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Review

Bibliometric Review of Research on Knowledge Management and Sustainability, 1994–2018

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Abstract: Even though Knowledge Management (KM) is already widely used in business and public sector organisations, it also has potentially important implications when applied to the concept of sustainability. This research review aimed to examine the topography of research on KM and Sustainability. A total of 3025 articles from 1994 to 2018 were selected and analysed using bibliometric analysis to identify the growth trajectory of this literature, identify influential researchers and documents, explore the intellectual structure of the knowledge base and identify topical trends. The review found a knowledge of moderate but rapidly growing size. Key authors and documents were identified who can serve as guiding references for scholars entering this field of sustainability studies. Author co-citation analysis yielded a network map visualising the intellectual structure of this knowledge base which consisted of four Schools of Thought: Knowledge Management for Sustainability, Socio-Ecological System, Sustainability Science, KM for Sustainability Application. Keyword analysis highlighted climate change, learning, communities of practice and socio-economic management as topical trends emerging in the research front of this knowledge base. As the first bibliometric review of the KM and Sustainability literature, the findings from this paper establish a baseline for scholarship in this field which can be as a benchmark as the field continues to evolve in the future.

Keywords: knowledge management; knowledge; sustainability; sustainable development; bibliometric review

1. Introduction

The world is undergoing rapid changes that put strains and challenges on many aspects of life. We, as a society, are moving forward in continuous growth at the conscious and unconscious expenses of environmental, social and economic issues [1]. This is where the sustainability concept comes into play, with the aim to create a balanced interaction between natural resource utilisation, social advancement and economic investments for current needs and future potentials [1]. The United Nations has been pushing and developing this agenda from the Brundtland Report, Millennium Development Goals (MDGs) and the latest commencement of the Sustainable Development Goals (SDGs) [2–4]. The 17 SDGs are a collective direction to promote prosperity and sustainability by corporations of businesses, governments and communities [4].

Management science is an important branch of scientific study to sustainability, with one particular trajectory that is crucial in today's global economy being Knowledge Management (KM) [5]. KM aims to leverage knowledge within an organisation to maximise benefits [6]. With the knowledge-based perspective, an organisation can use knowledge embedded in multiple entities such as organisation culture, systems, guidelines or even its members to enhance productivity, efficiency and sustainable

competitiveness [7]. Even though KM is already widely used in the business context, it has potentially important implications when applied to the concept of sustainability [8].

Given the potential impact of effective KM on sustainability, this research review aimed to examine intellectual topography of this field. This paper addressed four research questions about the field of KM and Sustainability.

1. What is the topography of KM and Sustainability in terms of time and geography?
2. What are the influential contributions to the knowledge base on KM and Sustainability in terms of authors and documents?
3. What is the intellectual structure of the knowledge base on KM and Sustainability?
4. What is the 'research front' in terms of topical trends in studies KM and Sustainability?

To answer these questions, bibliometric review methods were used to analyse 3025 articles drawn from the Scopus database. Bibliometric reviews analyse meta-data associated with a body of research rather than substantive findings from studies. As both KM and Sustainability are gaining their momentum in the research field, there has been a number of previous research reviews on KM and Sustainability. A systematic review through manual selection of articles could offer insights on research gaps in the literature such as sustainability in Small to Medium Enterprises (SMEs), or guidelines to develop effective use of knowledge exchange for environmental management [9,10]. Nevertheless, the adoption of the scientific review through bibliometric method provided this paper a different, comprehensive view of the field [11–13]. The results could be more rigour and unbiased as the articles are drawn from large bibliometric database, which leads to a more comprehensive sample. Therefore, this research can be used as a reference for scholars who are interested in KM and Sustainability, or looking for ideas to further develop this field or related fields.

2. Conceptual Framework

A framework for this paper was developed by integrating these key concepts from KM and Sustainability. This included the sustainability framework, UN Sustainable Development Goals and KM processes and activities, which are depicted in Figure 1. This framework was used to scope related keywords and areas for the research review database.

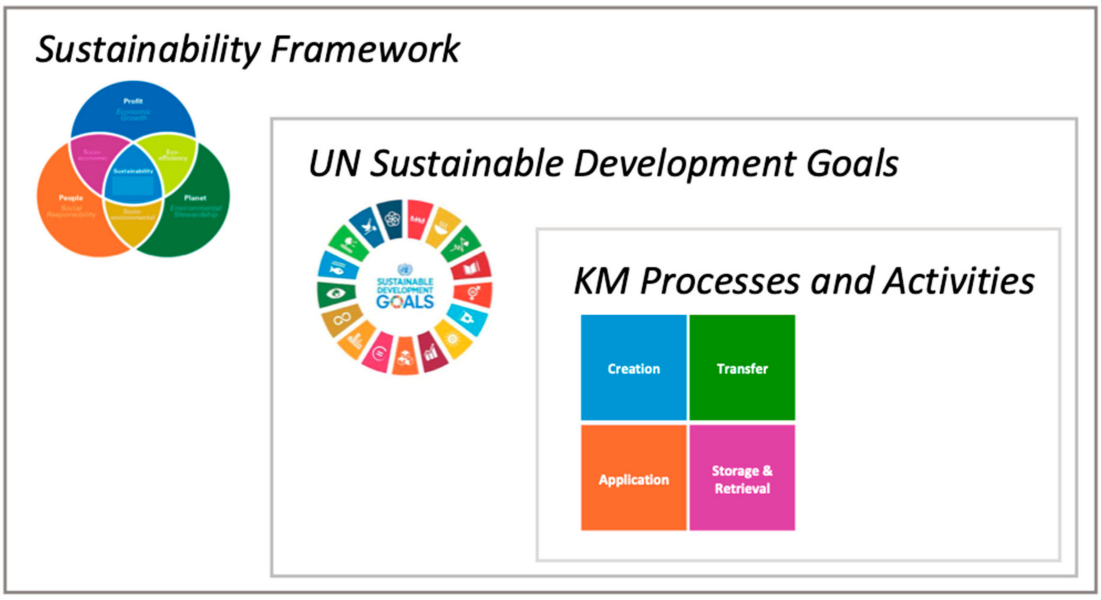

Figure 1. Framework on Knowledge Management (KM) and Sustainability.

The term sustainability is used in various contexts intended for different meanings; however, in this paper, sustainability is a framework referring to three overlapping pillars of environmental, social

and economic issues [14–16]. Environmental sustainability focuses on the input, waste and capacity of natural resources that need to be maintained in the environment [16]. Social sustainability touches upon social issues to create sustainable community such as social cohesion, equity, justice and inclusivity [17]. Economic sustainability is concerned with a sustained level of economic growth, development and productivity from limited capitals [15]. To further investigate sustainable development, the 17 SDGs can be used as a guideline of the world's current issues, which also fall into the three pillars of sustainability framework [18]. The interaction of the sustainability framework can illustrate a comprehensive view of sustainable development.

The use of KM can elevate sustainability through its core processes and activities. KM processes are comprised of four sets of activities dealing with the management of explicit and tacit knowledge within the organisation [7]. Firstly, knowledge creation is the development of new knowledge or replacement of the existing one, where innovations and solutions are generated. Secondly, knowledge storage and retrieval is referred to the memory that keep, hold and share knowledge across time and space, which helps reduce duplication of work and waste of resources. Thirdly, knowledge transfer is the exchange of knowledge at different levels between individuals, groups or organisations using various communication methods. Lastly, knowledge application is the process that knowledge is used in practice in order to bring competitive advantage to life. These KM processes are more effective with appropriate use of KM activities such as organisational culture, knowledge platform and community of practice [19,20].

3. Materials and Methods

The paper employed bibliometric method based on performance analysis and science mapping analysis procedures. On the one hand, statistical analysis is used to analyse the productivity performance of the bibliographic data associated with the published studies. On the other hand, science mapping analysis produces a visualisation of interactions between published studies within the extracted database as well as with related external database. Together, these procedures give the study insights on the structural and relational of knowledge base of KM and Sustainability. The results can provide previous, current and trending directions in this field for better understanding and future research.

3.1. Identification of Sources

To begin the process of bibliometric review, a database of relevant literatures had to be obtained. Search criteria were set from the developed framework based on KM and Sustainability topics (see Table 1). Combinations of keywords were searched to obtain bibliographic data of relevant researches. The results of documents to be included in the database had to fit with both KM and Sustainability topics.

Table 1. Keywords Used in Search Inquiry for KM and Sustainability.

Knowledge Management	Sustainability
Knowledge Management	Sustainability
Knowledge Management System	Sustainable Development
Knowledge Creation	Environmental Sustainability
Knowledge Acquisition	Social Sustainability
Knowledge Sharing	Economic Sustainability
Knowledge Transfer	Climate Change
Knowledge Adoption	
Knowledge Storage	
Knowledge Retrieval	
Knowledge Bank	
Knowledge Portal	
Knowledge Codification	

Table 1. *Cont.*

Knowledge Management	Sustainability
Knowledge Application	
Knowledge Verification	
Knowledge Based System	
Knowledge Integration	
Knowledge Behaviour	
Knowledge Worker	
Community of Practice	

Since the purpose of this research review was to gain an overview of KM and Sustainability, some inclusion and exclusion criteria were set. The database included journal articles, journal reviews, books, book chapters, conference papers and conference reviews. It excluded less reliable document types such as letter, short survey, note and article in press. The exclusion criteria were based on the quality, reliability and validity of the document, as the aforementioned types did not go through a peer-review process [21]. Even though documents from conferences may be viewed as less reliable than journal-based documents due to the lack of peer-review process, conference-based documents were the major contribution of the available documents. Moreover, the scope did not put any limit on geography, languages or time period as the research aims to achieve a topographical view of the field.

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) was followed for sources identification and extraction guideline and reporting [22]. The database was sourced and extracted from Scopus, an online abstract and citation database that contained bibliographic data such as article title, source title, author, author's affiliation, abstract and keywords. Scopus was selected as the source of database as it holds large journal coverage with more reliable quality articles [23]. Although its strongest domain is in social sciences, Scopus also has higher coverage in natural sciences and engineering, biomedical research and humanities [23,24]. Moreover, the platform can provide a complete bibliometric data with a simple extraction process, which is suitable for bibliometric analysis.

The initial results comprised of 4,461 articles from 1994 to 2018. Among these, 72 were screened out according to the research scope, while 64 were excluded due to topic relevance. The database was then extracted and downloaded as CVS files. These files were input into VosViewer, a bibliometric network software program. This freely available program can handle a large database, while it can construct visualised graphical representations of the network. The graphics can display the cluster, density, proximity and labels of the network map, which is useful in interpreting science mapping analysis [25]. After duplicated items were removed, the final database consisted of 3025 articles (Scopus = 843; VosViewer = 457). These steps are depicted in Figure 2.

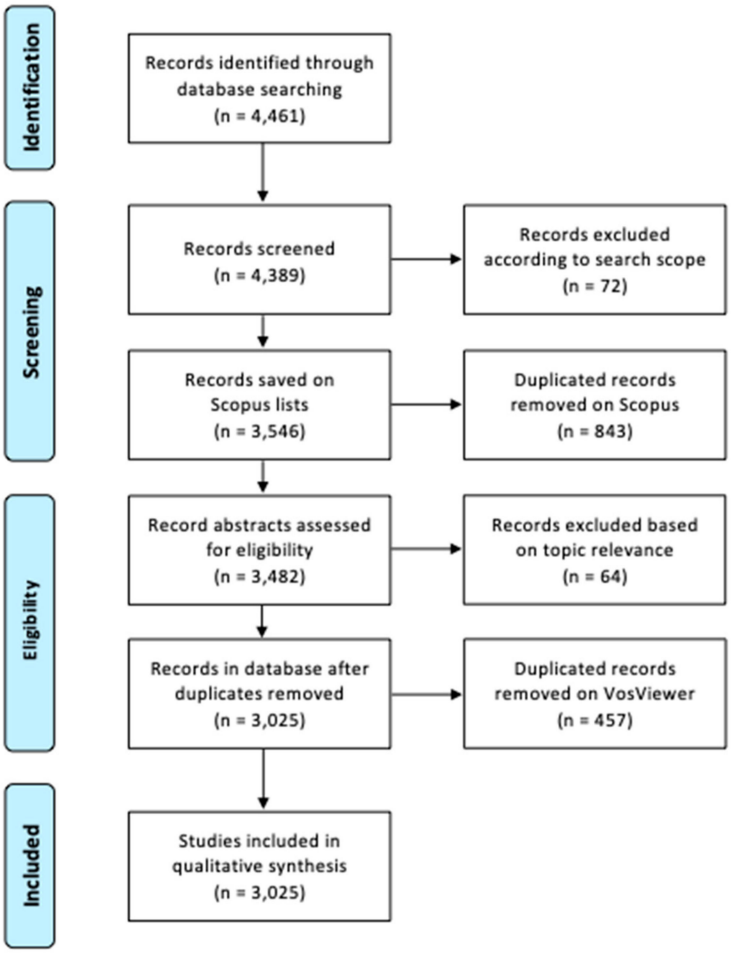

Figure 2. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram for KM and Sustainability database sourcing and screening.

3.2. Data Analysis

VosViewer software can run quantitative methods for performance and science mapping analyses. There are three main approaches to science mapping used in the paper to illustrate structural and relationship knowledge bases, which are citation, co-citation and co-occurrence analyses. Citation analysis examines the direct link between articles when one article references another article within the database [26]. From the database, it can generate a series of productivity and performance indicators such as numbers of citation on document, author, source, organisation and country. This citation analyses usually come in a form of the top lists, which can be extracted from VosViewer and input into Microsoft Excel to be ranked, graphed or sought for more related information from the database, for instances, h-index and expertise areas of the author.

At the same time, in addition to citation analysis, VosViewer can conduct co-citation analysis to examine the inter-connection between documents, authors or journals. This is done by measuring how frequent two units are cited together, as this indicates that their contents are likely to be related to each other [27]. Moreover, co-citation is not restricted to articles within the extracted database but linked with external database when analysis is performed in VosViewer. Additionally, with co-citation analysis, canonical documents or authors related to the studied topics can be identified. Similar to co-citation, co-occurrence is an analysis referring to groups of keywords that appear in the same place in multiple occasions over a period of time [12,13].

Each approach of science mapping analysis is intended for different purposes. Citation analysis is a measure of influence of a particular unit through the counts of direct references within the database. On the other hand, co-citation and co-occurrence analyses can provide inter-relationships of cited

records beyond the extracted database [28]. Nonetheless, using these analyses together can offer a comprehensive picture of how influential and canonical units in KM and Sustainability are interlinked across multi-disciplines over time.

Despite the usefulness in identifying important articles, authors or themes from bibliometric analysis, there are limitations in activity and impact of publications that should be considered. Activity limitations pose a concern on the number of cited items in the reference list. When a publication's length is limited, authors usually include only the most influential works to the publication, resulting in incomplete list [29]. In contrasts, there are cases where some works included in the reference list are not actually used in the research. Impact limitations may cause bias in the research review through the use of the readily available citation rate, also known as impact factor [30]. Journal impact factor is determined by the citation rate of articles, but it does not always reflect the quality of individual journal articles. The field of research also determines the impact factor, where fields with larger size or connection with other fields tend to have a higher impact factor. Hence, these points should be taken into account when interpreting the analyses.

4. Results

This section presented the results around the four research questions regarding the topography of KM and Sustainability field. Patterns were identified based on performance and science mapping analyses. It should be noted that although the following results are relevant evidences to the research, they are limited to the analyses carried out with the bibliometric method.

4.1. Growth Trajectory and Geographical Distribution of the KM and Sustainability Literature

The first research question about the topography in terms of time was depicted in Figure 3, where growth trajectory showed a rising trend of interest in KM and Sustainability. The knowledge base comprised of 3025 documents, including 51% conference papers, 38% journal articles, 4% journal reviews 4%, 2% conference reviews, book chapters and 1% books. The literature initiated in 1994 and gradually emerged during the 1990s and early 2000s. It first began to show evidence of increasing popularity in 2004, when the number of publications doubled compared to the previous year. The number of publications peaked in 2018 with 351 documents. Thus, KM and Sustainability gained continuously increasing interest among scholars over the past 25 years until the present day.

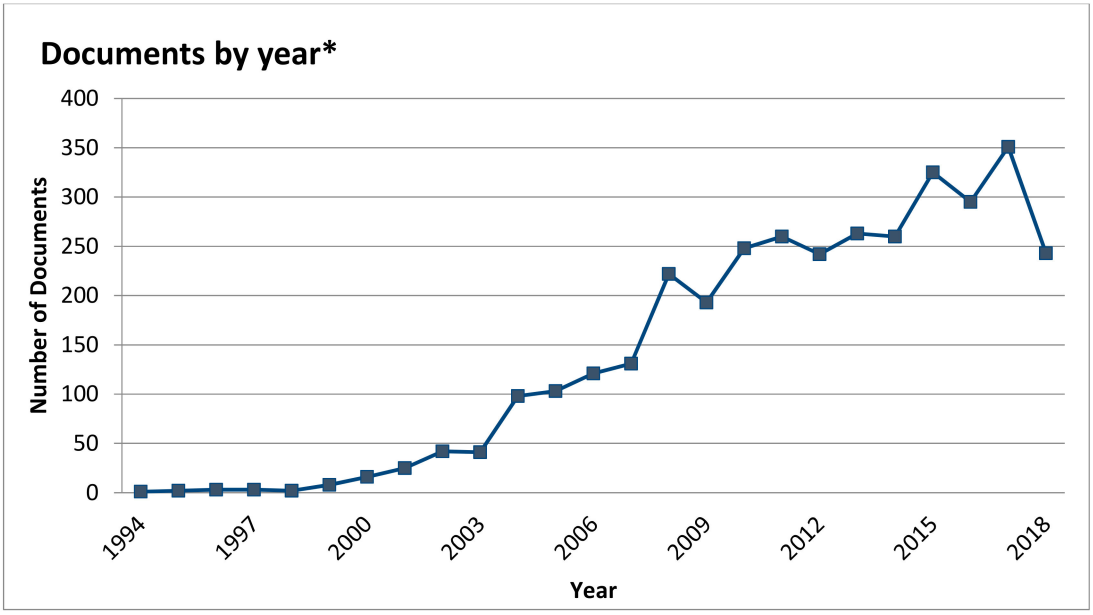

Figure 3. Growth trajectory of the literature in knowledge management and sustainability, 1994–2018 (n = 3025). * Data retrieved in December 2018.

The heat map depicting the distribution of KM and Sustainability literature by country was shown in Figure 4. It revealed dominant contribution from the USA, UK, China and Australia. Other major contributors with over 100 publications included Germany, Canada, Malaysia and the Netherlands. Publications from these countries represented a majority of the collected knowledge base. It was as expected that there would be a predominance of scholarship from the Anglo-American region, although it was interesting to see the emergence of a significant body of Chinese and Malaysian scholarship in the field. Nonetheless, the broader interest in KM and Sustainability among scholars in both developed and developing countries was notable.

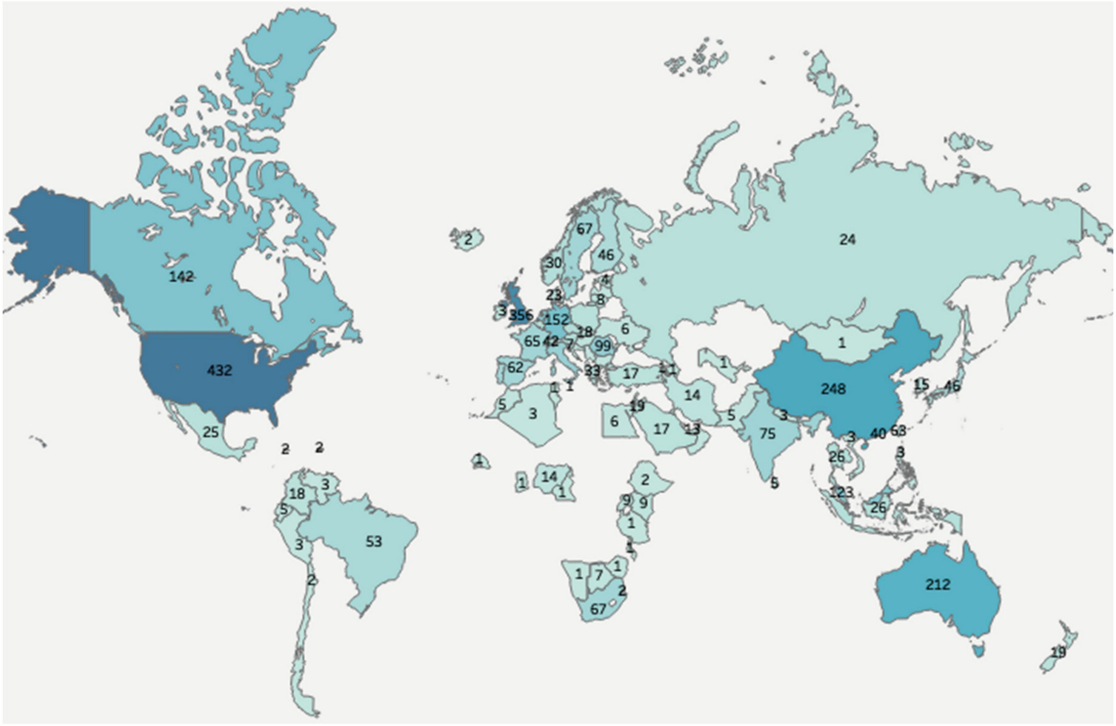

Figure 4. Global distribution of literature in knowledge management and sustainability, 1994–2018 (n = 3025).

4.2. Key Authors and Documents

The second research question aimed to identify the main researchers and documents in the line of inquiry on KM and Sustainability. A number of analyses were conducted to find out about most productive authors, top cited authors and most co-cited authors by KM and Sustainability articles. Additional information about the authors was included in the result tables, including h-index and research focus.

The most productive authors in this literature were Thomson (11 documents, 58 citations), Y. Zhang (11/29), J. Wang (9/63), Scholz (8/371), Liu (8/278), H. Zhang (8/4), X. Zhang (7/234), H. Li (7/83) and W. Wang (7/29) and H. Wang (7/3). The list of most productive scholars writing on KM and Sustainability came from China (not tabled).

Citation analysis, however, offered a different picture on contributions to this literature. The top 20 cited authors were extracted from the database by Scopus citation analysis (see Table 2). The list showed that Helbing ranked first as the most frequently cited author by articles in the field of KM and Sustainability. He produced two documents related to the field, which accumulated to 798 citations by other articles found within the database. This was followed by Bettencourt, Kuhnert, Lobo and West. These authors had 782 citations from only one document. This means that they had the highest Citation per Document (CPD), which was even higher than the most cited author Helbing with a CPD

of 399. It is notable that the most highly cited authors differ substantially from the most productive authors, as measured by the number of Scopus documents authored.

Table 2. Most highly-cited authors writing on KM and Sustainability.

Author	University Affiliation	Country	Documents	Citations	CPD [1]	H-Index
D. Helbing	ETH Zurich	Switzerland	2	798	399	70
L. Bettencourt	U. of Chicago	USA [2]	1	782	782	32
C. Kühnert	Dresden U. of Technology	Germany	1	782	782	6
J. Lobo	Arizona State U.	USA	1	782	782	19
G. B. West	U. of Oxford	UK [3]	1	782	782	44
L. C. Stringer	U. of Leeds	UK	5	586	117	32
R. Phaal	U. of Cambridge	UK	3	580	193	26
M. S. Reed	Newcastle U.	UK	4	564	141	38
J. H. Dyer	Brigham Young U.	USA	1	555	555	20
N. W. Hatch	Brigham Young U.	USA	1	555	555	9
A. C. Evely	U. of St Andrews	UK	3	546	182	14
C. M. Raymond	Swedish U. of Agricultural Sciences	Sweden	3	485	162	26
I. Fazey	U. of St Andrews	UK	2	475	238	33
K. Yew Wong	U. Teknologi Malaysia	Malaysia	1	436	436	25
Y. Caloghirou	NTUA [4]	Greece	1	424	424	15
I. Kastelli	NTUA	Greece	1	424	424	3
A. Tsakanikas	NTUA	Greece	1	424	424	7
L. Van Kerkhoff	Australia National U.	Australia	3	388	129	16
P. Almeida	Georgetown U.	USA	1	385	385	13
A. Phene	U. of Utah	USA	1	385	385	10

[1] CPD = citations per document, [2] United Kingdom, [3] United States of America, [4] National Technological University of Athens.

Furthermore, influential researchers who have influenced the field of KM and Sustainability were identified by author co-citation analysis (see Table 3). Nonaka was ranked first, followed by Wenger and Folke. Interestingly, Reed, who appeared in the top author co-citation list, could also be found in the most highly cited author table. Furthermore, from the list, there was an equal amount of authors in either topical domain of KM or sustainability. H-index of these authors showed higher numbers on average than authors who were highly cited or productive.

Table 3. Most highly co-cited authors of articles on KM and Sustainability.

Author	Research Focus	University/Affiliation	Country	Number of Citations	Link Strength	H-Index
I. Nonaka	Know Creation	Nhitotsubashi U.	Japan	631	3633	29
E. Wenger	Comm of Practice	Wenger-Trayner	USA	404	1703	54
C. Folke	Ecology & Society	Stockholm U.	Sweden	265	5689	127
R. W. Scholz	Sust Science	ETH Zurich [1]	Switzerland	254	11110	59
H. Takeuchi	Know Creation	Harvard U.	USA	251	1528	9
F. Berkes	Social-Eco System	U. of Manitoba	Canada	236	4047	100
L. Prusak	KM	Columbia U.	USA	184	1129	46
T. Davenport	Info Systems	Babson College	USA	176	1121	88
C. Argyris	Learning Orgs	Harvard U.	USA	154	1906	23
E. Ostrom	Inst'l Analysis	Indiana U.	USA	152	3110	143
A. Wiek	Transform Sust	Arizona State U.	USA	145	3987	43
M. E. Porter	Econ Devel	Harvard U.	USA	133	806	162
M. S. Reed	Stakeholder Part	Newcastle U.	UK	133	1915	47
M. Polanyi	Tacit Knowledge	U. of Oxford	UK	130	1322	25
R. M. Grant	Strategic Manage	Bocconi U.	Italy	129	1143	41
C. S. Holling	Ecological Sci	U. of Florida	USA	126	3122	33
W. C. Clark	Sust Development	Harvard U.	USA	120	2404	48
D. J. Teece	Strategic Manage	UC Berkeley	USA	120	803	103
J. Lave	Geology	CRPG-CNRS [2]	France	119	722	32
C. Pahl-Wostl	Resources Man	U. of Osnabrück	Germany	112	1250	62
M. Alavi	Info Systems	Georgia Tech [3]	USA	112	652	40

[1] Swiss Federal Institute of Technology in Zurich, [2] The Centre de Recherches Pétrographiques et Géochimiques - The French National Centre for Scientific Research, [3] Georgia Institute of Technology.

Next, we sought to pinpoint influential documents relevant to KM and Sustainability. A document citation analysis was performed with a minimum number of 180 citations, resulting in the top 20 most highly-cited documents within the field of KM and Sustainability (see Table 4). The first rank was "Growth, innovation, scaling, and the pace of life in cities" [31]. This was followed by "Human capital and learning as a source of sustainable competitive" by Hatch and Dyer, and Phaal, Farrukh and Probert's "Technology roadmapping—A planning framework for evolution and revolution" [32,33]. The authors of these top-cited articles were also the most highly-cited authors in the field. The documents were categorised into each of the three sustainability Schools of Thought or viewed as an integrated one. It was found that economic-related documents were the highest, with 40% of the list. Other documents were found to be 30% in the Environmental School and 15% in the Social School. The last 15% were located in the Integrated School.

Table 4. Most highly-cited documents in the field of KM and Sustainability.

Author/Year	Title	Scopus Citations	School of Thought
Bettencourt (2007)	Growth, innovation, scaling, and the pace of life in cities [31]	782	Social
Hatch (2004)	Human capital and learning as a source of sustainable competitive advantage [32]	555	Economic
Phaal (2004)	Technology roadmapping—A planning framework for evolution and revolution [33]	519	Economic
Yew Wong (2005)	Critical success factors for implementing knowledge management in small and medium enterprises [34]	436	Economic
Caloghirou (2004)	Internal capabilities and external knowledge sources: Complements or substitutes for innovative [35]	424	Economic
Almeida (2004)	Subsidiaries and knowledge creation: The influence of the MNC and host country on innovation [36]	385	Economic
Raymond (2010)	Integrating local and scientific knowledge for environmental management [37]	367	Environ-mental
Schipper (2006)	Disaster risk, climate change and international development [38]	292	Environ-mental
Chandrase-garan (2013)	The evolution, challenges, and future of knowledge representation in product design systems [39]	285	Economic
Liu (2013)	Framing sustainability in a telecoupled world [40]	277	Integrated
Roux (2006)	Bridging the science-management divide: Moving from unidirectional knowledge transfer to [41]	275	Social
Van Kerkhoff (2006)	Linking knowledge and action for sustainable development [42]	274	Integrated
Olsen (2007)	The clean development mechanism's contribution to sustainable development: A review [43]	240	Environ-mental
Nambisan (1999)	Organizational mechanisms for enhancing user innovation in information technology [44]	238	Economic
Dao (2011)	From green to sustainability: Information Technology and an integrated sustainability framework [45]	229	Environ-mental
Chambers (2013)	The dynamic sustainability framework: Addressing the paradox of sustainment amid ongoing change [46]	226	Integrated
Viviroli (2011)	Climate change and mountain water resources: Overview and recommendations for research [47]	214	Environ
Shen (2011)	The application of urban sustainability indicators—A comparison between various practices [48]	205	Social
Fuhrer (2003)	Ecological issues related to ozone: Agricultural issues [49]	193	Environ-mental
Sharif (2006)	Emergence and development of the National Innovation Systems concept [50]	187	Economic

Document co-citation analysis can also be used to identify influential documents that have been referenced by articles in KM and Sustainability. The top three documents from the analysis were "Dynamic theory of organizational knowledge creation" [51], "The knowledge-creating company: how Japanese companies create the dynamics of innovation" [52] and "Absorptive capacity: a new perspective on learning and innovation" [53] (not tabled). These articles can be called canonical as they are frequently co-cited not only at one point in time, but throughout the period of KM and Sustainability study.

4.3. Intellectual Structure of the Knowledge Base on KM and Sustainability

The third research question intended to investigate the intellectual structure of the knowledge base regarding KM and Sustainability. According to Zupic and Cater, intellectual structure refers to the examined composition of research topical domains and their interrelationships [27]. In order to answer this research question, a co-citation of author analysis with a minimum of 50 occurrences was used to extract important keywords within the database and visualise the interaction between them. The analysis categorised authors into four different coloured clusters, meaning that there are four main Schools of Thought within the field of KM and Sustainability (see Figure 5). The red and green clusters were largest, thereby suggested greater breadth of influence in this field. The clusters did not overlap with each other; however, a group of nodes in the middle of the figure shows the links between KM and Sustainability. The yellow cluster also illustrated these interactions. The green cluster was closely related to the blue cluster, as seen by their proximity.

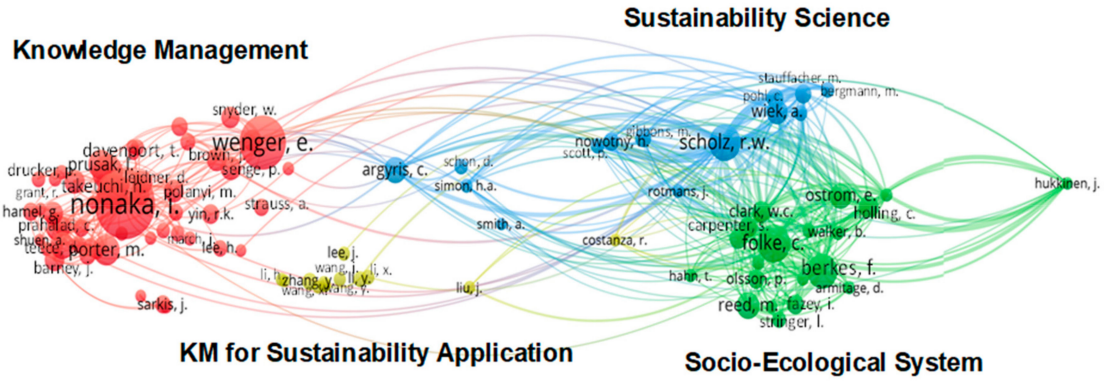

Figure 5. Author co-citation map depicting the intellectual structure of the knowledge base on KM and Sustainability (threshold 55 author co-citations, display 100 authors).

From the co-cited authors, field of their expertise could be used to interpret the School of Thought. In addition, the intellectual structure from the co-citation analysis could identify key topics within each School of Thought. The red cluster, which was largest, represents a School of Thought on Knowledge Management for Sustainability (KMS). The predominant nodes included key authors in KM such as Nonaka [51,52], Wenger [54], Takeuchi [52] and Prusak [55]. The dominant sub-topics in the KMS were knowledge creation (Nonaka and Takeuchi), community of practice (Wenger), information systems (Davenport [55]), commerce (Porter [56], Grant [57] and Teece [58]) and tacit knowledge (Polanyi [59]). It can be seen that these authors either published literature on overall KM, or one of the four KM processes.

With Berkes, Folke and Reed dominating the green cluster, this could be identified as the Socio-Ecological System School of Thought. It includes both social and environmental aspects of sustainable development. Authors within this area include experts in the fields of ecology and society (Folke [60,61], Berkes [61], Holling [62]), institutional analysis (Ostrom [63]) and stakeholder participation (Reed [37,64]). This cluster focused on the interactions between people and their surroundings, either a natural or a constructed environment and society. An example of KM and Sustainability research in Socio-Ecological System area is the case study about the use of integrated local

and scientific knowledge for environmental project design and implementation in the UK, Solomon Islands and Australia [35].

The blue cluster claimed the Sustainability Science School of Thought, where Scholz [65,66], Wiek [67], Nowotny [68] and Argyris [69–71] were the key authors. The sub-topics within this School of Thought relate to creating competencies in sustainability, such as education (Scholz [65,66] and Nowotny [68]), research (Wiek [67]) and organisational learning (Argyris [69–71]). Sustainability science covered different methods to gain better understanding of sustainability mechanisms. For example, knowledge brokerage as a part of knowledge transfer is used to study approaches and techniques of environmental and sustainability assessments [72].

The last and smallest School of Thought was the yellow cluster, which could be seen as KM for Sustainability Application by looking at the works of Y. Zhang [73], J. Wang [74] and Y. Li [75]. Although knowledge application is a part of the four KM processes, this cluster was formed separately because it concerns KM application specifically in sustainability contexts. KM for sustainability application could be considered as the use of any KM process and sustainability concepts in various fields such as water resource management, agricultural landscaping, energy and urbanisation. For instances, knowledge dissemination in sustainable agriculture in China through web portal, voice-based service, text-based service, online community, interactive video conferencing service, mobile internet based service and unified multi-channel service [73].

4.4. Topical Trends in the KM and Sustainability Knowledge Base

The last research question concerned the key topics studied by scholars researching KM and Sustainability. The top 50 co-keyword analysis was used to illustrate key issues in KM and Sustainability, which could be categorised into four clusters (see Figure 6). Each cluster was given a name to represent the topical theme based on related keywords: "Socio-Environmental Sustainability" (red), "Strategy and Management" (green), "Macroeconomic Management" (blue) and "Knowledge Creation" (yellow).

An example of a Socio-Environmental Sustainability study is about the use of KM tools to support sustainable forestry, such as intelligent agents, expert systems and cognitive maps for planning process or web-based tool for participatory planning [76]. Under the Strategy and Management theme, an example is a study about the integration of information system, knowledge and supply chain to develop sustainability capabilities beyond mere energy consumption reduction [45]. Another example study can be within both Macroeconomic Management and Knowledge creation themes. It discussed about the use of knowledge creation to build an open-ended innovation and improvements in order to increase standards of living [31].

The same co-occurrence of keywords analysis can be used to identify the research front in terms of topical trends in KM and Sustainability. Instead of viewing the coloured clusters of the network map, VOSviewer could present an overlay visualisation based on the average publication year of documents associated with specific keywords (see Figure 7). The older topics were in blue, whereas more recent topics were in yellow. Together with the points of consideration including size of the node and link strength, trends of topics could be identified using this method.

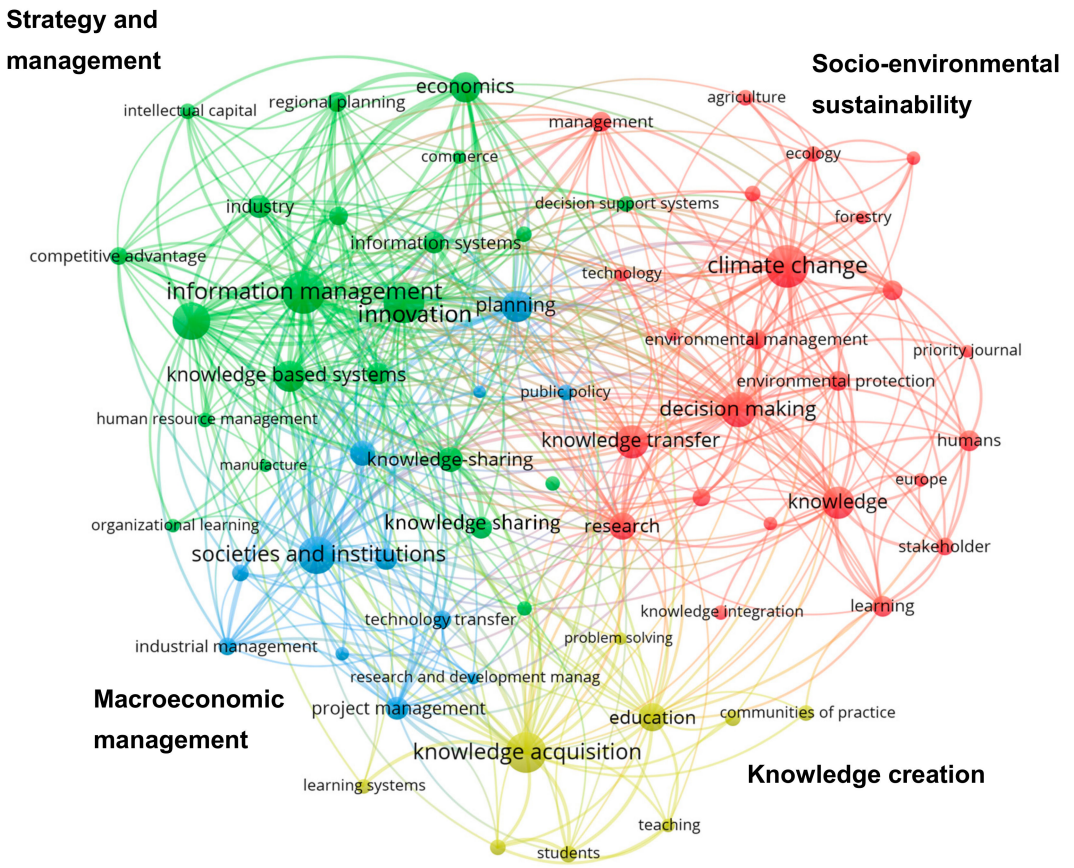

Figure 6. Analysis of keyword co-occurrence of KM and Sustainability, 50 minimum number of word occurrences, top 50 (n = 3025).

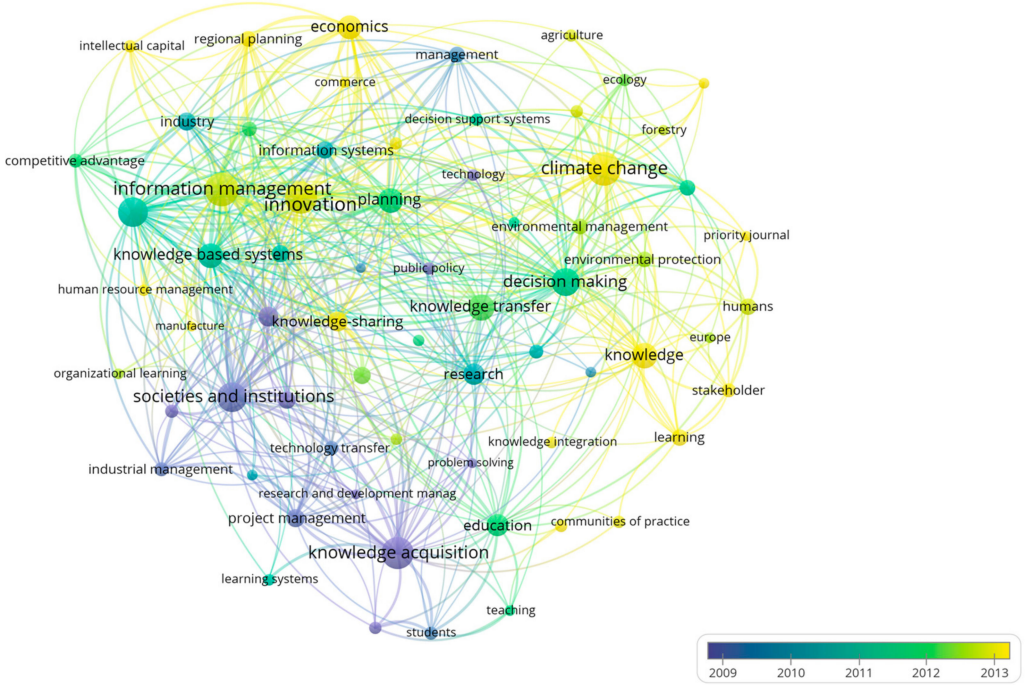

Figure 7. Overlay visualisation of keyword co-occurrence analysis of KM and Sustainability (threshold of 50 keyword word occurrences, display 67).

The overlay visualisation of the keyword co-occurrence analysis informed the emerging topical trends. Previously, keywords within the macroeconomic management and knowledge creation themes were more popular in this domain of research. In contrast, the yellow and bright green coloured nodes reflect emerging topics that scholars are currently being studied with greater frequency. The size of these nodes suggested that they represent an emerging critical mass of interest among scholars.

It could be seen that topics associated with macroeconomic management and strategy and management represent relatively mature lines of inquiry. Topics within these themes included societies and institutions [31–33,35,36,39], knowledge acquisition [35,39,42], project management [34,37,39] and information systems [33,34,42,45]. For example, knowledge management application in Australian transportation infrastructure projects to promote sustainability [77]. The latter topics of interest included climate change [31,33,38,40], knowledge [31,32,36,37], learning [31–33] and communities of practice [37,38,41]. These topics were a part of socio-environmental sustainability and knowledge creation. For instance, a study about adapting to climate change stated that natural resource management organisations could enhance knowledge transfer through tailored information delivery to improve exchanges between stakeholders [78].

Additional trending topics include economics [31,42,45], regional planning [36,38,47,48], commerce [34,39,40,66] and intellectual capital [34,41,45]. These topics were largely located in the strategy and management theme in social and economic aspects. An example of a study about KM and regional planning is about the co-creation in sustainable urban planning where KM processes are adopted to facilitate collaboration in Canada [79]. Another example of a trending topic is the study about the application of KM and intellectual capital to promote sustainable development in Italian healthcare organisations [80].

5. Discussion

This research adopted a bibliometric method with the objective to scientifically review the field of KM and Sustainability. This section of the paper highlights limitations to the methodology as well as offering the authors' interpretation of the findings.

5.1. Limitations

The limitations of this review arise primarily from the nature of the database of articles soured on KM and Sustainability. Firstly, it should be noted that, due to limitations of Scopus, the database, though comprehensive, does not represent all extant research on KM and Sustainability. Related to this limitation, the authors also noted that a majority of the database consisted of conference papers. They may not, in all cases, have passed the same rigorous peer review process that is applied to journal articles. Secondly, as mentioned earlier in the materials and methods section, there are activity and impact limitations of the bibliometric approach that could lead to biased citation analysis in the database. Finally, bibliometric reviews, by their nature, do not delve deeply into the findings of specific studies. Thus, this review was conceptualised with the goal of documenting the evolution of the KM's contribution to sustainability literature and framing the emerging intellectual structure of this field of sustainability inquiry.

5.2. Interpretation and Implications

In the results section, the authors presented a topographical overview of KM and Sustainability research. As the majority of the database consisted of conference papers, it can be assumed that studies of KM in sustainability are only beginning to become established in mainstream research journals. The accelerating growth trajectory of this literature suggests, however, that this field is rapidly progressing in line with changing management practices that increasingly seek to incorporate new technologies for managing knowledge around the world [81].

Multiple analyses indicated that most authors contributing to this literature came from developed countries such as the USA and in Europe. Their leadership in this literature reflects efforts in

economically developed societies to achieve SDGs in parallel with economic growth [82]. The less frequent representation of authors from developing countries may reflect broader patterns of scholarly productivity or later adoption of KM practices for sustainability in developing countries [83–85]. Nonetheless, given the increasing urgency and importance of sustainability issues in developing societies, we expect that future reviews will document a larger proportion of documents on this topic authored in these countries.

As a case in point, we note the large number of studies authored by scholars from China identified in this review. In contrast with past practices, China's emerging regional development strategy focuses on the effective implementation of economic development while sustaining environmental and social development. Thus, it appears that KM for sustainability is part of China's strategy for rapid coping with unbalanced and unsustainable economic growth [8,86].

Together, these trends with respect to the geographical distribution of this literature lead to two recommendations. First, although our review did not examine findings from specific studies, our bibliometric findings reinforce the assertion that KM represents a highly salient enabler for sustainability in developing as well as developed societies. Second, these findings suggest that scholars prioritise research on the application of KM for sustainability in developing societies. This research will have broad and immediate applicability across a wide range of international contexts.

The identification of highly cited authors and documents through a series of citation and co-citation analyses has multiple implications. First, it honours the contributions of scholars who have pioneered the development of this subfield of sustainability research. Second, we suggest that these authors and documents can be used as a 'reading list' for those who wish to learn more about this topic. This is a highly practical outcome for an emerging field of inquiry. The empirical identification of key authors and documents will enable newcomers to this field of inquiry to 'get up to speed' much more quickly than random searches of the literature.

The overlap between author citation and co-citation lists showed that Reed is directly and indirectly influential in KM and Sustainability studies. Several publications by Reed revolved around environmental management and stakeholder participation [10,37,64,87]. Traditionally, KM would start from an individual's knowledge; however, this evidenced that collective knowledge from stakeholders as a result of participatory process is crucial for KM in Sustainability.

Canonical documents identified by document co-citation analysis were not only part of the reading suggestion but hold their importance throughout time due to the dynamic nature of their concepts. This also implied that learning and knowledge creation are fundamental to KM and Sustainability. Most KM concepts are multi-disciplinary, which are pulled from other fields such as psychology, information system and technology or organisational science. Cohen's study on absorptive capacity fits with this statement, as the learning theory is a part of cognitive science [53]. However, the top two co-cited documents by Nonaka [51] and Nonaka with Takeuchi [52] focused on the SECI knowledge creation model (Socialisation, Externalisation, Combination and Internalisation), which is one of a handful of ground-based KM theories. Nonaka and his co-authors have been continuously developing the model since the early 1990s. As the SECI model is a spiral, context-sensitive process, the dynamic nature of it is adopted and studied in different settings.

Another key finding from this review lies in the identification of the intellectual structure of KM and Sustainability research. Notably, because co-citation analysis examines the reference lists of documents in the authors' database, this analysis is able to reveal the constellation of relevant themes located inside and outside of knowledge management and sustainability. Referring to Figure 5, author co-citation analysis revealed four coherent, inter-related Schools of Thought that comprise the knowledge base on KM and Sustainability: KM, Socio-Ecological System, Sustainability Science, KM for Sustainability Application.

KM emerged as the predominant School of Thought, confirming its conceptual centrality to this literature that linked back to KM as the core of the paper's conceptual framework. Leading KM scholars such as Nonaka and Takeuchi established the widely-used knowledge creation model,

SECI, which has been applied widely by proponents of knowledge management in sustainability projects [51,52]. Since the SECI model is an adaptable process, it has been applied to sustainability initiatives in various contexts, ranging from family businesses to larger corporations and financial firms [88,89]. SECI processes have also shaped the use of externalisation modes of knowledge creation in enhancing team performance [90]. Research by Davenport and Prusak has established knowledge as a source of competitive advantage with salient implications for strengthening the sustainability of organizations [55]. Their "resource-based perspective" proposes tools for building capabilities and also protect organisations from knowledge drain [91,92].

Folk and Berkes, the top two highly co-cited authors in the Socio-Ecological System School of Thought, have elaborated how organizations build resilience through social and ecological systems [61,62]. The nodes of this School were generally quite compact thereby suggesting strong intellectual affiliation among authors as well as the concepts and practices within this line of inquiry. This could be explained by the fact that elements within the socio-ecological system can be found in two of the three sustainability pillars, aligning with the conceptual framework. Moreover, these elements are systemically related and need to be balanced so they are closely connected [93]. For instances, behaviour change in land use in one region could impact water resources in another.

Within the Sustainability Science School, Scholz's research has highlighted the importance of sustainability education [65,66]. Notably, he was also one of the most productive authors in the KM and Sustainability field. This highlights education, learning and knowledge sharing as key processes within KM and Sustainability. This view is reinforced by Argyris' location in this School. His research on individual and organizational learning has shaped the application of KM to the solution of sustainability issues [69–71]. More specifically, Argyris introduced the terms single-loop and double-loop learning, where the former focuses on problem solving and the latter involves rethinking and modifying the way to solve such problem [71]. It is only through double-loop learning that managers and organizations are able to create "sustainable solutions" to the complex problems that characterise sustainability science.

In comparison to the other Schools, the KM for Sustainability Application School of Thought was relatively small in terms of size and influence. Referring to the conceptual framework, KM application is only a fraction of KM processes used for sustainability, which could explain the size and influence of this School of Thought. A number of Chinese authors (e.g., J. Liu, Y. Zhang, J. Wang, H. Li) are the intellectual leaders of this School [40,73–75]. This again highlights the effort that China is putting into KM and Sustainability initiatives.

On the author co-citation map, the Socio-Ecological System and Sustainability Science Schools were close in proximity, as they both concerned sustainability, where one was about 'what', while the other was about 'how'. These two Schools of Thought were on the opposite side of KM. This could be because KM is a context-sensitive discipline that can be applied to several fields, and sustainability is one of them. However, some co-cited authors from the sustainability science were placed closer to KM, because education as an approach to understand sustainability is closely related to knowledge creation.

In contrast, the KM School was located at some distance from the others, reflecting its broader focus. The KM for Sustainability Application School of Thought located in the middle of the map, with less dense links to the other Schools. This is in line with the conceptual framework that KM application, as part of KM processes, is central to the framework. Furthermore, this is interesting in that the School is largely comprised of Chinese scholars. This suggests that this School may be developing as a distinctive School grounded in 'indigenous' KM practices used to address sustainability challenges in the Chinese (developing) context.

These observations concerning the intellectual structure of the KM and Sustainability knowledge base yield recommendations for future research. First, they reinforce and extend our earlier recommendation for prioritizing research on KM and Sustainability in developing societies. More specifically, they suggest that the "Chinese experience" in adopting and refining KM practices to sustainability challenges may hold value for other societies, especially developing societies. Second, the identification of these Schools of Thought also offer points of reference or foci for subsequent

reviews of research using research synthesis methods that examine the conceptual models, methods, findings of studies. Each of these Schools of Thought should be reviewed. Finally, regarding our discussion of key authors and documents, the identification of these Schools of Thought also represents coherent, empirically derived conceptual pillars of KM and Sustainability research.

Keyword analyses identified underlying themes that complement those identified through co-citation analysis. Topical trends identified from the network map were in line with global trends. Climate change was a trending topic as it is directly aligned with one of the key SDGs [3]. Within knowledge and learning trends, advancements in information technology allow people to connect without limitations in time and space [94]. This application of Information Technology (IT) to KM is not limited to the real world but can also be taken place in virtual world with those who participate in the community of practice to share knowledge [95,96]. If used appropriately, IT platforms enable KM to enhance the dissemination of sustainability solutions more broadly (e.g., knowledge banks, knowledge exchange platforms) [14,97].

Socio-economic management, including sub-topics such as economics, regional planning, commerce and intellectual capital, represents emerging trends in the field of KM and Sustainability. We found that state, private and non-profit organisations are increasingly incorporating KM practices in order to achieve SDG goals [3]. Thus, our findings suggest a trend towards greater cooperation between societies and organisations in planning for sustainability [98], with the implication that KM will play an increasingly important in global sustainability efforts.

6. Conclusions

While the authors found numerous reviews of research on KM and on sustainability, few have examined the interrelationship between these two domains of knowledge [9,10]. Moreover, none, to date, applied the bibliometric review method to this topic. Thus, the findings from this review provide a baseline against which the future development of this line of sustainability research can be assessed. Moreover, we hope that our findings can be used to guide future research that seeks to explore the interrelationship between KM and Sustainability.

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