities and into the intellectual structure of the domain, as well as indications for future studies. The results dig into the evolution of the topic and instigate further research explorations toward the industrial applications of frugal innovation, addressing whether and how this approach could deliver benefits to companies in terms of product development, industrial systems, and logistics.**

***Index Terms*—Bibliometric analysis, frugal innovation (FI), intellectual community, research collaboration, scientific mapping.**

I. Introduction

THE CONCEPT of frugal innovation (FI) dates back to 2006 when Renault-Nissan CEO Carlos Ghosn coined the term "frugal engineering," inspired by the Indian engineers' ability to innovate "cost effectively and quickly under severe resource constraints" [1]. A few years later, the term appeared in an article of *The Economist* [2], which introduced the idea of a frugal approach to innovation in the Indian healthcare system. In this article, the logic of FI was explained as follows: "[u]nlike the hidebound health systems of the rich world … 'in [a] patient-centric health system you must innovate.' This does not mean adopting every fancy new piece of equipment. Over the years he [interviewed doctor] has rejected surgical robots and 'keyhole surgery' kit because the costs did not justify the benefits. Instead, he has looked for tools and techniques that spare resources and improve outcomes" [2].

FI has been defined as designing low-cost products, systems, and services by removing the sophisticated technology without losing technical functionalities, which, thus, makes them affordable for low-income customers either in low-, middle-, or high-income countries [3]. One of the most prominent examples is the General Electric (GE) portable diagnostic ultrasound machine, developed for China's rural areas [4], [5], and based on an old and low-cost ultrasound technology device that can be connected to any laptop. This device differs from its "traditional" counterpart for its ease of use (due to a simplified user interface), lower price (80% lower than conventional prices), portability, and battery endurance.

The FI approach is becoming increasingly popular among companies as a different way to innovate and design creative and innovative solutions [1], [4]. This approach is clearly attractive to companies thanks to its beneficial and appealing consequences, such as squeezing costs, enlarging the consumer base, and exploiting existing resources. Another reason behind the appeal of the topic relates to a major change in the consumer's behavior, which is arguably moving from "ever bigger and better" solutions toward a growing demand for reduction "in the needless complexity layered on the technology-based products" [6]. This trend is furthermore reflected in the phenomenon of "innovation overload" [7], defined as a consumer's response to the increasing pace of innovations, information, and knowledge. In other words, this phenomenon refers to the fact that consumers are suffering from the so-called overengineering syndrome, thereby they are no longer willing to pay for features they perceive as not valuable, whereas they might be interested in simpler but still valuable products.

Although FI was created and developed in a practitioner context [1], it has also captured an increasing interest in academia. After a few years of "incubation," various scholars have been attracted by the novelty of the topic, and FI has become an academic field of research. In the academic sphere, the major scholars debate the overlap of FI with multiple similar terms, such as jugaad, frugal engineering, constraint-based innovation, Gandhian innovation, catalytic innovation, grassroots innovation, indigenous innovation, and reverse innovation [8]. In fact, other terms describing similar concepts have become popular among both practitioners and scholars, which makes the boundaries of FI blurred.

It is, thus, hardly surprising that previous research on FI has included the systematic literature reviews for several purposes: to

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TABLE I
OVERVIEW OF THE PREVIOUS LITERATURE REVIEWS

Authors	References	Purpose	Methodology
Brem and Wolfram	[8]	Review of the literature	Literature Review
Zeschky et al.	[10]	Identify criteria to classify innovation for emerging markets	Theoretical Paper
Agarwal et al.	[9]	Review and organize the literature and the terminology	Systematic Literature Review and Cluster Analysis
Hossain	[14]	Mapping frugal innovation	Systematic Literature Review
Soni and Krishnan	[13]	Definition of frugal innovation	Systematic Literature Review
Weyrauch and Herstatt	[11]	Definition of frugal innovation	Literature Review, Interview
Pisoni et al.	[12]	Summarize the key findings	SLR Frugal Innovation Literature

SLR = Systematic literature review.

define the differences between the FI and related terms [8]–[10]; to provide a definition of the concept [11]–[13]; to summarize the key findings of extant research [12], [14]; and to map the scientific domain [9], [15]. Although the systematic literature reviews allow us to assess the state of a research domain, it encompasses weaknesses, which may skew the results: First, the need to find a metric to evaluate and summarize the findings may miss out relevant contributions; and second, the nonreplicability of the analysis, which is due to the qualitative dimension of the systematic literature reviews, as researchers may report only the literature that is relevant to and consistent with their bias.

The purpose of the article is to examine and classify the literature on FI by relying on a quantitative approach in order to provide a deeper understanding of the current state of the research and to outline directions for future research. To overcome the aforementioned limitations, we conducted a bibliometric analysis of the literature. Notably, bibliometrics is a quantitative method for conducting a literature review, which combines the classification and visualization methods of analysis of aggregated bibliographic data produced by scientists of a research domain [16]. Our data set, which consists of 67 articles covering the period 1985–2018, was obtained using the Web of Science Social Science Citation Index (SSCI) database, which includes journals with impact factor and refers only to business and management, as the data source, through a search by topic using the keyword "FI."

We uncovered the presence of four communities of scholars active in the field as well as the strength of the connections and similarities between their different contributions. Our analysis provides a scientific mapping of the research domain based on the similarities between the pieces of existing research. Our contribution to the literature on FI is twofold: first, we unveil the subareas of the research domain and the key insights offered by the scholars thereof; second, we discover the potential weaknesses of the current research, suggesting how future research may address those gaps.

The rest of this article is organized as follows. In Section II, we "review the reviews" of FI. Section III explains the bibliometric approach and the methodology. Section IV presents and discusses the results. Finally, Section V concludes this article.

II. OVERVIEW OF THE LITERATURE

Over the past years, various authors have contributed to defining and reviewing the FI field of research, as summarized in Table I. Brem and Wolfram [8] included FI in the more general category of innovation in emerging markets. Similarly, Zeschky *et al.* [10] clustered the innovation approaches to emerging markets into three groups according to the attributes of market novelty and technical novelty, with FI being one of the three clusters besides cost innovation and good-enough innovation. Agarwal *et al.* [9] focused on the innovation under scarcity, synthetizing the extant research to organize the fragmented literature and the terminological confusion. Although the systematic literature review carried out by these authors identified the progress of extant research and future directions, providing a clusterization of the extant research domain, it included FI and other terms under the umbrella of resource-constrained innovation. Therefore, these results span much broader boundaries and do not provide helpful insights into the FI domain. Hossain [17] addressed this gap,

providing a map of the FI phenomenon based on the country of origin of the researchers and the journals publishing the studies. Later on, Pisoni *et al.* [12] assessed and reviewed the key findings of the FI literature through an in-depth systematic literature review. Based on the qualitative-content analysis, these authors provided multiple classifications of the contributions based on the different metrics, thus resulting in a very complete framework of the research which, however, may also appear overly elaborate and difficult to summarize. A bibliometric analysis had been previously conducted by Tiwari and Kalogerakis [18] with the aim to investigate the theoretical base and the antecedents of FI in the scholarly discourse. However, their study considers a broader definition of FI, including also related topics, such as "reverse innovation," "jugaad," and "low-cost innovation." Accordingly, their results offer a comprehensive overview of state of the art, the relevant articles, and the most active authors. Nonetheless, these authors do not consider the different shades of the terms employed to perform the search of the articles. In this respect, although the previous studies offer a comprehensive overview of the existing terms and provide various keys to draw the boundaries between these terms, a more focused quantitative analysis of the overall state of the art in the FI literature is still lacking. Understanding the fields of interest of FI, based on its "strict" definition, may also clarify the definition itself and the difference with similar terms.

III. Methodology

We conducted a bibliometric analysis to construct a scientific map of the scientific domain of FI. A bibliometric analysis is a quantitative methodology that analyzes the bibliographic data to identify the strongest interconnections among articles and research topics by analyzing the citation relations, cocitation relations, and co-occurrence of the keywords [19]. This methodology enriches the findings obtained through the traditional methods of review studies, notably the qualitative approach of the systematic literature review and the quantitative approach of metaanalysis [20], [21]. In fact, it combines an initial quantitative analysis and a second subjective analysis of the results through coding procedures, thus providing a more complete understanding of how the authors and articles are related to one another and also producing visual representations [20], [22]. A bibliometric analysis is based on the assumption that any scientific area results from a cumulative research tradition occurring over time, which can be captured through a pattern of citations [23]. By analyzing these patterns of citations, it is possible to scrutinize the relationships among documents contributing to the development of a research area [24].

A. Analytical Approach

The unit of analysis is constituted by a single article. In line with previous scholarly studies [23], [25], we relied on bibliographic-coupling strength to detect scholarly research communities [25]–[27]. The bibliographic-coupling strength (or frequency) between two documents is defined as the number of items these two documents share in their reference lists. Two documents are bibliographically coupled if they both cite one or more documents in common; the higher the number of documents cited by the two documents, the higher the bibliographic-coupling strength. The rationale behind the measure is that the documents that share the same references are likely to be similar, and this similarity is higher as the extent of the shared bibliography increases. We choose the bibliographic coupling as the similarity measure to map the scientific domain [26], since it has been recognized by the literature as the most accurate for representing a research front [27] and it is not affected by the cumulative amount of a citation, unlike other similarity measures [28]. Over the past years, the accuracy of the bibliographic-coupling measure to study the academic fields has been compared with the another method of analysis of scientific publications, namely the cocitation technique, i.e., the frequency with which two documents are cited together (small, 1973). The object of the comparison was the suitability of each method to cluster the academic fields of research as well as whether the literature on bibliometrics agreed on the higher accuracy of bibliographic-coupling techniques as compared with cocitation techniques [27], [29]–[31].

The bibliographic-coupling strength assumes that articles sharing the same references are similar, and that the higher the amount of shared references, the higher the similarity between the articles. In this view, the bibliographic-coupling analysis applied to the references allows, through the similarity analysis, the identification of the main clusters of scholars working on subtopics. For the purpose of our study, we performed a content analysis of the clusters identified by the software algorithm, and each cluster was manually screened and labeled through a coding procedure [32]. The VOSviewer software (version 11.4) generates maps [33] using the visualization of similarities (VOS) mapping and VOS clustering techniques [34]. These are novel techniques, alternative to the multidimensional scaling (MDS) approach [35], to some extent resembling the latter as they both locate items in a low-dimensional space, in such a way that the distance between any two items reflects the similarity or relatedness of the items as accurately as possible [35]. However, in contrast to MDS, which is based on the calculation of similarity measures, such as the Cosine and the Jaccard indexes, VOS adopts a different procedure for normalizing co-occurrence frequencies [33], [36], namely, the association strength (1). Specifically, the association strength is calculated as follows:

$$a_{ij} = \frac{mc_{ij}}{c_{ii}c_{jj}} \tag{1}$$

where m represents the total number of abstracts, c_{ij} indicates the number of times concept *i* and concept *j* occur together in the abstracts, and c_{ii} and c_{jj} indicate the number of times concept *i* and concept *j* occur together in the abstracts. To compute the similarity of two documents, a two-step approach is taken. In the first step, for each pair of items, the number of bibliographic-coupling links is calculated. In the second step, the association strength formula is used to normalize the bibliographic-coupling strengths. The normalization corrects for the fact that some items (e.g., some documents, authors, or journals) may have many more references than others and may, therefore, also have more bibliographic-coupling links.

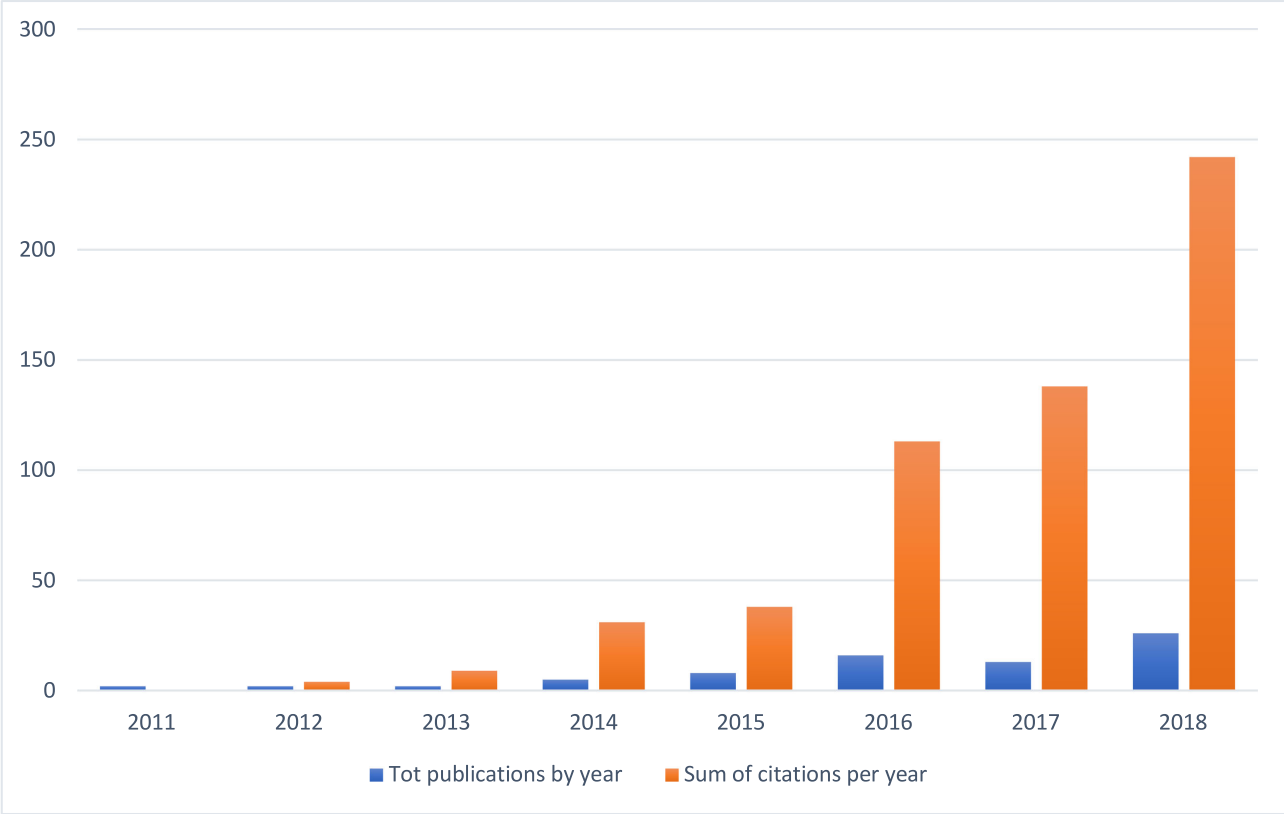

Fig. 1. Total publications and citations per year.

B. Data

We collected our dataset from the SSCI at the Web of Science Core Collection.[1] By selecting the SSCI, we ensured that we would filter out any bibliographic data from less reputable journals, and we, therefore, obtained a dataset made of the articles published in the best peer-reviewed journals in social science. In order to detect the first occurrence of FI in academia, we did not set any date restriction for the search, which was preset by default to the interval 1985–2018. The data set was obtained by running a "search by topic" with the keyword "FI," which resulted in 67 articles (56 articles, 7 reviews, and 4 editorial materials). We screened the data set to filter out any incompatible article, thus, resulting in a final data set consisting of 65 units in total. Out of the final data set, seven items were not connected and have, therefore, been omitted from the cluster representation and analysis, which eventually resulted in a final set of 58 articles. Although the literature has reported differences between the concept of FI and its established synonyms (Gandhian innovation, *Jugaad*, frugal engineering) [9], there are still some taxonomical issues, which may alter our results. To account for this potential distortion, we verified the gap between our sample (keyword "FI") and the samples obtained by searching the other terms (Gandhian innovation, *Jugaad*, frugal engineering). The results show an overlapping of 45% with the keyword "Jugaad," 33% with the keyword "Gandhian Innovation," and 18% with the keyword "frugal engineering."

[1]Our results refer to articles available in the Web of Science database in October 2018.

IV. Results

A. FI as an Emerging Field

The analysis of the descriptive statistics provides a first overall understanding of the research field. Fig. 1 shows that the first academic publication appeared in 2011. In addition, the observation period can be divided into two different phases: an initial phase of less intense activity from 2011 to 2014, with four publications on average per year, and a "take-off phase" between 2015 and 2018, which was the most prolific year with 21 publications.

The observation of the cumulative citations that occurred over the years shows a significant increase during the take-off phase, with a peak of 191 citations in 2018, as shown in Fig. 1, and a total number of 519 citations over the entire period.

The geographical distribution of the publications shows that the most prolific country is the U.S. followed—not surprisingly—by India and Germany, as shown in Fig. 2.

B. Scholarly Communities

Following van der Have and Rubalcaba [25], we created a network of scientific articles on FI based on the bibliographic-coupling data [26], as displayed in Fig. 3. Articles are

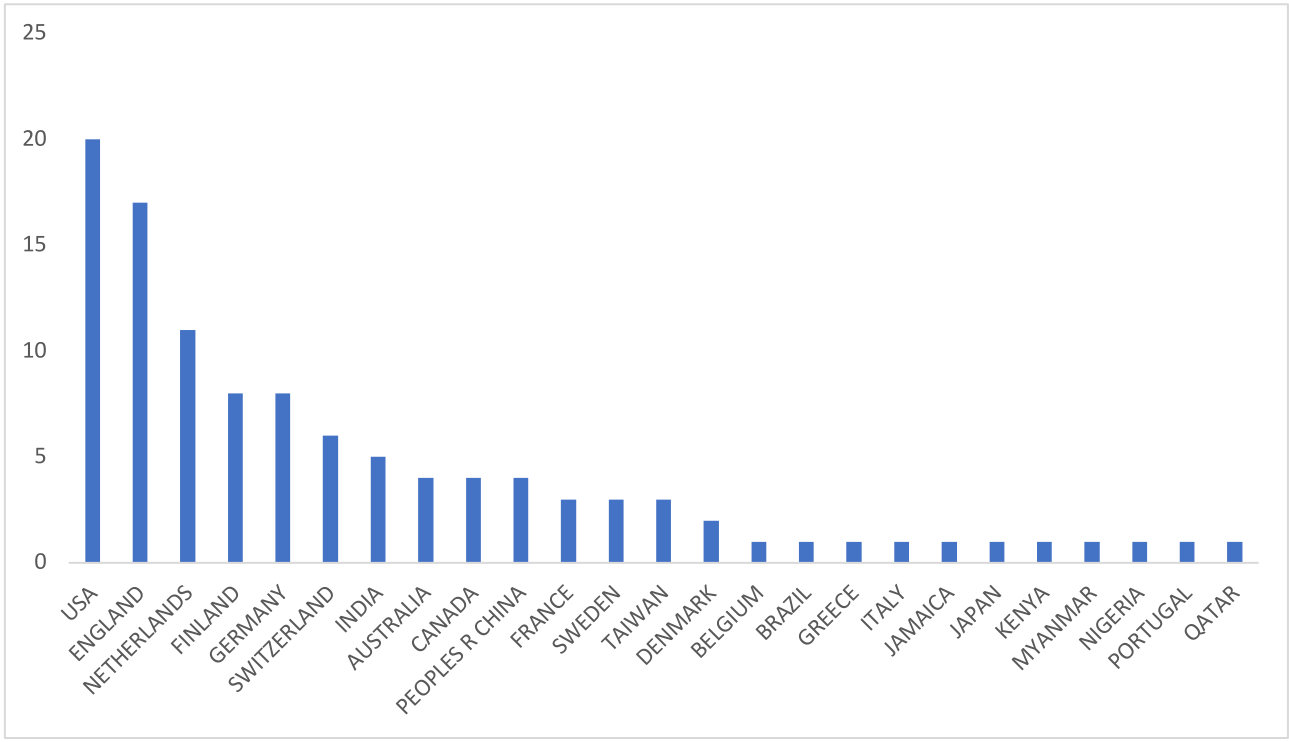

Fig. 2. Number of publications per country.

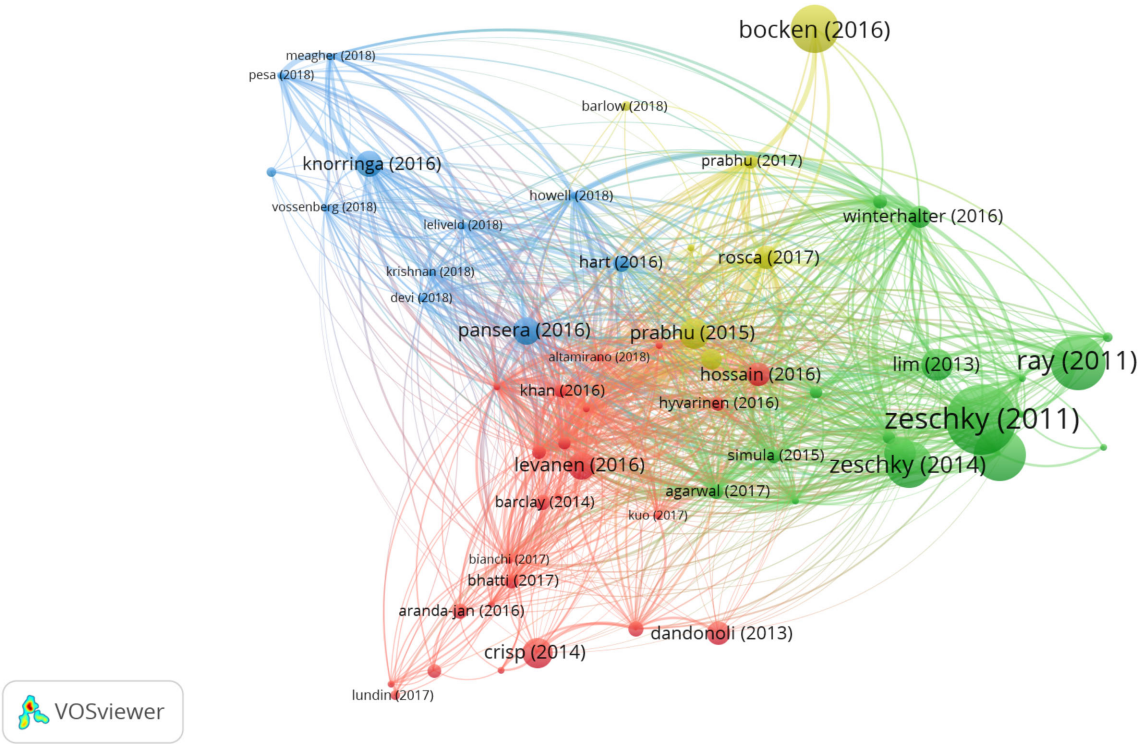

Fig. 3. Bibliographic-coupling map.

bibliographically coupled when different authors cite one or more articles in common. In other words, if two or more authors cite the same article, the authors are connected. The higher the number of citations the articles share with other documents, the higher the strength of their similarities.

Fig. 3 reports our bibliographic-coupling map, covering 59 items out of 66 in total, i.e., 92% of the entire dataset. The bibliographic-coupling map provides a visual representation of the network of articles belonging to a research domain, where each node represents a scientific article and each tie represents a bibliographic-coupling relation. The size of the nodes represents the number of citations the article has received over time, while the distance between nodes represents the similarity between the nodes (as measured by bibliographic coupling). The colors of the nodes represent the different clusters of articles. The bibliographic-coupling map shows 58 out of 65 total articles of the initial dataset, since the seven remaining articles were not connected with any other and have, therefore, been dropped from the map.

The articles that are not connected do not share any common citations with other articles in the dataset. A deeper analysis of the abstracts of those articles explains why they are disconnected from the map: those articles are scientific works about sophisticated technical applications of FIs to surgery procedures [37], [38] or technical applications of FI to solar energy [39], and they apparently belong to different fields of research and refer to different literature bodies. The final network is made up by four main clusters. After an analysis of each title and abstract therein, we came up with the following cluster labels based on their main content:

1) strategic challenges (green);
2) inclusive development (blue);
3) sustainability (yellow);
4) industrial application (red).

Table II summarizes the results and the key findings of the cluster analysis.

1) Green Cluster (Cluster 1): Strategic Challenges: The green cluster comprises the most cited articles—as shown by the size of the nodes—thus implicating a potential dominant position of this cluster over the others in terms of popularity of the research focus. The analysis shows that the cluster addresses the strategic challenges of FI in terms of how organizational structures interplay with FI [40], [41], how to reconfigure the organization in terms of dynamic capabilities, innovation strategies, and resource allocation [42]–[45], and the new product development strategies necessary to meet the requirements of FI [46]–[48]. The main rationale for this community is that both for western firms and emerging market firms, an FI activity requires reconsidering the philosophy behind the traditional innovation strategy and adopting a different view and mindset in order to configure the value chain and to adapt the organizational structure to guide this new challenge. Besides the attention to the strategic and organizational themes and to possible recipes for companies to tackle FI strategies, a subgroup of authors addressing the "frugal" product development strategy emerges [40], [48], [49]. These authors cross the external layer of the strategic-challenge themes and seek to "get their hands dirty" with more technical issues. Indeed, they observe the phenomenon from a product performance perspective exploring the product architecture implications of FI in terms of product design. This subarea, although immature, constitutes a promising avenue for future research, as it may disentangle the relation between the FI and the product design and provide findings about the performance of FI products, which in turn may encourage companies to embrace FI strategies.

2) Blue Cluster (Cluster 2): Inclusive Development: The second cluster deals with the theme of inclusiveness promoted by FI. Scholars focus on how FI can pursue the social goals of reducing poverty and inequalities and promote an improvement of the quality of life by ensuring employment and providing adequate public services delivery to remote rural areas [50]–[56]. This research community is characterized by a two-folded trend: on the one hand, the specificity of the setting of the studies thereof, which is mainly contextualized in Africa [52]–[55], [57] and, in line with the topic of the cluster, in emerging markets as a whole [58]; on the other hand, the idea that FI for inclusiveness is a matter of global politics and development economics and would be better addressed from a macroeconomic perspective [50], [53]–[57]. In fact, the role of the local institutional environment and the local governments is crucial to promote an FI model. As such, a global-policy perspective could address the issue by prompting the participation of western incubators and firms facilitators, as well as non governmental organizations (NGOs) and western funds to provide both financial support and the transfer of technical knowledge [59], [60]. These ingredients are determinant to avoid small, localized, and grassroot private initiatives, which would not survive the market effects.

A further issue, which is properly addressed by the literature, is the threats of potential socioeconomic inequalities driven by the diffusion of FI models [54], [55] or the increase of capitalist exploitation and inequality [61]. Future research is encouraged to address these issues to find new solutions that would enable "win–win" situations, in which companies could earn profits while alleviating poverty and ensuring equal possibilities for the whole population of potential consumers [54].

A potential response to address the challenges posed by income inequalities could be offered by intertwining the impact of FI on inclusiveness with the idea of democracy as an innovation enabler [62]. In this respect, the political system is a critical factor, which can serve as an innovation incubator under certain conditions, which are above all those of a "highly qualified" democracy. Indeed, a functioning democracy is arguably a prerequisite for the development and adoption of an effective innovation system, as it promotes an extensive coverage and ensures social welfare.

The current literature considers FI as an essential ingredient for an onward development trajectory of the low-income areas of the world, assuming that there is only one possible development trajectory to which the whole society aspires. This is true because people from lower segments of the social pyramid seek a lifestyle improvement close to that of western consumers [63].

3) Yellow Cluster (Cluster 3): Sustainability: The yellow cluster is the "least popular" of the research domains with only seven items, thus revealing a limited interest of practitioners

TABLE II
FI RESEARCH STATUS.

Cluster	Authors	Key insights	Future Research
C1: Strategic challenges (17)	Zeschky, Marco; Widenmayer, Bastian; Gassmann, Oliver Ray, Sangeeta; Ray, Pradeep Kanta Zeschky, Marco B.; Winterhalter, Stephan; Gassmann, Oliver Sharma, Arun; Iyer, Gopalkrishnan R. Zeschky, Marco; Widenmayer, Bastian; Gassmann, Oliver Winterhalter, Stephan; Zeschky, Marco B.; Gassmann, Oliver Winterhalter, Stephan; Zeschky, Marco B.; Neumann, Lukas; Gassmann, Oliver Shan, Juan; Khan, Miqdad Ali Pandit, Deepak; Joshi, Maheshkumar P.; Sahay, Arun; Gupta, Rajen K. Thun, Eric Altmann, Peter; Engberg, Robert Altamirano, Monica A.; van Beers, Cees P. Lai, Wen-Hsiang; Woodside, Arch Malik, Omar R. Gupta, Budhaditya; Thomke, Stefan Amankwah-Amoah, Joseph; Egbetokun, Abiodun; Osabutey, Ellis L. C. von Janda S, Schuhmacher, MC Kuester, S	Frugal Innovation requires organizational reconfiguration (R&D department localization), collaboration with suppliers, understanding how to deliver the new value proposition, establishing new value chains	Focus on Frugal Innovation product performance and the product architecture dimension
C2: Inclusiveness (11)	Knorringa, Peter; Pesa, Iva; Leliveld, Andre; van Beers, Cees Hart, Stuart; Sharma, Sanjay; Halme, Minna Howell, Rachel; van Beers, Cees; Doorn, Neelke Meagher, Kate Leliveld, Andre; Knorringa, Peter Pesa, Iva Baud, Isa Vossenberg, Saskia Krishnan, Aarti; Foster, Chistopher Devi, Wairokpam Premi; Kumar, Hemant Pansera, Mario; Sarkar, Soumodip	Frugal Innovation may promote development and inclusiveness and contribute to alleviate poverty and inequalities	Need to integrate the Frugal Innovation managerial perspective with Economics and Global Studies
C3: Sustainable Development (7)	Bocken, N. M. P.; Short, S. W. Prabhu, Jaideep; Jain, Sanjay Nair, Anil; Guldiken, Orhun; Fainshmidt, Stav; Pezeshkan, Amir Prabhu, Jaideep Gupta, Ravi Kumar; Belkadi, Farouk; Buergy, Christian; Bitte, Frank; Da Cunha, Catherine; Buergin, Jens; Lanza, Gisela; Bernard, Alain Barlow, Allison; McDaniel, Judy A.; Marfani, Farha; Lowe, Anne; Keplinger, Cassie; Beltangady, Moushumi; Goklish, Novalene Rosca, Eugenia; Reedy, Jack; Bendul, Julia C.	A shift towards systemic Frugal Economy is the key to address the global economy challenges	Empirical investigation of the ability of frugal innovation to fulfill multiple goals at the same time
C4: Industrial Application (24)	Levanen, Jarkko; Hossain, Mokter; Lyytinen, Tatu; Hyvarinen, Anne; Numminen, Sini; Halme, Minna Pisoni, Alessia; Michelini, Laura; Martignoni, Gloria Agarwal, Nivedita; Grottke, Michael; Mishra, Shefali; Brem, Alexander Khan, Rakhshanda Dandonoli, Patricia Barclay, Corlane Hyvarinen, Anne; Keskinen, Marko; Varis, Olli Hossain, Mokter Rosca, Eugenia; Arnold, Marlen; Bendul, Julia C. Bhatti, Yasser; Taylor, Andrea; Harris, Matthew; Wadge, Hester; Escobar, Erin; Prime, Matt; Patel, Hannah; Carter, Alexander W.; Parston, Greg; Darzi, Ara W.; Udayakumar, Krishna Simula, Henri; Hossain, Mokter; Halme, Minna Murphy, Jill; Goldsmith, Charles H.; Jones, Wayne; Pham Thi Oanh; Vu Cong Nguyen Lundin, Johan; Dumont, Guy Rai, Amit S. Carbone, Sarah; Wigle, Jannah; Akseer, Nadia; Barac, Raluca; Barwick, Melanie; Zlotkin, Stanley Sun, Yuan; Cao, Haiyang; Tan, Barney; Shang, Rong-An Agarwal, Nivedita; Brem, Alexander; Grottke, Michael Kleczka, Bernadette; Musiega, Anita; Rabut, Grace; Wekesa, Phoebe; Mwaniki, Paul; Marx, Michael; Kumar, Pratap Kuo, Anthony Altamirano, van Beers Aranda-Jan, Clara B.; Jagtap, Santosh; Moultrie, James Crisp, Nigel Harris, Matthew; Weisberger, Emily; Silver, Diana; Dadwal, Viva; Macinko, James	Fi is more efficient in terms of energy production or water purification than existing solutions and are more climate neutral; sustainability impact of frugal innovations should be considered throughout the value chains in which they are created; consumers appreciate 'affordable value innovations' and 'ease of use' functionalities	Analysis on Frugal Innovation processes

toward the themes of sustainability and environment. The articles focus on how innovating under resource scarcity principles and the reduction of nonessential characteristics may address environmental and resource consumption issues [64]–[66]. The idea that FI has the potential to achieve sustainable-development goals reconciles the community of scholars of Cluster 3; in fact, they all agree on the latent capability of FI to tackle pressing sustainability issues, thanks to its default attributes of less resources and optimized performance [11].

In this respect, FI blends with the broader literature on sustainability issues and commitment toward the environment as a part of the sustainable development goals promoted by the United Nations [67]. Accordingly, FI enables us to simultaneously address the aim of "eradicating poverty" and the goals "to protect the planet from degradation, including through sustainable consumption and production" and to "ensure that all human beings can fulfil their potential in dignity and equality and in a healthy environment," thanks to its applicability also in disadvantaged settings. Given the growing interest for sustainability themes, we encourage research in FI to address these issues through an empirical investigation of the ability of FI to fulfill multiple goals at the same time.

4) Red Cluster (Cluster 4): Industrial Applications: The red cluster comprises the industrial applications of FI and is considered to be the largest cluster with its 24 articles. This community is characterized by the presence of a small group of scholars from industrial engineering and environmental science, who have been working on the industrial applications of FI.

The first level of analysis shows that the contents of the articles are diverse and span across different case studies analyzing various applications of FI. Popular applications appear to concern the water supply system [68], [69] and the energy sector [69], the Indian mobile phone industry [70], the supply chain [71], and the general applications of FI to foster green technologies [72], [73]. However, the most popular application among scholars appears to be the one regarding the healthcare sector [74]–[77], possibly to honor the tradition of FI originated in the healthcare setting [78].

A deeper analysis shows that some of the articles belonging to Cluster 4 could be included in other clusters: for example, the industrial application of FIs encompasses also themes related to the product development issues (Cluster 1), although Cluster 4 focuses on process rather than product design. The theme of FI applied to industrial processes and utilities suffers from a narrow focus on its application in low-income settings and emerging economies [68], [70], [72], [79], which hinders a more comprehensive view of the effects of the application of FI to the industrial systems of more advanced economies. Future research should address the issue by providing the missing link between the FI and the industrial-process application in the advanced economies. In addition, future research is encouraged to concentrate more on the FI process and product development, in view of a possible increase in the adoption of FI practices and to equip practitioners with a "user manual." Moreover, future research may investigate the relation between the industrial applications and the patent activity issues, for example, with respect to how many FIs would turn into patent applications and granted patents, or which technological fields have the highest patent application rate. To the best of our knowledge, a little attention has been devoted to the analysis of FI production in relation to patent activities [52], [80]. The promises of eventual future revenues from FI patenting activities could encourage innovation efforts in such direction, resulting in advantages for both companies as innovation generators and society.

C. Sensitivity Analysis

The resolution parameter γ of the clusters determines the level of detail provided by the software technique; the higher the value of the parameter, the higher the number of clusters that will be obtained and the smaller the clusters. We set a resolution parameter of 0.75, resulting in four clusters. Following Waltman *et al.* [34], we experimented with several different values for the resolution parameter. Accordingly, there is no general optimum value of γ, which should be based on the most purposeful results depending on the specific needs. In addition, the exploratory nature of the analysis justifies the testing of different values. After some experimenting, we decided to set this parameter equal to 0.75. This resulted in a clusterization with a satisfactory level of detail for the purpose of our research, that is, to detect the most influential communities in the research field. Indeed, on the one hand, a higher resolution parameter would result in a higher number of clusters, with a higher level of detail and a more accurate detection of the content of the clusters. On the other hand, however, this would be pointless for the purpose of this specific research, since it would result in a multitude of small clusters.

To assess the goodness of the resolution parameter, we conducted a sensitivity analysis to determine how changing the parameter would affect the variation in the results.

By setting a resolution parameter $\gamma = 0.5$, the clusterization algorithm detects two clusters.

1) Cluster 1^*: Industrial applications, inclusiveness, and sustainability.
2) Cluster 2^*: Strategic implication of FI /creating value with FI.

Cluster 1^* comprises Cluster 2, Cluster 3, and Cluster 4, including the works that focus on the case studies on FI and on how this approach can address social purposes. Cluster $2*$ reflects Cluster 1 in the main analysis, as it addresses the strategic challenges posed by the adoption of FI strategies and how this approach can contribute to value creation, thus showing that a lower resolution parameter results in a merging of the clusters identified in the main analysis into two macrocategories.

By setting a resolution parameter $\gamma = 1$, the resulting network shows six clusters.

1) Cluster 1^: Case studies and applications.
2) Cluster 2^: Inclusiveness and social development
3) Cluster 3^: Strategic implications.
4) Cluster 4^: Sustainability.
5) Cluster 5^: Development of FI capabilities.
6) Cluster 6^: Applications in utilities sector.

The higher resolution parameter results in a higher number of clusters. A deeper analysis shows that a higher parameter

leads to the decomposition of the clusters identified in the main analysis: Cluster 1^ and Cluster 6^ are subunits of Cluster 3, Cluster 2^ overlaps with Cluster 2, Cluster 3^ and Cluster 5^ are subunits of Cluster 1, and, finally, Cluster 4^ overlaps with Cluster 4 in the main analysis.

The results of the sensitivity analysis show how, by setting a higher or lower resolution parameter, the clustering configurations result in macrogroups in the case of a lower resolution parameter, and subgroups in the case of a higher resolution parameter, confirming the goodness of the resolution parameter selected for our analysis.

D. Popular Theoretical Lenses

The qualitative analysis of the clusters shows some recurring patterns among the different clusters, for example, the theoretical lenses employed by scholars to observe the phenomenon. In particular, we observed that 17% of scholars pertaining to Cluster 1 (strategic challenges) relied on disruptive innovation as the theoretical perspective applied to observe the phenomenon of FI, whereas 45% of scholars pertaining to Cluster 2 (inclusive development) relied on bottom-of-pyramid (BoP) as the theoretical setting used to observe the phenomenon.

Disruptive innovation [81] describes a situation where existing companies are focused on satisfying the needs of the high end of the market (where the profitability is high), while ignoring the low end of the market, which demands less sophisticated and less performing products. In such situations, new firms can enter the market serving the low-end consumers, who have lower expectations and requirements. As these innovations improve over time, they overtake the existing technologies by satisfying the current market needs [82]. The metrics of disruptive innovation show many similarities with FI, e.g., the unserved consumer groups and low-income markets, which are potential targets for FIs [49], [83], and the features of disruptive innovations, which are typically simpler, more convenient, and more affordable [84]. Since there has thus far not been any empirical evidence of FIs that have displaced their "traditional version," as the definition of disruptive innovation would require, the association between the FIs and the disruptive innovations is incomplete and mostly theoretical. Disruption is a process and not an event [85], and the evolution of the healthcare industry in developed markets, as well as other factors, will most certainly play a role in this disruption process. The articles that have relied on disruptive innovation to observe the FI phenomenon [10], [45], [47], [86], [87] belong, not surprisingly, to the strategic challenge cluster (Cluster 1). The researchers in this cluster aim to disentangle all the possible strategic challenges that firms are dealing with FI may encounter, since the potential disruptiveness of FI may be significant. In addition, these scholars try to address the bridge between the FI and the disruptive innovation, broadening the spectrum of what can result as disruptive for the existing incumbents and what threats the existing companies may face from "unsuspected" entities. The scholars belonging to the strategic challenge cluster should reinforce the relationship between the disruptive and FI, as the latter is a subclass of the former, and address how companies could foster the potential disruptiveness of FIs.

The second theoretical perspective assumes a demand-based view and looks at FI from the potential targeted market side. The characteristics of FI, i.e., low cost, ease of use, and valuable performance, can target the low-income segment of the population. For this reason, a part of the FI literature has connected FI with the concept of BoP [88]. BoP refers to the largest but poorest socioeconomic group, i.e., the four billion people living with less than $2 per day, a group that has traditionally been ignored by large companies. Despite its low purchasing power, this group constitutes a large potential market to serve. Serving BoP markets entails the idea of producing specific products for those disadvantaged consumers in the rural areas of the poor and emerging economies, with the double purpose of making businesses enlarge their markets while at the same time creating social value by improving the quality of life of less wealthy people.

In this perspective, FI stands beside the innovation approach to low-income markets. The results section provides an in-depth analysis of the literature output in this area [8], [9], [89], [90].

V. Discussion and Conclusion

In this article, based on a bibliometric analysis integrated with a qualitative assessment, a scientific map of the literature on FI was provided. The existence of FI has been documented by scholars for many years; however, the attention of scholars and practitioners has increased during the past decade. Yet, research has been criticized for being fragmented and inconsistent as a multitude of definitions, perspectives, and misleading terms have emerged. Therefore, we had circumscribed the analysis to the FI domain to assess the scope of the domain and its intellectual structure. The result of the analysis is beneficial for scholars who want to contribute to the further advancement of the field and to foster a homogeneous and consistent knowledge accumulation.

We identified four main clusters in the research domain: strategic challenges, inclusive development, sustainability, industrial applications. A more detailed summary of the findings of the study and the cluster analysis, in particular key insights and future research directions, were provided in Table II.

Compared with a previous bibliometric analysis [18], which identified four clusters concerning themes of innovation for emerging markets, this study had identified a more diversified cluster composition, despite the narrower search. The difference may be due to the choice of FI as the sole research keyword, which has allowed to focus on a more specific research domain and to better capture the nuances of the phenomenon, thus distinguishing it from other similar terms in use. In this respect, FI presents strong connections with the technical aspects of innovation and the issue as to how the approach can be translated into industrial applications, as well as its potential weaknesses and bottlenecks. FI seems to transcend the issue of inclusiveness, by reducing inequality and promoting the development of rural areas, to embrace a more "concrete," technical value (as demonstrated by Cluster 1 and Cluster 4).

However, the results showed that the intellectual communities are characterized by a variety of multidisciplinary approaches within each one of them, spanning from industrial engineers to management scholars, although some common patterns emerge

in the cases of Cluster 1 and Cluster 2. In fact, a significant portion of Cluster 1 adopted a common approach and considered FI as a variety of disruptive innovation, and a significant portion of Cluster 2 assumed a mere consumer perspective to observe FI as capable of serving BoP consumers. Apart from this, the results showed that the majority of the studies did not rely on existing theoretical constructs in an attempt to incorporate FI into one coherent and consistent body of existing knowledge but rather work on building their own distinct theory for FI. For this reason, we believe that a smooth communication and cooperation between the different communities is crucial to enhance a consistent and cohesive work, where each theoretical block is based on the same validated and shared fundamental body of knowledge.

All in all, despite the novelty of the phenomenon, which results in a rapidly emerging area of research, FI constitutes in itself a research field with a specific research community, whose premises are auspicious. In addition, the current scenario showed a new arrangement of the innovation systems, with consumers becoming increasingly aware of the issues of sustainability [91] and deprivation [92], while at the same time being sensitive to technology and every experience connected to it. Therefore, it is of utmost importance to integrate FI with these themes, where possible, detecting new potential applications and assessing how this approach can find its own place in the forthcoming innovation systems.

This article provided a replicable assessment of the state-of-the-art of FI. While an in-depth discussion and synthesis of the previous research findings are beyond the scope of our goals, our results are primarily of interest to scholars who want to contribute to the further advancement of the FI field of research. In this respect, the theoretical contribution of this bibliometric review is indirect. In fact, it did not provide a theoretical block to understand the FI phenomenon, but it represented an auxiliary tool to identify the existing theoretical framework and the areas in need of clear theoretical contributions. Understanding the clusterization of the field may help improve the researchers' ability to identify and formulate adequate conceptual building blocks.

Our analysis highlighted several research areas, which may address new potential future research avenues. First, an additional perspective from economists and researchers in the field of global and development studies would be useful in order to obtain a broader view of the potential impact of a more comprehensive adoption of FI. In particular, further research should attend to the consequences of FI in low-income economies as it may potentially generate further inequalities and income gaps [93]. Notably, the lack of a solid legal and institutional framework hampers the attempts to promote inclusiveness and may exacerbate the income gap to the advantage of the "few" [94]. The role of policy makers is essential to create a local network, including western firms, incubators, NGOs, and financial intermediates, in order to provide the infrastructural system that is lacking today. In addition, most of FIs are created in a local context from "grassroot" innovators at a bricolage level, generated by the spur of the moment and lacking any structured innovation project. A proper network may also support the transferability of knowledge and the exploitation of creative ideas, as well as the creativity and the idea generation of the grassroot innovators [40]. In addition, we encourage future researchers to broaden the spectrum by observing the FI phenomenon through additional theoretical frameworks. To date, the most popular theoretical framework is the BoP lens. We argue that the strong contextualization of FI in low-resource settings or BoP markets [51], [54], [93], low-income environments, India [47], [58], and Africa [52], [53], [55], [57], may result in a misleading consideration of FI. In fact, this approach may create a bias in the minds of managers and practitioners in general, thereby reducing the sphere and the attractiveness of FI [95].

Our analysis had identified the lack of a study of the most suitable fields for the application of FI. Thorough research would help firms and practitioners to understand the most promising and suitable applications of FI, supporting their technological-exploration strategy and potential cost savings and fostering the adoption of an FI approach in firms' strategy. Furthermore, from a product development perspective, we encourage future researchers to address the issues of compliance with safety standards and compliance with legal frameworks. In addition, a stronger focus on the FI process was also recommended [58] in order to identify similarities and differences compared with other innovation processes. Moreover, further work investigating the differences between the frugal-product innovations and the frugal-business model innovations stands out as a potentially fruitful research focus.

As final remarks, we acknowledged the limitations of our study, which leaves room for further refinements. First, our dataset was extracted only from the Web of Science SSCI. A combination with other databases would provide additional and arguably more comprehensive insights into the scientific domain. Second, by relying on bibliographic coupling as the measure of similarity, we relied on the assumption that documents that share parts of their bibliographies are similar. Finally, the clusterization conducted by the software had been conducted through a content analysis on the title, abstract, and keywords, excluding articles not containing the keyword in their title or abstract.

The limitations of the article offered interesting and inspiring ideas to address future research efforts. In fact, adding a temporal dimension to the analysis would provide additional insights into how the network structure of the field has evolved over time. Moreover, the qualitative analysis of the clusters may suffer from the subjectivity inherent in the coding procedures, which may affect the consistence of the results.

The assessment of the research field leads toward an unsolicited question: what are the next steps? The FI approach has recognized strengths that make it an interesting advancement of the innovation concept, such as the focus on core functionalities, cost reduction, complexity reduction, optimized performance, simple user-centric design, and lean tools and techniques. All these attributes endow FI with the power to face the difficulties imposed by several current major social and societal challenges: natural resource degradation, climate change, poverty reduction,

and the need for sustainable solutions to slow the deterioration of the planet. In response to all these threats, a frugal approach [95] to business and economics and to the entire way of life, appears to be one of the most effective paradigms to achieve the sustainable development goals set by the United Nations [67]. In this scenario, the role of institutions and policy makers is crucial in terms of promoting interdisciplinary and collaborative efforts among the different stakeholders, to encourage an FI approach among companies, in conjunction with the attempts to educate people to a more "frugal" lifestyle.

APPENDIX

A. Visualization Algorithm

The research has been conducted using software designed for the construction and visualization of bibliometric maps and the graphical representation of such maps, VOSviewer. VOSviewer is a powerful tool to construct and visualize maps based on large data. It can be used, for instance, to construct maps of authors or journals based on the cocitation data or to construct maps of keywords based on the co-occurrence data. To construct a map, VOSviewer uses a mapping technique developed for the VOSviewer software called the VOS mapping technique [33], where VOS stands for visualization of similarities.

The construction of the map starts from the construction of a co-occurrence matrix. After that, the software creates a similarity matrix based on the co-occurrence matrix. The similarity measure used to build the co-occurrence matrix is called *association strength* [36], and it is calculated between objects through the content analysis of the dataset. The association strength a_{ij} of the objects (nodes) *i* and *j* is defined in a general form as follows:

$$a_{ij} = \frac{mc_{ij}}{c_{ii}c_{jj}} \tag{1}$$

where *m* indicates the total number of abstract, c_{ij} indicates the number of abstract, where concept *i* and concept *j* occur together, and c_{ii} and c_{jj} indicate the number of abstracts in which, respectively, concept *i* and concept *j* occur.

Using the association strength, the similarity s_{ij} between two items *i* and *j* is calculated as follows:

$$s_{ij} = \frac{c_{ij}}{w_i w_j} \tag{2}$$

where c_{ij} denotes the number of co-occurrences of items *i* and *j* and where w_i and w_j denote either the total number of occurrences of items *i* and *j* or the total number of co-occurrences of these items.

After calculating the similarities, the VOS mapping technique constructs a map based on the similarity matrix obtained. Let *n* denote the number of objects to be mapped. The VOS mapping algorithm constructs a two-dimensional map in which the items 1 …,*n* are located in such a way that the distance between any pair of items *i* and *j* reflects the similarity s_{ij} as accurately as possible. Items that have a high similarity should be located close to each other, while items that have a low similarity should be located far from each other. The VOS mapping technique minimizes the weighted sum of the squared Euclidean distances between all pairs of items. The higher the similarity between the two items, the higher the weight of their squared distance in the summation. To avoid situations where the objects are overlapped, a constraint is imposed in the way that the average distance between two items must be equal to 1 (in this way, we impose that there cannot be any overlapping objects having a distance equal to zero). In mathematical notation, the objective function to be minimized is given by

$$V(x_{1,\ldots}, x_n) = \sum_{i<j} s_{ij} ||x_i - x_j||^2 \tag{3}$$

where the vector $\mathrm{x}_i = (x_{i1},\, x_{i2})$ denotes the location of item *i* in a two-dimensional map and where $\|\circ\|$ denotes the Euclidean norm. The minimization of the objective function is performed subject to the constraint

$$\frac{2}{n(n-1)} \sum_{i<j} ||x_i - x_j|| \; = 1. \tag{4}$$

At this point, we have an optimization problem of minimizing (3) subject to (4).

The constrained optimization problem of minimizing (3) subject to (4) is solved numerically in two steps. The constrained optimization problem is first converted into an unconstrained optimization problem. The latter problem is then solved using a so-called majorization algorithm. The majorization algorithm used by VOSviewer is a variant of the scaling by majorizing a complicated function (SMACOF) algorithm described in the MDS literature [96]. To increase the likelihood of finding a globally optimal solution, the majorization algorithm can be run multiple times, each time using a different randomly generated initial solution. In this way, the software generates different global optima solutions with the same dataset and procedure, so the replicability of the analysis would not be guaranteed, and the results would not be consistent.

To overcome the issue, the VOSviewer software applies three transformations to the global solution.

1) Translation: The solution is centered at the origin.
2) Rotation: The solution is rotated in a way that the variance on the horizontal axes is maximized (principal component analysis).
3) Reflection: If the median of x11, …,*xn*1 is larger than 0, the solution is reflected in the vertical axis. If the median of *x*12, …,*xn*2 is larger than 0, the solution is reflected in the horizontal axis.

These three transformations ensure the replicability and the consistency of the resulting analysis.

An additional action to further increase the goodness of the results was using the fractional counting method as a normalization procedure to assign the same weight to a coauthored article [97]. Fractional counting means that a coauthored publication is assigned fractionally to each of the coauthors, with the overall weight of the publication equal to one (in the full counting method a coauthored publication is counted with a full weight of one for each coauthor, which implies that the overall weight of a publication is equal to the number of authors of the publication). For example, in the construction of a coauthorship network,

suppose an author has a publication with the other three authors. In the full counting method, the author will have three links with the other authors even if the publication is the same, while in the fractional counting method, each of the three different coauthorship links has a weight of 1/3 [36], [98].

Once the software has created the bibliometric network, it allows to also perform a cluster analysis of the results. The cluster analysis allows to identify groups of researchers that are more connected to others. More in general, cluster analysis is the task of grouping a set of objects in such a way that objects in the same group (a cluster) are more similar (in some sense or another) to each other than to those in other groups (clusters). For this purpose, VOSviewer software has a unified approach for mapping and clustering [34]. The unified approach implies that the visual map already shows a clusterization operated by the software. For the clusterization procedures, the software calculates the similarity matrix (calculated through the association strength as previously defined). For mapping purposes, for each node *i,* there is a vector x_i that indicates the spatial location of *i* in a *p*-dimensional map. For clustering, the algorithm imposes to find for each node *i* a positive integer that indicates the cluster to which *i* belongs. The software algorithm assigns a node to a specific cluster by solving an optimization problem on the basis of the minimization (or maximizing, is equivalent [99]) of the function

$$V\left(x_{i,}\ \ldots, x_n\right) = \sum_{1<j} s_{ij} d_{ij}^2 - \sum_{i<j} d_{ij} \tag{5}$$

with respect to $x_{1,}\ \ldots, x_n$. The element d_{ij} is the distance between the nodes *i* and *j* and it is determined by the following condition:

$$d_{ij} = \begin{cases} 0, & x_i = x_j \\ \frac{1}{\gamma} & x_i \neq x_j \end{cases}. \tag{6}$$

The parameter γ is the resolution parameter ($\gamma > 0$), and the higher the parameter, the higher the number of clusters that will be obtained.

The first term of the function (4) can be interpreted as a combined effect of attractive and repulsive forces between the nodes: the higher the distance and the similarity, the higher the attractiveness power. The algorithm minimizes the distance and maximizes the similarity. The overall effect of the two forces is given by the combined effect of similarity and distance.

VOSviewer uses colors to indicate the cluster to which a node has been assigned. The clustering technique used by VOSviewer is discussed by Waltman, Van Eck, and Noyons [34]. The technique requires an algorithm for solving an optimization problem. For this purpose, VOSviewer uses the smart local moving algorithm introduced by Waltman and Van Eck [100].To construct the co-occurrence map of keywords, the software extracts the text data from title and abstract; VOSviewer also relies on Apache OpenNLP toolkit to identify noun, verbs, adjectives etc., where a filter identifies noun phrases (phrases that have a noun at the head of the phrase and ends with a noun) and eventually converts the plurals into singular. Some noun phrases are very general and useless for the analysis, and the VOSviewer software can detect the general ones by assigning a relevance score to each noun phrase: the ones that cooccur randomly with other noun phrases are given a low relevance, while the noun phrases that occur mainly with a limited set of other noun phrases have a high relevance. The noun phrases with a low relevance score are dropped out, and the remaining noun phrases are the keyword terms that the software analyzes.

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