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Managing ICT for Sustainable Education: Research Analysis in the Context of Higher Education

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Abstract: The use of information and communication technologies (ICTs) for the benefit of the environment favors the development of a sustainable education, which will help to train more responsible and aware students. The management of educational technology in the context of a sustainable higher education must achieve the internalization of ethics and the sustainable development of humanity. The main objective of this study is to, at a global level, examine the research during the period 2000–2019 on the management of ICTs for sustainable education in the context of higher education. Global research trends on this topic during the period 2000–2019 have been analyzed. Consequently, bibliometric techniques have been applied to a sample of 1814 articles selected from the Scopus database. The results provided data on the scientific productivity of the journal, authors, research institutions, and countries that contribute to the development of this topic. The evidence reveals an exponential trend, mainly in the last five years. In addition, current and future lines of research have been identified. Research at an international level presents a growing trend of publication that allows determination of the relevance of research on ICT management to achieve sustainable education in the context of higher education. This study makes it possible to establish the relationship between science, sustainability, and technology in higher education institutions, and to base the decision-making process for the driving agents of this area of knowledge.

Keywords: sustainable education; higher education; ICT; management; educational technology; research

1. Introduction

In recent years, higher educational institutions have been experiencing important changes derived from technological, sustainable, and social trends towards digitization [1,2]. The adoption of information and communication technologies (ICTs) by educational institutions is conceived as an interconnected environment that enables student digital learning [3]. Moreover, ICTs help learners to make informed decisions and adopt responsible measures for the integrity of the environment and the viability of the economy. This link fosters a quality, comprehensive, and transformative education that affects content and learning outcomes [4,5].

In this context, the learning content brings together issues related to climate change, disaster risk reduction, and sustainable consumption and production in the curricula [6]. Furthermore, both pedagogy and learning environments understand teaching and learning in an interactive, learner-centered way that enables exploratory and action-oriented learning [7,8]. In other words, it is about rethinking learning environments to infuse in students the desire to act in favor of sustainability. On the other hand, sustainable education from the perspective of ICT contributes to social transformation, enabling students to transform themselves and the societies in which they live [9,10].

Technological innovation plays a key role in improving economic development, facilitating social inclusion, and allowing better protection of the environment. ICTs are specifically considered as a means of implementing the Sustainable Development Goals (SDGs), highlighting their transversal transformative potential [3,7]. The expansion of information and communication technologies and global interconnection have great potential to accelerate human progress, overcome the digital divide, and develop knowledge societies. This has justified the interest of this research. Therefore, the motivation of this study is to document how the knowledge base of the management of the tools provided by ICTs to promote education as a basis for sustainable development has evolved [8].

Advancement in education for sustainable development (ESD) includes progressing in the training of students capable of making informed decisions, in addition to adopting responsible measures in favor of the integrity of the environment and the viability of the economy. For this reason, ESD aims to achieve social justice for current and future generations while respecting cultural diversity. It is lifelong learning and is an integral part of a quality, comprehensive, and transformative education concerning content, environment, and learning outcomes, as well as pedagogy [2,9]. In this way, it achieves its main purpose by transforming society.

This has justified the interest of this research; therefore, the motivation of this research is to document how the knowledge base of the management of the tools provided by ICTs to promote education as a basis for sustainable development has evolved.

The review of the literature carried out has made it possible to pose research questions on ICT management for sustainable education, which refer to determining:

(i) What is the evolution of scientific production?
(ii) What are the relationships of the most productive journals, authors, research institutions, and countries?
(iii) What lines of research have been developed and what new directions are they taking?

Accordingly, the main objective of this study is to examine the research at a global level during the period 2000–2019 on ICT management for a sustainable education in the higher education context. For this, bibliometric techniques have been applied to a sample of 1814 articles selected from the Scopus database. Mainly, the evolution of the number of articles per year, the journals where they were published, the authors, research institutions, and the most productive countries have been identified. Likewise, the main current and future lines of research have been detected. Six lines of research developed between 2000 and 2019 have been detected, which, have mainly analyzed the research topics related to: (i) education, (ii) information technology, (iii) higher education, (iv) knowledge management, (v) e-learning, and (vi) teaching. The different schools of thought have comprehensively examined the interrelationships of the ICT management variables to obtain a sustainable education in higher education (HE).

The main contribution of this study is the determination of the scientific production and collaborations between the main agents that stimulated the topic on the management of ICTs for sustainable education in the context of HE during the last 20 years, in addition to the identification of the main lines of research developed and the detection of the main future directions of research.

In this way, as theoretical–practical implications of this work, it can be added that the analysis of scientific production and the actors that stimulate ICT research for sustainable education in an educational context during the period 2000–2019 supposes a greater and better identification of the

lines of research and their evolution and transformation. Innovation in this field of research has been identified from the morphology of the groups of authors, institutions, countries, and keywords, as well as the intensity of the relationships that develop among them. Thereby, the results obtained represent a complement and contribution to the knowledge of ICT management for sustainable education in the educational context, allowing the establishment of the relationship between science and technique, in addition to supporting the decision-making process.

To get the aim and clarify its understanding, this study is organized as follows. Section 2 justifies the relevance of the research topic by conducting a review of the basic concepts of this study topic. Section 3 specifies the applied methodology. Section 4 shows the main results and their discussion in the context of this research. Finally, in Section 5, the obtained conclusions are shown.

2. Conceptual Framework

Section 2 is the result of a previous analysis of the literature, while its purpose is to act as a guide and framework in the global research on ICT management for sustainable education in the HE context. In this way, the interrelation of the terms or variables that allow conceptualization of this field of knowledge is described to consolidate the purpose of the research. The objective of this section is to provide a theoretical and conceptual framework that guides the investigation and enables the interpretation of the results.

Table 1 shows the main articles analyzed in the initial phase of reviewing the literature on the research topic, establishing a conceptual framework on the management of ICT for sustainable education in the context of HE. The study and analysis of these have made it possible to determine the problem as the purpose and objective of the research. On the other hand, the literature reviewed has made it possible to establish the key terms to apply the methodology in Section 3: ICT, higher education, sustainable education, and management.

The initial review of the literature provides definitions for the basic concepts or variables on this topic. Consequently, some reflections on the terms and concepts used in the context of this research that have shaped this field of research are included. Therefore, with the intention of avoiding different interpretations, the basic concepts of this research that will be used in the development of the study are defined.

In the first place, the concept of education refers to the process of socialization of individuals, since when being educated, a person assimilates and learns knowledge [23]. It also implies a cultural and behavioral awareness, where the new generations acquire the ways of being of previous generations. The educational process is materialized in skills and values, which produce intellectual, emotional, and social changes in the individual [24,25]. On the other hand, the concept of higher education refers to the stage that refers to the last phase of the academic learning process, that is, to the post-secondary training paths that each country contemplates in its educational system, and that is taught in universities, higher institutes, or technical training academies [25,26].

One of the transversal concepts of this study is sustainability, which refers to the development that meets the needs of the present without compromising the capacity of future generations, guaranteeing the balance between economic growth, environmental care, and social well-being [27,28]. In the same way, the concept of sustainable development arose in 1987 with the publication of the Brundtland Report, which warned of the negative environmental consequences of economic development and globalization, trying to find solutions to the problems derived from industrialization and population growth [29,30].

Table 1. Main articles reviewed on the research topic (2000–2019).

Ref.	Year	Title	Author(s)	Journal	Terms
[11]	2020	Sustainable ICT equals not ICT for sustainability	Hofstetter, M.; Gees, T; Riedl, R.; Koumpis, A.	*Sustainable Futures*	ICT-SE
[12]	2020	Measures to facilitate the scale-up of education for sustainable development in higher education	McConnon, R.	*International Journal of Sustainable Society*	SE-HE
[13]	2020	Higher education for sustainable development: stakeholders' benefits	Kotomina, O. V.; Sazhina, A. I.	*Management and Business Administration*	SE-HE-M
[14]	2019	Lifelong learning in Sustainable Development Goal 4: What does it mean for UNESCO's rights-based approach to adult learning and education?	Elfert, M.	*International Review of Education*	SE-HE
[15]	2016	Education with ICT for developing employability in higher education institutions	Gogoi, L.	*TechnoLearn: An International Journal of Educational Technology*	ICT-HE
[16]	2016	Education for sustainability—challenges and opportunities	Wade, R.	*Management in Education*	SE-M
[17]	2014	ICT Integration in Teaching and Learning: Empowerment of Education with Technology	Kler, S.	*Issues and Ideas in Education*	ICT-HE
[18]	2014	New Literacy for Reading Using ICT	Roig-Vila, R.; Mengual-Andrés, S.	*ECPS - Educational, Cultural and Psychological Studies*	ICT
[19]	2012	How to Assess Transformative Performance towards Sustainable Development in Higher Education Institutions	Mader, C.	*Journal of Education for Sustainable Development*	SE-HE-M
[20]	2011	Understanding the Importance, Impacts, and Barriers of Information and Communication Technology (ICT) in Higher Education	Siddiqi, D. S.	*Indian Journal of Applied Research*	ICT-HE
[21]	2009	Internationalization in higher education and global access in a digital age	Hammond, E. H.	*Library Management*	ICT-HE
[22]	2006	ICT Teaching Experience Sharing in Higher Education: An Education Development Approach	Pow, J.	*Informatics in Education*	IC-HE

Ref.: bibliographic reference; ICT: information and communication technology; SE: sustainable education; HE: higher education; M: management.

However, to achieve sustainable development, the United Nations approved the 2030 Agenda that contains the Sustainable Development Goals (SDGs), that is, 17 common goals for, in general terms: (i) eradicating extreme poverty and hunger on a global scale, and demonstrating the contribution of international institutions and national governments; (ii) universalizing access to basic services (water, sanitation, and sustainable energy); (iii) supporting the generation of development opportunities through inclusive education and decent work; (iv) promoting innovation and resilient infrastructure, thus creating communities and cities capable of producing and consuming in a sustainable way; (v) reducing inequalities in the world; (vi) taking care of the environment; and (vii) promoting collaboration between the different social agents [31–33].

In the context of this research, the fourth SDG (SDG-4) seeks to guarantee an inclusive, equitable, and quality education, in addition to promoting lifelong learning opportunities for all that, since education allows upward socioeconomic mobility and is key to leaving poverty. Through the 10 targets, the SDG-4 focuses on ensuring equal access for all men and women to quality technical, professional, and higher education, including university education. It also seeks to considerably increase the number of young people and adults who have the necessary skills, particularly technical and professional, to access employment, decent work, and entrepreneurship [34–36].

Hence, the concept of sustainable education refers to finding lasting solutions through education, that is, regarding social, environmental, and economic problems [37]. It is a concept that involves active academic participation to create economic, social, and environmental programs that improve living standards, generate empowerment, and respect interdependence. It also focuses on training and educating people on sustainable development and practices [38,39]. Higher education for sustainable development (HESD) has the function of transmitting and developing knowledge, skills, values, and attitudes, which empower and motivate students to actively contribute to sustainable development. Sustainability in the use of ICTs in HE refers to promoting their application, always respecting the proper functioning of university activity.

The concept of information and communication technologies (ICTs) is an extensive term for information technology (IT), emphasizing the role of unified communications and the integration of telecommunications and computers, as well as the necessary software, middleware, storage, and audiovisual systems, which allow users to access, transmit, store, and manipulate information [40,41]. Accordingly, ICT within the field of education focuses on the design, development, and application of resources in educational processes, referring to those of a computer, audiovisual, and technological nature, as well as information processing and those that facilitate communication [42].

In these terms, educational technology arises as a set of information and communication resources, processes, and tools applied to the structure and activities of the educational system in its various fields and levels. The digital age has revolutionized every aspect of education. This trend is part of the digital transformation, which has introduced the participation of technology in education. Therefore, the incorporation of new technologies in universities has changed educational methods, that is, educational problems have a solution in the use of information technology [43–45].

ICT contributes to the SDGs, specifically SDG-4, by driving a revolution in online training, which has become one of the fastest growing industries in the world. Mobile devices allow students to access learning resources anywhere, anytime. Teachers use mobile devices for everything, includingtraining and interactive tutoring. In fact, mobile learning could help break down economic barriers, differences between rural and urban areas, and gender inequality.

From the perspective of this study, that is, the management of ICT for sustainable education in the context of HE, the primary objective of the management is to increase the optimal results of an institution based on the: (i) strategy; (ii) culture, that is, the values of the institution; (iii) structure, understood as actions to promote cooperation, to design ways to share knowledge, or to put the best qualified people at the forefront of initiatives; and (iv) execution, which refers to making appropriate and timely decisions, promoting improved productivity, and meeting the needs of consumers [46–48].

In this line, the concept of knowledge management arises, which, applied in educational institutions, refers to the transfer of knowledge and existing experience between its members [49,50].

3. Data and Methodology

Bibliometrics applies mathematical and statistical methods to scientific literature to analyze the activity of a certain scientific field. This methodology has become widespread in the analysis of scientific research and has contributed to reviewing knowledge in multiple disciplines. The explicit objective of this methodology is to search, identify, organize, and analyze the trends of the research topic, in addition to the intellectual representation of a scientific discipline [51,52]. Studies on the scientific literature make it possible to identify certain relationships between the documents of a certain research area and, in this way, to observe the influence of authors, recognize subdisciplines, or trace the historical development and progress in an area of interest [53,54].

The objective of this study was to show a vision of the general dynamics of research on ICT management for sustainable education in the HE context. To achieve this objective, a quantitative analysis was carried out by applying bibliometric techniques.

From the literature reviewed about study, the terms chosen in the search string were higher education, digital, technology, ICT, sustainability, and management. The Scopus database was used to apply bibliometric techniques to the sample of articles. The choice of this database was due to the fact that, when performing the first search in the Web of Science (WoS) and Scopus databases, it showed a significant difference in the volume of articles in the analyzed period of 2000–2019, that is, WoS showed 360 articles and Scopus showed 1814 articles. Scopus is the world's largest citation and abstract database of peer-reviewed research literature, including the most cited journals in each field of study. Furthermore, this database provides a wide variety of data in each of the publications, which allows the comparison of different analyses and the download of useful information for the analysis process in different formats [55,56]. Numerous recent bibliometric studies have used the Scopus database [57,58].

The search selected records of subfields of titles, abstracts, and keywords in the period from 2000 to 2019, that is, the last 20 years, in the same way that has been applied successfully in various studies [59,60]. The representation of this sample of documents is supported by the proven quality of the Scopus database with respect to the indexing protocol, and by the systematic procedures of the search criteria. The final sample only included scientific articles in both open-access and non-open access publications. Hence, a total of 1814 scientific articles were obtained for the period 2000–2019. The process followed in the selection of the sample conforms to the flowchart of Figure 1, according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [61].

In phase 1 (Identification), 156,061 records from the Scopus database were identified, considering all the fields for each of the key search terms (higher education institution, digital, technology, ICT, sustainability, and management), all types of documents, and all data in the range (all years—August, 2020). Search terms were identified from the first literature review (see Table 1).

In the next phase, phase 2 (Screening), the option of "article title, abstract, and keywords" was chosen in the field of each term, so that 150,594 records were excluded. Subsequently, in phase 3 (Eligibility), of the 5467 records, only articles were selected as the type of document to ensure the quality derived from the peer review process. In this phase, 2841 documents were excluded. Hence, in the last phase, phase 4 (Included), of the 2626 records, 812 documents were excluded by limiting the period analyzed from 2000 to 2019 and excluding the thematic areas that distorted the sample. Hence, the final sample included 1814 articles, both open access and non-open access.

It was decided to consider the research since 2000, since in that year, the UN adopted the Millennium Development Goals (MDGs), which were the promise to defend the principles of human dignity, equality, and equity. Among its eight goals, goals 2, 7, and 8 stand out for this research, which set as targets: (i) basic education for all; (ii) ensuring a healthy and safe environment; and (iii) achieving a global society A series of measurable and time-bound goals were also included, which laid the foundations for solving the greatest development challenges of our time. In this sense, 2015 was

the date set for their fulfillment; however, not all the established goals were achieved and, therefore, also in 2015, the SDGs were raised with their 17 goals. Likewise, it was decided to set the year 2019, as it is the last full year.

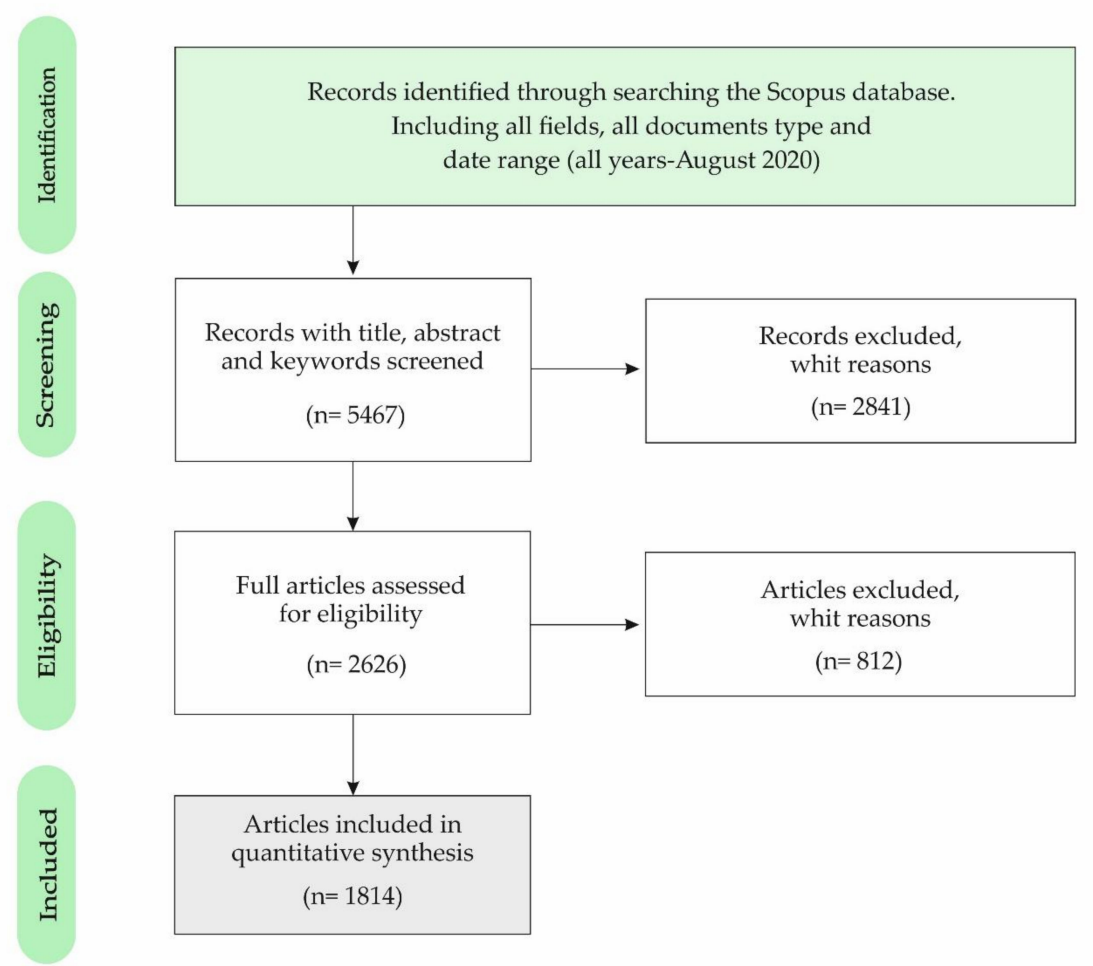

Figure 1. Flowchart of the methodology—Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).

In this study, the quantity indicators were analyzed to measure the number of publications per year; structural indicators were analyzed to measure the connections established between the different drivers of this research field (authors, institutions, and countries), and to measure the connections established between the keywords that define the publications [62,63].

Among the structural indicators, in this analysis, the following were carried out: (i) co-citation analysis: used when one document cites two others, showing the probability that both cited sources are related by their content [64]; (ii) co-authorship analysis: studies the social structure of a research field, and has been used to understand and evaluate the patterns of scientific collaboration at the institutional and country level based on bibliographic data that provide information on institutional affiliations of the authors and their geographic locations [65,66]; and (iii) co-occurrence analysis: refers to the proximity relationship of two or more terms in a text unit; in this way, if two terms coexist in a text, that is, they appear together in it, it is likely that they are semantically related. The analysis of the keywords allowed the detection of the main current and future research topics based on co-occurrence analysis, since scientific texts can be reduced to the set of joint appearances between the words that compose them [67,68].

For the structural indicators, the VOSviewer software (version 1.6.15., University of Leiden, Leiden, The Netherlands), which offers data on the interactions and the evaluation of subject matter, was applied to measure the activities of research networks. This tool allows analysis from the visualization of relationship maps and network links between journals, authors, institutions, countries, and keywords [69,70]. That is, network maps were used to provide values on international collaborations and trends in this field of research.

The applied methodology has some limitations, but could be the basis for future research. Bibliometric analysis is mainly a method of quantitative analysis, so it could be extended with other quantitative or qualitative tools to seek a different perspective of this research. On the other hand, this study focused only on articles published in scientific journals, so different documents could be included to analyze the impact they have on the results.

4. Results and Discussion

4.1. Temporal Evolution of Scientific Production

Figure 2 shows the evolution of the number of articles on global research on ICT management for sustainable education during the period from 2000 to 2019. It is observed that, of the 1814 articles in the period studied, 914 were published in the last five years (2015–2019), that is, 52.98% of the total; in the last decade (2010–2019), 1475 articles (81.31%) were published. It is also important to note that in the last year (2019), 288 articles (15.88%) were published. These data confirm the interest in recent years in this research topic by the scientific community at the international level, with a growing publication rate from the beginning. On the other hand, the greatest percentage variations occurred between the years 2012 (88) and 2013 (122) with 39%, as well as between 2018 (198) and 2019 (288) with 45%. Likewise, Figure 2 shows the exponential trend line, which denotes the number of articles in this research field increasing faster over time in the last 20 years. This line shows its goodness with an R^2 of 0.9649.

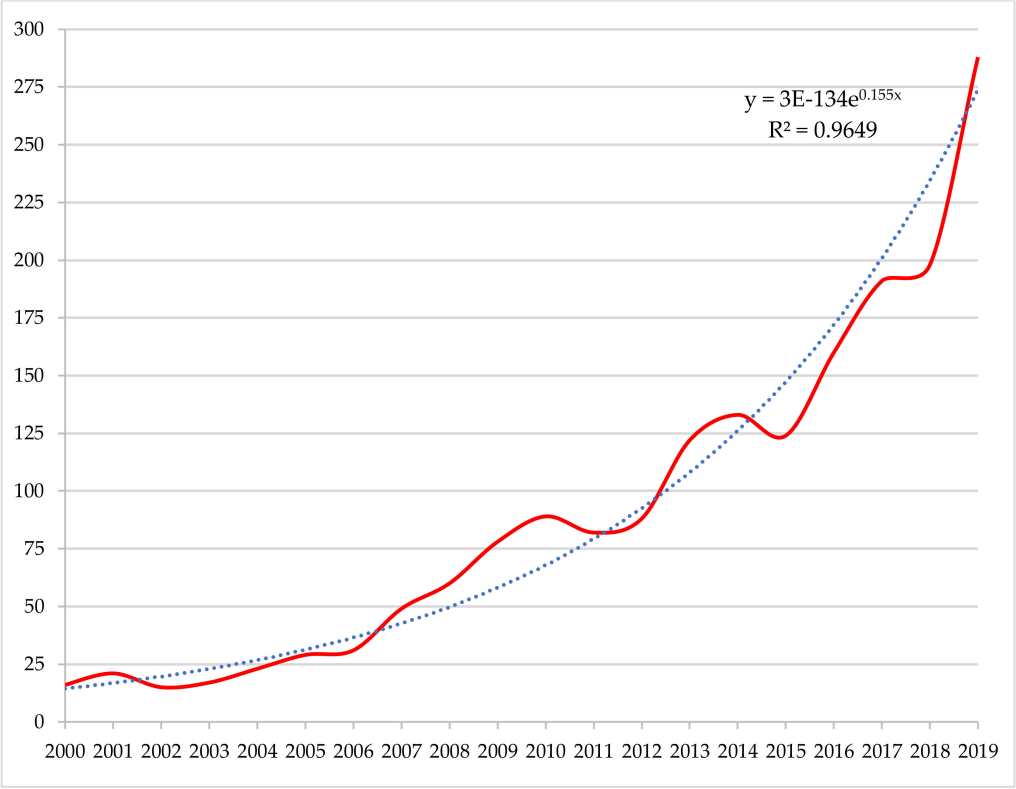

Figure 2. Evolution and trend of scientific production (2000–2019).

In this field of research, 91.01% of the articles are written in English (1651). This circumstance is related to the fact that the publication in this language broadens its audience, as widely happens in the searches carried out in the Scopus database [71]. Moreover, the articles were published in other languages with less representation: Spanish (100, 5.51%), Russian (32, 1.76%), Portuguese (24, 1.32%), German (5, 0.28%), and Chinese (3, 0.17%). The rest of the languages did not exceed 2% of the articles published.

The first article published in the analyzed period is from 2000, with the title "Quality management applied to higher education" in the British journal Total Quality Management (later called Total Quality Management and Business Excellence), by the authors Mergen, E., Grant, D., and Widrick, S.M. This document had 59 citations in August 2020, and the journal is classified in the subject area Business, Management, and Accounting [72]. Furthermore, the most cited article, with 408 citations, was published in 2008 by the British journal Computers & Education, with the title "The effectiveness of m-learning in the form of podcast revision lectures in higher education", and was written by Evans, C. The journal is classified in the subject areas Computer Science and Social Sciences [73]. On the other hand, the most relevant article, which refers to the contribution that most closely matches the search terms in the Scopus database, has 19 citations. This article was published in the British Journal of Educational Technology under the title "From e-campus to e-learning: An overview of ICT applications in Chinese higher education", and was written by the authors Zhao, G., and Jiang, Z ., affiliated with the Peking University (Beijing, China) [74].

4.2. Journals and Authors: Clustering Analysis

The 1814 articles were published in 757 scientific journals. According to the Scopus database, the 10 most productive journals are: Sustainability (33 published articles), Turkish Online Journal of Educational Technology (29), International Journal of Sustainability in Higher Education (27), Journal of Higher Education Policy and Management (23), British Journal of Educational Technology (22), Espacios (20), Journal of Cleaner Production (19), Computers and Education (18), International Journal of Emerging Technologies in Learning (18), and Izvestiya Vysshikh Uchebnykh Zavedenii Seriya Teknologiya Tekstil Noi Promyshlennosti (16). These 10 journals comprise a total of 199 articles and represent 11.37% of the total sample.

Figure 3 shows the network of journals, based on co-citation analysis, that have been published worldwide on ICT management for sustainable education in the HE context. The color of each component is associated with the cluster of journals in the publication of articles, while the diameter of the circle indicates the number of articles in the journal. The network shows a great dispersion in the association of journals by co-citation during the period analyzed (2000–2019). In this way, the journals are associated in five clusters, and the nodes are displayed by the weights of the citations.

Cluster 1 (pink), the most numerous, groups 69.81%, and is led by Computers and Education, presenting relationships with: British Journal of Educational Technology, Management Information Systems Quarterly, Computers in Human Behavior, Higher Education, and The Internet and Higher Education, among others.

Cluster 2 (green) groups 12.45%, and is headed by Journal of Cleaner Production, showing relationships with, among others: International Journal of Sustainability in Higher Education, Sustainability, Energy Policy, Science, Energy, and Energy and Buildings.

Cluster 3 (red) groups 8.68%, and is led by Library Management, presenting relationships with: The Electronic Library, Library Hi Tech, D-Lib Magazine, Journal of The American Society for Information Science and Technology, Scientometrics, The Journal of Academic Librarianship, and Library Trends, among others.

Cluster 4 (yellow) groups 6.04%, and is headed by Research Policy, showing relationships with, among others: Journal of Technology Transfer, Technovation, Journal of Business Venturing, The Journal of Technology Transfer, Small Business Economics, Science and Public Policy, and Technological Forecasting and Social Change.

Finally, Cluster 5 (purple) groups 3.02%, and is led by Journal of Sport Management, presenting relationships with: Sport Management Education Journal, Situated Learning: Legitimate Peripheral Participation, Calico Journal, Journal of Education and Work, International Journal for Academic Development, and Journal of Industrial Technology, among others.

The thematic areas in which journals classify scientific articles are broad, mainly in Social Sciences, referring to the concepts of education and sustainability [75,76]; Computer Science, in relation to ICT and digital transformation in the education sector [77,78]; and Business, Management, and Accounting, due to the strategies and actions carried out by higher educational institutions to link ICT with sustainable education [47,79].

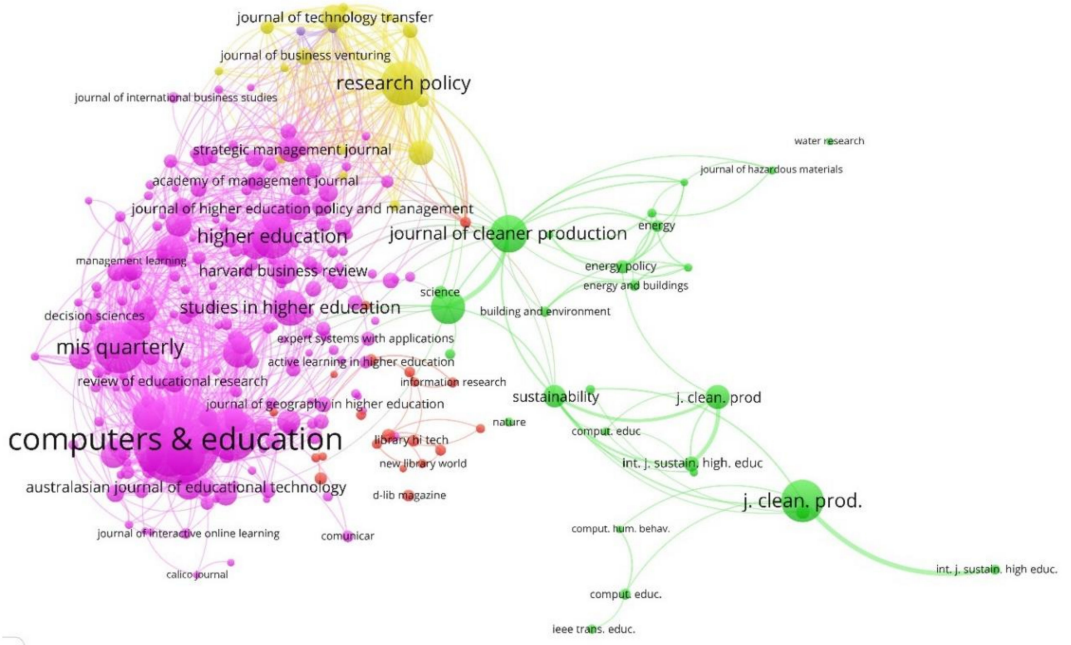

Figure 3. Network of journals based on the co-citation method (2000–2019).

On the other hand, the 1814 documents were written by 4457 authors. According to the Scopus database, the 10 most productive authors and their affiliations are: Dawson, S. (University of South Australia, Adelaide, Australia); Abdous, M. (Old Dominion University, Norfolk, United States); Akhmetshin, E.M. (Kazan Federal University, Kazan, Russian Federation); Aleksic-Maslac, K. (Zagreb School of Economics and Management, Zagreb, Croatia; Luxembourg School of Business, Luxembourg, Luxembourg); Beckers, R. (University of Twente, Faculty of Engineering Technology, Enschede, Netherlands; Hogeschool van Arnhem en Nijmegen, Faculty of Economics and Management, Nijmegen, Netherlands); Bikfalvi, A. (Universitat de Girona, Department of Business Administration and Product Design, Girona, Spain); Brandli, L.L. (Universidade de Passo Fundo, Postgraduate Program in Civil and Environmental Engineering (PPGEng), Passo Fundo, Brazil); Budroni, P. (Universitat Wien, Vienna, Austria); Cox, A.M. (The University of Sheffield, Information School, Sheffield, United Kingdom); and Dewulf, G. (University of Twente, Department of Research and Development, Enschede, The Netherlands).

These 10 authors comprise a total of 31 articles and represent 0.70% of the total sample. This result indicates that the articles on this subject during the last 20 years are very scattered, and are not concentrated with a small number of authors, as can be produced in other fields of research [80].

Figure 4 shows that the authors are associated in five clusters, according to the visualization tool used. The color of each node, representing an author, is associated with the group of authors based on the co-authorship analysis, and the diameter of the circle refers to the number of articles by the author.

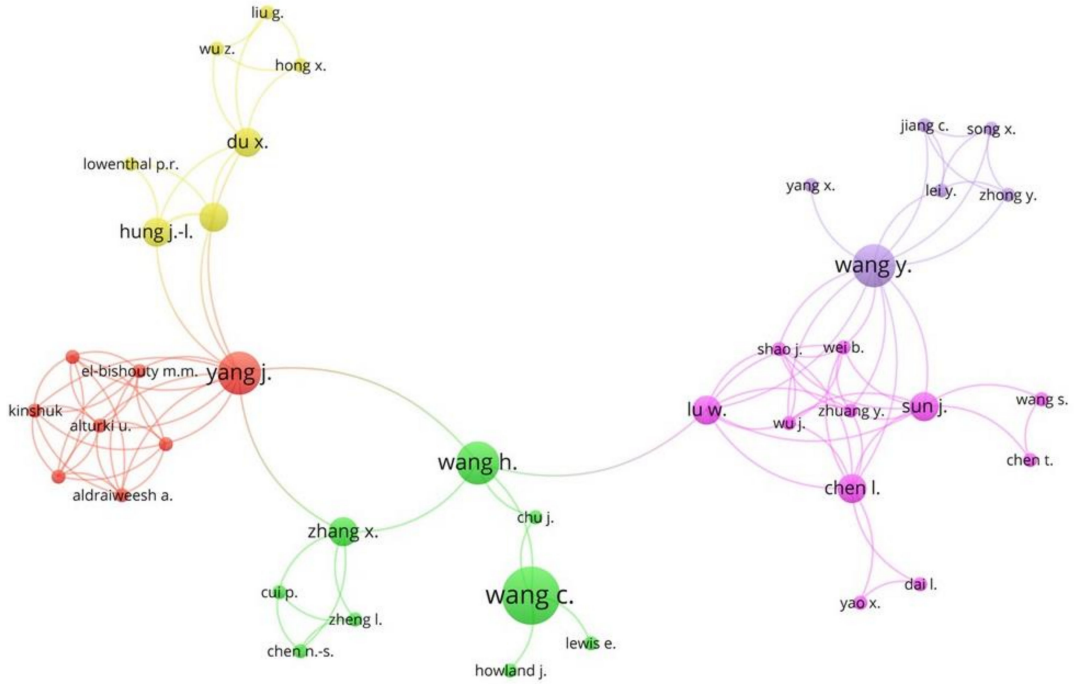

Figure 4. Network of authors based on the co-authorship method (2000–2019).

Cluster 1 (pink) is headed by Chen, L., and associates 26.83%. This author is associated with, among others, Lu W.; Sun J.; Chen T.; Dai L.; Shao J.; Wang S., or Wei, B.

Cluster 2 (green), the most central, associates 21.95%, and is headed by Wang, C. This author is linked, among others, to Wang, H.; Zhang, X.; Chen, N.-S.; Chu, J.; Cui, P.; Howland, J., or Lewis, E.

Cluster 3 (red) associates 19.51%, and is led by Yang, J. The author is associated with, among others, Aldraiweesh, A.; Alturki, U.; Chang, T.-W.; El-Bishouty, M.M.; Graf, S.; Kinshuk, or Tortorella, R.

Cluster 4 (yellow) is led by Du, X., and groups 17.07%. This author collaborates with, among others, Hung, J.-L.; Shelton, B.E.; Hong, X.; Liu, G.; Lowenthal, P.R.; or Wu, Z.

Finally, cluster 5 (purple), the least numerous, associates 16.43%. This component is headed by Wang, Y., and is associated with, among others, Jiang, C.; Lei, Y.; Song, X.; Yang, X., or Zhong, Y.

In recent years, the Chinese educational system has responded notably with the technology applied in HE, especially in distance learning. China has created alliances, even more so with the COVID-19 pandemic, between national and local governments, the private sector, and civil society to strengthen capacities through supplemental learning resources. In this regard, efforts are being made related to: (i) greater support for parents so that they can effectively review their children's learning activities; (ii) multilingual content aimed at ethnic minorities; (iii) better accessibility for disabled people; (iv) better connectivity of ICT and teacher skills in rural regions; (v) increased security and protection of the privacy of students online; and (vi) focusing education for sustainable development on a global scale [74,81–83]. ICTs are driving a revolution in online training, which has become a great opportunity to ensure inclusive, equitable, and quality education and to promote lifelong learning opportunities for all. All these actions have an impact on the amount and quality of research, in addition to collaboration between researchers, institutions, and territories.

4.3. Research Institutions and Countries: Clustering Analysis

The 1814 research articles were carried out by 3183 institutions. Figure 5 shows that the authors affiliated with the different research institutions that participate in this topic are grouped into three clusters, according to the co-authorship method used in the visualization tool for scientific production, VOSviewer.

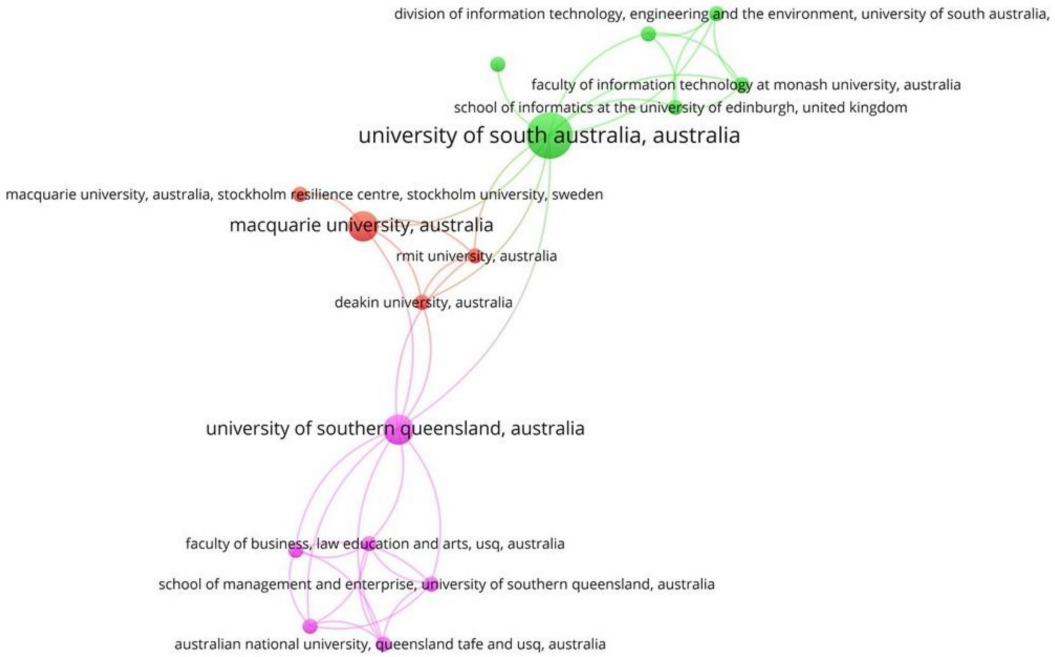

Figure 5. Network of affiliations based on the co-authorship method (2000–2019).

Cluster 1 (pink) groups 37.50% of the institutions with which the authors of the publications about this field of study are affiliated. This cluster is led by Australian National University—Queensland Tafe and University of Southern Queensland (Australia), and is associated with, among others, Faculty of Business, Law Education, and Arts—University of Southern Queensland (Australia), School of Linguistics, Adult, and Specialist Education—University of Southern Queensland (Australia), or School of Management and Enterprise—University of Southern Queensland (Australia).

Cluster 2 (green) also groups 37.50%, and is headed by the Division of Information Technology, Engineering, and the Environment—University of South Australia (Australia). This institution is associated with, among others, the Faculty of Information Technology—Monash University (Australia), Institute for the Application of Learning Sciences and Technology—National University of Singapore (Singapore), School of Informatics—University of Edinburgh (United Kingdom), University of British Columbia (Canada), or University of South Australia (Australia).

Finally, cluster 3 (network), the least numerous, is led by Deakin University (Australia), and is associated with, among other institutions, the Macquarie University (Australia), Stockholm Resilience Center—Stockholm University (Sweden), Royal Melbourne Institute of Technology (RMIT) and Melbourne Technical College—RMIT University (Australia), or Macquarie University (Australia).

In this context, in Australia, learning by basic technological competencies is of great importance for the educational system, so that training in this sense is given among students belonging to the first educational levels, which, over time, leads to university students that are fully adapted to educational technologies. This has led to educational institutions that collaborate in the investigation of methodologies, advances, and results.

The 1814 documents were developed in 108 countries. Figure 6 shows that, using the co-authorship method, the countries promoting this topic are grouped into five clusters. Therefore, cluster 1 (pink) groups 28.09% of the countries that publish on this subject. This group is led by Russia and is associated with, among others, Indonesia, Canada, Germany, Turkey, Italy, Netherlands, Sweden, Saudi Arabia, or Ecuador.

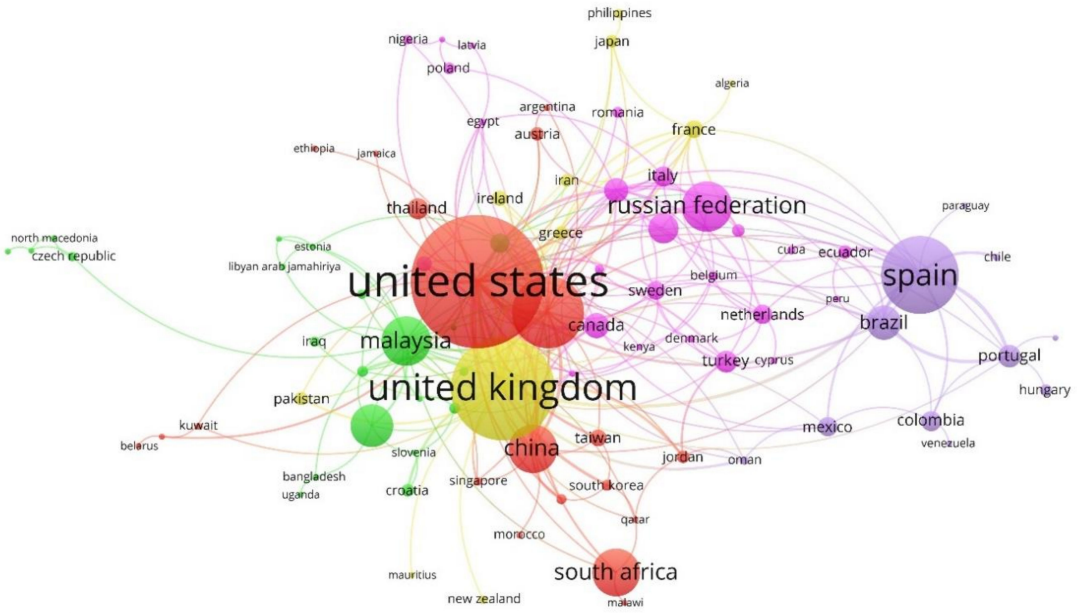

Figure 6. Network of countries based on the co-authorship method (2000–2019).

Cluster 2 (green) associates 23.36% and is led by Malaysia. This country is linked with, among others, India, Finland, Croatia, Israel, United Arab Emirates, Iraq, Czech Republic, Ghana, Ukraine, Slovenia, Palestine, Serbia, Bangladesh, Bosnia and Herzegovina, or Estonia.

Cluster 3 (red), the most central, groups 22.47%, and is headed by the United States. This country is associated with, among others, Australia, China, South Africa, Thailand, Taiwan, Austria, Jordan, South Korea, Hong Kong, Singapore, Argentina, Kuwait, Morocco, or Lebanon.

Cluster 4 (yellow) groups 13.48% and is headed by the United Kingdom. This group links it with, among others, France, Ireland, Pakistan, Greece, Iran, Japan, Philippines, New Zealand, Algeria, or Mauritius.

Finally, cluster 5 (purple), the least numerous, is led by Spain, and groups 12.36%. This country is associated with, among others, Brazil, Portugal, Colombia, Mexico, Hungary, Oman, Chile, Venezuela, or Angola.

At the international level, research on the management of ICTs to promote sustainable education in HE is led by the United States, the United Kingdom, and, to a lesser extent, by Spain and Australia. These countries/territories collaborate in the development of the publications for different reasons, such as the language, the continent, the historical international relations between certain countries, or because of the access to funds that finance the studies. During the period examined, these contributions have mainly revolved around, among other aspects, e-learning, knowledge management, educational innovation, student satisfaction, or collaborative learning [84,85]. All of them are key issues for planning university action strategies for sustainability.

4.4. Keyword Analysis

In the 1814 research articles in the analyzed sample, 7201 different keywords were found. Table 2 lists the 30 most used keywords in articles on ICT management for sustainable education, ordered by the number of articles in which they appear. Moreover, the information of the clusters with which they are associated is added (see Figure 7), as well as the weights of the attributes of the links and total link strength.

Table 2. Top 30 keywords (2000–2019).

R	Keyword	A	C	L	TLS	R	Keyword	A	C	L	TLS
1	Higher Education	620	847	3246	620	16	Management	59	223	419	59
2	Education	225	660	1858	225	17	Learning	58	256	470	58
3	E-Learning	163	381	1081	163	18	Education Computing	51	251	519	51
4	Students	156	455	1373	156	19	Blended Learning	46	138	240	46
5	Teaching	133	519	1368	133	20	Project Management	45	202	365	45
6	Knowledge Management	111	315	680	111	21	Information and Communication Technologies	42	155	310	42
7	Sustainability	91	287	643	91	22	Distance Education	41	145	260	41
8	Information Technology	90	342	693	90	23	Universities	40	163	241	40
9	Engineering Education	84	368	805	84	24	Educational Technology	34	89	149	34
10	Sustainable Development	82	320	702	82	25	Internet	33	165	261	33
11	Higher Education Institutions	77	266	537	77	26	Digital Libraries	29	78	123	29
12	Innovation	72	283	527	72	27	Online Learning	29	77	125	29
13	Technology	61	330	593	61	28	Decision Making	27	165	265	27
14	Information Management	60	251	473	60	29	Technology Transfer	27	102	148	27
15	Learning Management System	60	177	420	60	30	Distance Learning	24	101	155	59

R: rank; A: number of articles in which it appears; C: cluster (see in Figure 7); L: links; TLS: total link strength.

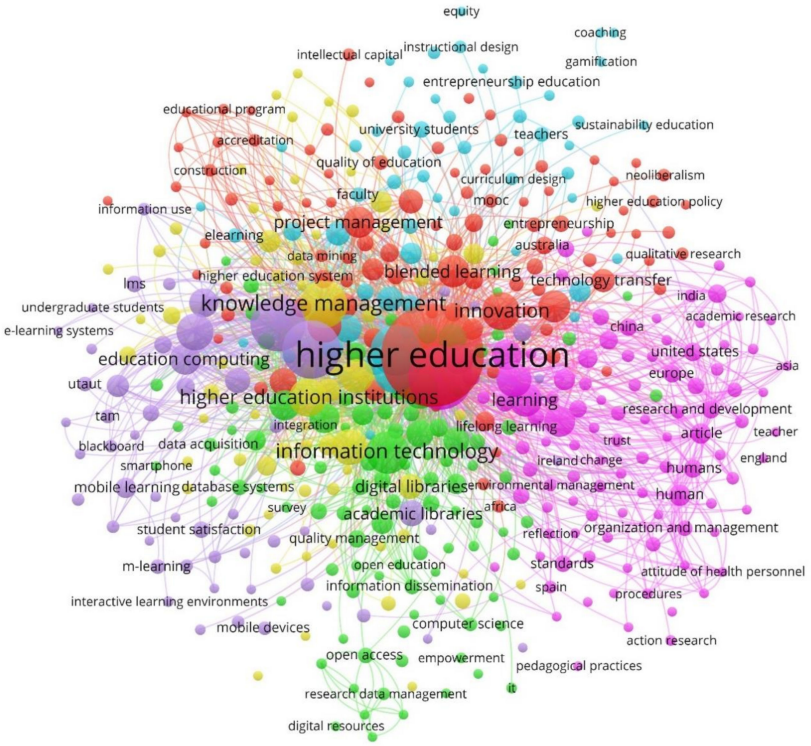

Figure 7. Network of keywords based on the co-occurrence method (2000–2019).

The two most prominent keywords in this field of research were "Higher Education" (620 articles, 34.18% of the total sample) and "Education" (225, 12.40%). These terms also presented the highest link weights and total link strengths. It is necessary to highlight that "Higher Education" was one of the terms considered for the search of documents in the Scopus database, together with "Sustainability" (91, 5.02%), in the seventh position; "Technology" (61, 3.36%), in the thirteenth position; and "Management" (59, 3.25%), in the sixteenth position.

The 30 top keywords associated with this topic are associated with the variables of the study (some keywords are linked to more than one variable):

- *Higher Education*: Education, E-learning, Students, Teaching, Knowledge Management, Engineering Education, Higher Education Institutions, Learning Management System, Learning, Education Computing, Blended Learning, Information and Communication Technologies, Distance Education, Universities, Educational Technology, Digital Libraries, Online Learning, and Distance Learning.

- *Digital or Technology or ICT*: E-learning, Information Technology, Engineering Education, Innovation, Technology, Education Computing, Blended Learning, Information and Communication Technologies, Distance Education, Universities, Educational Technology, Internet, Digital Libraries, Online Learning, Technology Transfer, and Distance Learning.
- *Management*: Knowledge Management, Higher Education Institutions, Information Management, Learning Management System, Project Management, Digital Education, Universities, Educational Technology, Decision Making, Technology Transfer, and Distance Learning.
- *Sustainability*: Sustainable Development.

4.4.1. Current Lines of Research

Likewise, an analysis of co-occurrences of the keywords of the total of the 1814 documents of the selected sample of Scopus was carried out. This analysis allowed the articles to be grouped into function groups of the keywords used to detect the lines of research developed in this field of research during the period examined (2000–2019).

Table 3 shows the six clusters that were detected from the analysis of co-occurrences, the color with which each one is identified, and the weight that each cluster represents over the total sample. Furthermore, it includes the main keywords of each of them, which define the name of the cluster, and the three main keywords with which they are associated within each group based on the occurrences, links, and the total link strength.

Figure 7 represents the network map of the keywords of the research articles on the management of ICT for sustainable education for the period 2000–2019. The color of the node is used to differentiate the different clusters based on the number of co-occurrences, while its size varies according to the number of repetitions. The size of each group refers to the importance of the keywords that make up the group, while the thickness of the joining lines between the keywords refers to the number of interactions established between two terms.

From the analysis of co-occurrences, six clusters were detected, which are grouped under the terms "Education", "Information Technology", "Higher Education", "Knowledge Management", "E-Learning", and "Teaching". These clusters are associated with the main lines of research developed by the different communities in this field of research.

Cluster 1 (pink) groups 21.25% of the keywords and is headed by "Education". This term is mainly associated with technology, learning, and sustainable development, as well as with universities, organization and management, science and technology, management of research and development, technological development, communication, and knowledge.

This first component contributed to laying the foundations of education in the context of this study, referring to the process of facilitating learning or the acquisition of knowledge, as well as skills, values, beliefs, and habits [15,23]. However, the educational process is carried out through research, debate, discussion, the sharing of reflections, teaching, example, and training in general, where information technologies will actively participate [86].

Cluster 2 (green) also concentrates 21.25% of the keywords and is headed by "Information Technology". This term is mainly associated with management, information and communication technologies, and distance education. It is also linked to the internet, management information systems, computer software, open systems, and knowledge sharing.

Table 3. Clusters and main associated keywords (2000–2019).

Cluster				Keyword 1	Keyword 2	Keyword 3
Number	**Color**	**%**	**Name**			
1	Pink	21.25%	Education	Technology	Learning	Sustainable Development
2	Green	21.25%	Information Technology	Management	Information and Communication Technologies	Distance Education
3	Red	20.42%	Higher Education	Innovation	Blended Learning	Sustainability
4	Yellow	14.38%	Knowledge Management	Higher Education Institutions	Information Management	Digital Libraries
5	Purple	11.46%	E-Learning	Students	Learning Management System	Academic Libraries
6	Blue	11.25%	Teaching	Educational Technology	Human Resource Management	Computer Aided Instruction

%: Percentage of keywords in the cluster over the total.

This second line of research examines the scientific–technical progress that requires preparing new generations to orient themselves and act in a world where science and technology have become a key element of human activity. In the context of research, education is understood as a key resource for acquiring the ability to process information and transform it into applied knowledge. In this order, the challenges posed for higher education institutions depend on the learning scenario, understood as the space–time frame where the student develops learning activities [20,50]. In this way, the orientation received and the technological availability are key elements in the exploitation of ICTs for training activities in these new scenarios [87].

Cluster 3 (network) groups 20.42% of the keywords and is led by "Higher Education". This term is primarily associated with innovation, project management, and blended learning. In addition, it is linked to sustainability, distance learning, learning management systems, online learning, technology transfer, and collaborative learning.

This line of research contributed to linking the management of ICTs for sustainable development with higher education. Consequently, the United Nations Educational, Scientific, and Cultural Organization (UNESCO), a specialized United Nations (UN) institution, has a mandate in HE and facilitates the development of evidence-based policies in higher education. In accordance with target 4.3 of Sustainable Development Goal 4: "By 2030, ensure equal access for all men and women to quality technical, vocational, and higher education, including university education"; UNESCO provides technical support to Member States so that they can review their higher education strategies and policies in order to improve equitable access to quality higher education and strengthen academic mobility and accountability [35,88,89].

Cluster 4 (yellow) groups 14.38% of the keywords and is led by "Knowledge Management". This term is mainly associated with higher education institutions, information management, and digital libraries. Moreover, it is linked to decision-making, knowledge transfer, developing countries, structural equation modeling, big data, cloud computing, and artificial intelligence.

This component has developed the concept of knowledge management in the context of this study, as the process that continuously ensures the development and application of all types of relevant knowledge of an organization in order to improve its ability to solve problems and contribute to the sustainability of its competitive advantages [49,90]. During this period, it has contributed to examining the function of knowledge management in relation to the planning, coordination, and control of knowledge flows that occur in the educational institution from the point of view of its activities and its environment to create essential competences [51,91].

Cluster 5 (purple) groups 11.46% of the keywords and is led by "E-learning". This term is primarily associated with higher education institutions, information management, and digital libraries. This term is linked to mobile learning, unified theory of acceptance and use of technology, m-learning, mobile devices, human computer interaction, learning experiences, and interactive learning environments.

Related publications in this section have developed the concept of e-learning, which refers to online teaching and learning through the Internet and technology. This term is directly related to virtual education, online training, teletraining, or distance training. This component has provided the academic environment with the main benefits that e-learning provides, such as the elimination of physical and temporal barriers and the opportunity to access lifelong learning adapted to the student's own needs [74]. For these reasons, e-learning is a training modality that provides flexibility and personalization in the learning processes [92,93].

Cluster 6 (blue) groups 11.25% of the keywords and is led by "Teaching". This term is mostly associated with educational technology, human resource management, and computer-aided instruction. This term is also linked to Moodle, Web 2.0, social networking (online), educational innovation, teacher training, and online education.

This school of thought has contributed to linking the teaching process with sustainable education, which enables students to make informed decisions and adopt responsible measures in favor of the integrity of the environment and the viability of the economy [17,22]. Research in this line

has allowed us to understand that it is a key learning in the formation of the student and is an integral part of a quality, comprehensive, and transformative education that influences the content, the environment, the learning results, and the pedagogy [94,95]. Technological innovation plays a key role in improving economic development, facilitating social inclusion, and enabling better protection of the environment. ICTs could help break down economic barriers, differences between rural and urban areas, and gender inequality.

4.4.2. Evolution and Future Lines of Research

Figure 8 shows the evolution of each group of keywords by differentiating the period in which they have been incorporated into the research. In addition, it allows us to understand the importance of keywords according to the time in which they have appeared because the most pioneering ones have had the greatest influence and have been a reference for those that emerged later. The existence of the six differentiated clusters allows us to understand research on ICT management for sustainable education in the HE context.

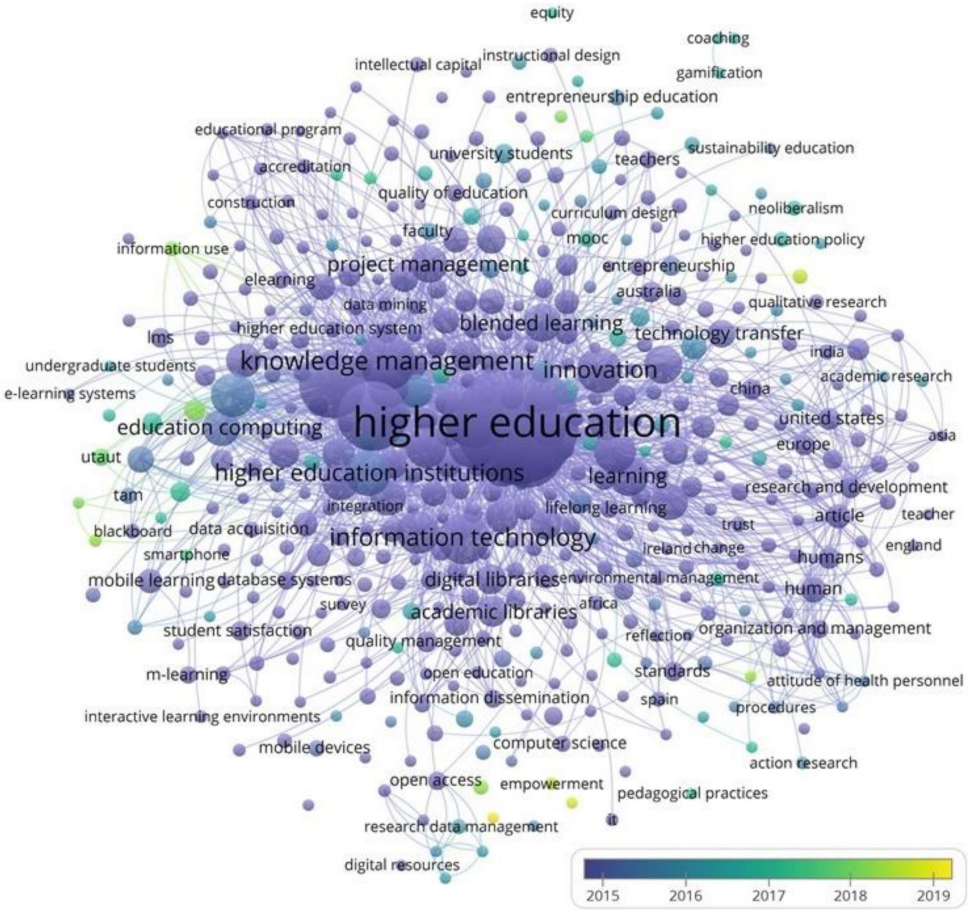

Figure 8. Evolution of the network of keywords based on the co-occurrence method (2000–2019).

In this evolution of keywords associated with the research topic, Figure 8 shows that the incorporation of the group of pioneering keywords creates the shape of the study of ICT management for sustainable education in the context of HE. This group includes terms such as: Information Technology, Students, Teaching, Project Management, Internet, Organization and Management, Learning, Knowledge Management, Computer Software, Universities, Distance Education, Distance Learning, Learning Systems, Technology Transfer, Methodology, Strategic Planning, and Computer-Aided Instruction.

The different sub-periods in which the scientific activity of this subject takes place represent an abundant collection of keywords. This allows us to verify the variety of study axes in the research

activity. Figure 8 visualizes the importance of the key terms based on the moment in which they have become associated with this research. Therefore, the oldest are references for the more recent [96,97].

After reviewing the literature of the latest studies being carried out by the main driving actors (authors, research institutions, and countries) and the analysis of the keywords on ICT management for sustainable education, what might be the main trends and the directions that they can take future lines of research were detected.

Hence, the set of the latest terms associated with this research was identified, which made it possible to determine new directions in this field of research. These are related to the development of the topics covered in the last period and to the appearance of new approaches. Therefore, Table 4 shows the nine future research directions detected based on the relevance of the terms, as well as a description of each of them.

Table 4. Future lines of research.

Future Line of Research	Description
E-tutorial	This line examines electronic tutorials as self-learning instructional systems that pretend to simulate the teacher and show the student the development of a procedure or the steps to carry out a certain activity or task. They are characterized by the brevity and shallow depth they provide [98,99].
Smart Campus	This will holistically develop the concept of smart campuses based on the application of new technologies for the benefit of sustainability. These allow combinations of functions related to the maintenance and adaptation of infrastructures, buildings, and other university spaces from a common perspective based on sustainability and the use of new technologies. It represents a framework for the development of transversal projects in the areas of teaching, research, innovation, and social commitment [100,101].
Technology Acceptance Model (TAM)	Examines information systems theory, which models how users come to accept and use technology. This model indicates that when users are faced with a new technology, there is a set of factors that influence their decision about how and when to use it: Perceived Utility (PU), Perceived Ease of Use (PEOU), and Perceived Enjoyment (PD) [102,103].
Many Open Online Courses (MOOC)	This develops a tool for online courses aimed at an unlimited number of participants through the Internet according to the principle of open and massive education. It is characterized by the fact that anyone can join and that it has no limit of participants. In addition, it provides interactive user meetings, which help build a community for students, teachers, and teaching assistants [87,104,105].
COVID-19	The coronavirus disease 2019 (COVID-19) pandemic has had consequences on the education system worldwide at all levels. The need to suspend classes has highlighted the shortcomings of the educational model and exacerbated existing inequalities. This line will examine the consequences of the pandemic to offer tools and reflections on this uncertainty [106–108].
Blended Learning Environment (BLE)	Analysis of this hybrid learning system, which combines face-to-face work (in the classroom) with online work (combining Internet and digital media), where the student can control some factors, such as the place, time, and workspace [92,109,110].
Technology-Enhanced Learning (TEL)	Study of the application of technology to teaching and learning. TEL refers to any technology, analogical or digital, that enhances the learning experience and transforms both education and educational institutions [111].
Digital Badge	This line will study the digital badge from different approaches, which is used to represent in detail the abilities and other educational achievements of the student. This digital tool can include metadata about associated learning success and has value and meaning in the educational context [112,113].
Virtual Learning Environment (VLE)	Comprehensive and global examination of web platforms that provide digital support for dissemination of media or study courses designed by educational institutions, and that make up educational processes developed partially or totally remotely. They provide a framework for communication between participants through multimedia and interactivity in the pedagogical organization of content, such as computer applications, lessons, and activities to promote exchange and interaction [114,115].

5. Conclusions

The objective of this study was to analyze the evolution of scientific production and research trends during the last 20 years on ICT management for sustainable education in the HE context at a global level. Consequently, bibliometric techniques were applied to a sample of 1814 articles selected

from the Scopus database. Mainly, the evolution of the number of articles per year, the journals where these were published, the authors, the research institutions, and the most productive countries were identified. Likewise, the main current and future lines of research were detected.

Six lines of research developed from 2000 to 2019 were detected, which mainly analyzed subjects related to: (i) Education, (ii) Information Technology, (iii) Higher Education, (iv) Knowledge Management, (v) E-Learning, and (vi) Teaching. The different schools of thought have holistically examined the interrelationships of the variables of ICT management to obtain a sustainable education in HE.

Likewise, research on the management of ICTs for sustainable education is evolving, so the main future directions of research were detected, and they are related to: (i) E-tutorials, (ii) Smart Campuses, (iii) the Technology Acceptance Model (TAM), (iv) Many Open Online Courses (MOOC), (v) COVID-19, (vi) Blended Learning Environments (BLE), (vii) Technology-Enhanced Learning (TEL), (viii) Digital Badges, and (ix) Virtual Learning Environments (VLE).

Nevertheless, this research presents a set of limitations that can be used for further research, such as that the Scopus database was chosen to select the sample of documents, the terms or variables chosen to extract the documents, the period of analysis, applied bibliometric techniques, or even the research questions posed. However, a variation of these variables would suppose the obtaining of other results, which would make comparison with those obtained in this study possible.

The main contribution of this analysis was the determination of the scientific production and collaboration between the actors that stimulated research on the management of ICTs for sustainable education in the context of HE over the last 20 years, as well as the detection of the main lines of research and future directions of research. The obtained findings are a complement to current knowledge on how ICTs contribute to sustainable education, so they allow the establishment of a relationship between sustainability and technology in order to favor the decision-making process, both from higher education institutions and from educational policies. The expansion of ICTs and global interconnection has great potential to accelerate human progress, bridge the digital divide, and develop knowledge societies. ICTs are specifically considered as a means of implementation of all the SDGs, highlighting their potential as a tool for transversal transformation.

Finally, it was observed that global research on ICT management for sustainable education in the context of HE shows an exponential trend, indicating interest at the academic and scientific level. In addition, it was confirmed from the future directions of research identified that this is a subject in continuous progression, and that research in this field seeks to increase knowledge about the link between information technologies and education for sustainable development, as suggested by UNESCO and the SDGs of the 2030 Agenda.

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