

Article

Sustainable Management of Digital Transformation in Higher Education: Global Research Trends

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Abstract: Digital transformation in the education sector has implied the involvement of sustainable management, in order to adapt to the changes imposed by new technologies. Trends in global research on this topic have been analyzed and studied, during the 1986–2019 period. To achieve this purpose, a bibliometric study of 1590 articles from the Scopus database has been applied. The results provided data on the scientific productivity of authors, journals, institutions, and countries that contribute to the development of this research area. The evidence reveals an exponential trend, with special interest in the last five years. The main categories are Social Sciences and Environmental Science. The most productive journal is Sustainability. The author with more articles is Mulder, from The Hague University of Applied Sciences. The most productive institution is Delft University of Technology. The USA is the country with the most academic publications and international collaborations in its studies. The main keywords used in the articles are “sustainability”, “sustainable development”, “higher education”, “innovation”, “technology”, “environmental technology”, “technological development”, and “environmental management”. Global research has followed a growing trend, with optimal publication levels in recent years.

Keywords: digital transformation; higher education; sustainable management; worldwide research

1. Introduction

In recent decades, universities have been experiencing a set of important changes, induced by technological and social trends towards digitalization. Like all revolutions, the digital involves an intense readjustment in all sectors, from the production and energy chain, to banking [1–3].

Currently, the adoption of technologies by universities is related to a paradigm shift, where technology is conceived as a complex and interconnected environment that enables digital learning [4]. In this way, the interest is focused more on the students than on the technology itself, in addition to the learning experiences it allows.

In this context, digitalization is a necessity in higher education institutions (HEIs) capable of attracting more and better students, improving the experience of courses, teaching materials, and the training process in general [5,6]. It also allows monitoring in order to detect training obstacles and reduce the risk of dropping out of school. However, reluctance to understand and take advantage of the opportunities to move towards this digital environment persists.

Thus, in the literature reviewed, it has been established that the digital transformation (DT) must be established according to the axioms of connectivism, to unify its commitment to meeting the expectations of the different interest groups in the economic, social, and environmental dimensions [7]. In relation to sustainable management, HEIs will invest in the use and development of clean technologies in their activities and will manage dissemination in their environment of influence [8]. Clean technology, also referred to in the scientific literature as environmental, green, or environmentally sound technology, refers to the process or service that reduces negative environmental impacts through significant improvements in energy efficiency, sustainable use of resources or environmental protection activities. These processes, fundamentally, are less polluting, use resources more sustainably, and recycle more waste, in addition to better handling waste. Likewise, the development of clean technologies is based on the evolution of information and communication technologies (ICT). HEIs are adopting telecommunications services, which, being hosted online in the cloud, thus eliminate additional physical devices and hardware [9].

The purpose of this research is to study the trends on the DT of higher education (HE), in order to analyze what has been the effect of the adoption of new technologies by HEIs.

In the review of the literature carried out, studies have been found that address this issue, so that the research question refers to determining whether the involvement of sustainable management in the digital university transformation has had an increasing interest in academic production over the past few years.

Likewise, the issue of this study is to understand whether, among other variables, the number of articles published is related to the interest generated by the DT, or, conversely, with regulatory regulations.

Consequently, the main objective of this article is to analyze global research trends on the implications of the sustainable management of DT in HE.

To obtain answers to the research question, a sample of 1590 articles of scientific journals selected from the Scopus database of Elsevier during the 1986–2019 period was analyzed, that is, since the publication of the first article on the subject of study, 1986, until the last full year, 2019. In order to examine the main subfields of each selected manuscript, a search string composed of the main terms of the study subject was used, according to the literature reviewed. The search only includes articles, due to the guarantees to the peer review process to guarantee its scientific quality. This study used the bibliometric method to summarize the knowledge base on the scope of sustainable management of DT in HE globally and, thus, determine its research trends. The results showed the contributions in this area of research, allowing the recognition of the main authoring agents, their research tendencies, and revealing certain critical knowledge gaps. Thus, it can be concluded that HEIs are making progress in guaranteeing the management of their economic, environmental, and social sustainability in relation to the DT of education in order to achieve the model of an open, digital, innovative, and networked institution.

Finally, it should be noted that, among the lines of research that are currently being developed in relation to the subject of the study, these refer, among others, to the development of models that meet the needs of the digital economy for higher education systems, or the promotion of educational digitalization in sustainable terms.

2. Literature Review and Conceptual Framework

The study of the sustainable management of the DT of HE is supported by the analysis of a theoretical framework that, together with the basic concepts, defines the frame of reference in this research work. Table 1 shows the main results of the status of the research topic. Each article indicates both the title of the contribution and the authors, the year of publication, and the journal where it was published.

Table 1. Main articles reviewed related to the objective of research.

Article Title [Reference]	Author(s)	Year	Journal
Defining Digital Sustainability [10]	Bradley, K.	2007	Library Trends
Teaching digital asset management in a higher education setting [11]	Slawsky, D.	2010	Journal of Digital Asset Management
Collaborative knowledge sharing strategy to enhance organizational learning [12]	Sita Nirmala Kumaraswamy, K.; Chitale, C.M.	2012	Journal of Management Development
Beyond the third mission: Exploring the emerging university function of co-creation for sustainability [13]	Trencher, G.; Yarime, M.; McCormick, K.B.; Doll, C.N.H.; Kraines, S.B.	2013	Science and Public Policy
Conceptualizing digital literacies and digital ethics for sustainability education [14]	Brown, S.A.	2014	International Journal of Sustainability in Higher Education
Critical success factors for the continuation of e-learning initiatives [15]	McGill, T.J.; Klobas, J.E.; Renzi, S.	2014	The Internet and Higher Education
Innovation in Higher Education [16]	Hansen, R.	2015	Journal of Digital Learning in Teacher Education
Contemporary Education and Digital Technologies [17]	Milicevic, M.	2015	International Journal of Social Science and Humanity
Toward transformation: Digital tools for online dance pedagogy [18]	Parrish, M.	2016	Arts Education Policy Review
Strategies for Higher Education in the Digital Age [19]	Ghemawat, P.	2017	California Management Review
Embodied digital technology and transformation in higher education [20]	Du Toit, J.; Verhoef, A.H.	2018	Transformation in Higher Education
Exploring sustainable learning and practice of digital citizenship: Education and place-based challenges [21]	Ghosn-Chelala, M.	2018	Education, Citizenship and Social Justice
ICT and the UN's Sustainable Development Goal for Education: Using ICT to Boost the Math Performance of Immigrant Youths in the US [22]	Kim, S.	2018	Sustainability
The Relationships of Family, Perceived Digital Competence and Attitude, and Learning Agility in Sustainable Student Engagement in Higher Education [23]	Kim, H.; Hong, A.; Song, H.-D.	2018	Sustainability
Institutional aspects of educational quality management in higher educational establishments [24]	Dybach, I.	2019	Economics of Development

The incursion of technology in society has transformed both the nature of services and products and the meaning of time at work, in addition to learning processes [25]. Thus, at present, technology has configured a new scenario in the educational field.

In this context, connectivism emerges as a learning theory for the digital age that tries to explain complex learning in a constantly evolving digital social world [26,27]. The educational community has considered this theory, so that the model, from computer science, uses the concept of a network with nodes and connections to define learning [15,28].

In this way, connectivism defines learning as a continuous process that occurs in different scenarios, that is, group, personal, and spatial. The relevance in learning the connection between networks is a conclusive difference between connectivism and traditional learning theories [29]. Thus, in 2004, Siemens indicated that some traditional learning theories have limitations, such as behaviorism, cognitivism, and constructivism, because they were developed when technology had not yet had a high impact on learning [30,31]. That is, these theories were developed when knowledge grew slowly; instead, nowadays, knowledge grows at a higher rate.

The principles of connectivism are based on the fact that learning and knowledge admit the diversity of opinions and that the connection between the sources of information is prioritized, facilitating the learning to be continuous [32]. Likewise, the ability to see the connections between topics, ideas, and concepts is essential. Finally, decision-making itself is a learning process, i.e., choosing what to learn and the changing meaning of the information received [33].

The literature reviewed provides definitions for the basics of this research topic. In this way, some reflections on the terms and concepts used in the context of this research are included. Figure 1 shows the conceptual structure about the study.

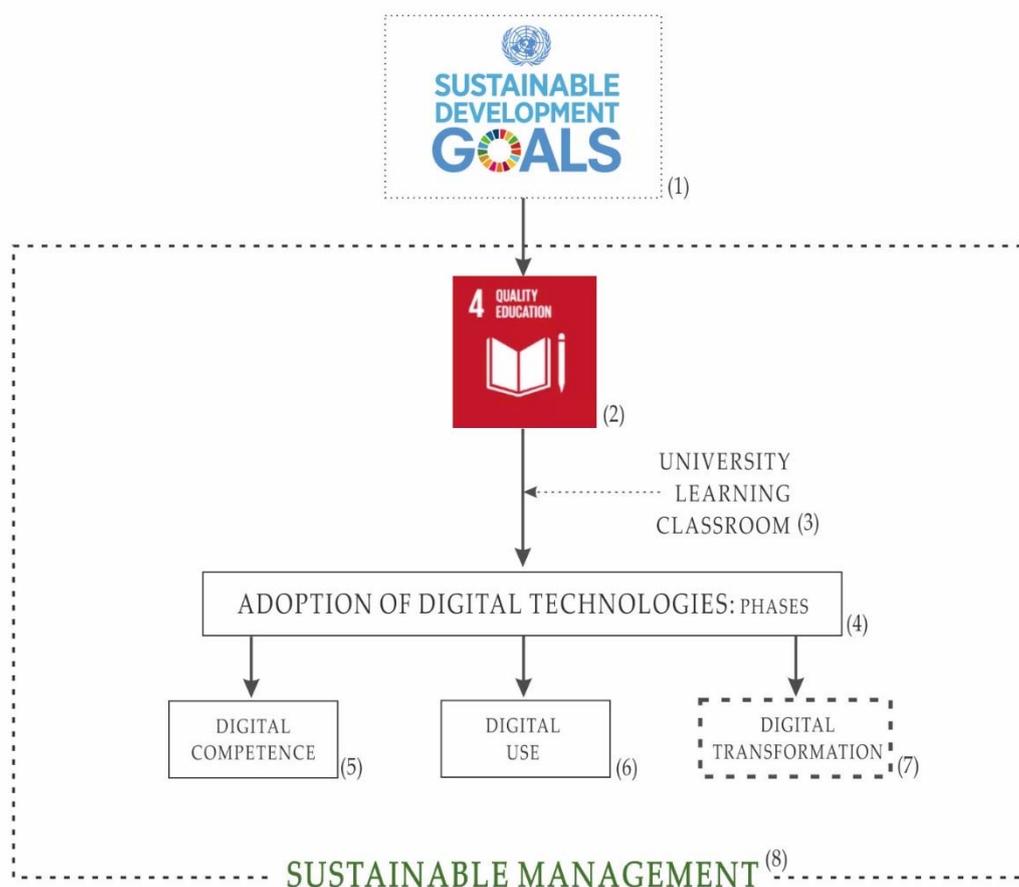


Figure 1. Conceptual structure on the sustainable management of digital transformation in higher education.

DT is a process that integrates digital technology in all aspects and requires changes in the areas of technology, culture, and operations, among others [34,35]. In order to take advantage of emerging technologies and their rapid expansion in human activities, organizations must reinvent themselves and transform all their processes. For this reason, DT requires a change of focus and involves innovating in technology and modifying the institutional culture to guarantee the evolution of DT.

Chronologically, the DT is considered the fourth industrial revolution [36–38], since this change is technological and involves the adoption of new skills of individuals, in addition to the reinvention of institutions (Figure 1, concept 4). On the other hand, the third phase of the adoption of digital technologies is also considered, after digital competence (Figure 1, concept 5) and digital use (Figure 1, concept 6) [39,40].

Likewise, the DT achieves, through digital literacy, the improvement of the use and application capacity. In the educational subject, DT (Figure 1, concept 7) is a process that requires evolution in the way it is taught and adaptation to the new learning needs of the student. Thus, this becomes a more efficient experience, which allows collaborative work [20,41]. Technological advances have made teaching hybrid, so that it combines traditional and virtual spaces, links online with offline, and introduces trends such as DIY (Do It Yourself).

The new learning spaces are including Big Data and Artificial Intelligence (AI) as educational resources, adding value to complex issues in HE. Thus, Big Data allows students to discover trends in relation to new teaching methods, such as adaptive learning, which generates personalized teaching derived from the collection of student data related to age, customs, or behavior. This tool involves teaching at a lower cost, which enhances the capabilities of users and creates a personalized student profile. This will enhance the teaching areas in which it presents difficulties, in order to create a unique course through the e-learning system [42]. On the other hand, HEIs are using AI in order to personalize the student admission process, and identify which applicants are most likely to succeed in their degrees and masters. In addition, this technology allows, among others, to help the teacher identify the student's progress, or to control the teaching process if she/he observes that there is a gap in understanding [43].

Robotics, automation, and other tech-learning tools are changing the way we live, work, and interact [44]. Thus, educational institutions present the challenge of sustaining a learning system that implements the culture of constant and immersive learning in relation to disruptive technologies and programming.

DT drives a practical and creative education, incorporating new didactic models for students to learn and teachers to teach [45], such as Flipped classroom, Digital Cooperative Learning (DCL), Gamification, Augmented Reality, Virtual Reality, or Mixed Reality. Betting on creativity and entrepreneurship, the DT applied in education advocates establishing learning methods based on individualized training, personalization of content, and the development of one's own skills, through social learning [46].

The digital age requires a flexible education that empowers new skills, to get the best of oneself, to develop in a time of constant changes like the current one. Thus, digital education is understood as the face-to-face and distance education that makes use of digital technologies and whose objective is the acquisition of skills and abilities to learn, both from teachers and students, in a process of ongoing training [47–49]. On the other hand, it represents an opportunity to increase the educational coverage and productivity of the institutions [50].

HE (Figure 1, concept 3) has maintained its traditional teaching paradigm, with a rigid and inflexible structure [11,51,52]. The emergence of digital technology has contributed to the revolution of classrooms and learning methods. For this reason, the DT must be in line with the mission and vision of the university [53].

The concept of "higher education" was defined in the World Declaration on Higher Education adopted by the World Conference on Higher Education in 1998, and is used, among other institutions, by the United Nations Educational, Scientific and Cultural Organization (UNESCO), the World Bank,

UNDP (United Nations Development Program). Thus, HE is considered as “all types of studies, training or research training at the postsecondary level, provided by universities or other educational establishments that are approved as institutions of higher education by the competent state authorities”. In this sense, it includes all the activities that a given country considers HE, that is, those that take place within current universities and postgraduate schools, in addition to short-term education and training courses, such as polytechnics, university colleges, and several forms of specialized technical schools, and correspondence courses that use ICT and are aimed at a wide variety of students [54].

On the other hand, UNESCO is the only specialized institution of the United Nations that has a mandate in HE and, for this reason, facilitates the development of empirically based policies on HE [55]. In accordance with Target 4.3 of Sustainable Development Goal (SDG) 4 (Figure 1, concepts 1 and 2): “By 2030, ensure equal access for all men and women to quality technical, professional and superior training, including university education”. UNESCO provides technical support to Member States so that they can examine their strategies and policies related to HE in order to improve equitable access to quality HE and to strengthen academic mobility and accountability [56,57].

Education is the basis for improving people’s quality of life and sustainable development globally [21,24]. In addition, access to inclusive and equitable education can help provide the population with the necessary tools to develop innovative solutions to problems. In this way, linking quality education with technology, leading to DT, allows students to provide knowledge, skills, and motivation to understand the SDGs, mobilize youth, provide academic or vocational training to implement solutions SDGs, and create more opportunities for capacity-building of students and professionals from developing countries to address the challenges related to the SDGs [58,59].

In relation to the concept of sustainable management (Figure 1, concept 8), this is defined as a decalogue of human, ethical, and environmental values, with the purpose of providing societies with an instrument for the sustainable development of companies, institutions, and communities, thus ensuring competitiveness and strengthening the global economic and social fabric [60–62].

In the context of HE, it must guarantee the sustainable management of DT to achieve the model of an open, digital, innovative, and networked institution that it pursues [63]. Thus, sustainable management must implement management systems based on good practices, which ensure greater competitiveness and better development of organizations. In this sense, transparency in the sustainability of the activities of educational institutions is a priority for stakeholders [64–67].

One of the most important challenges of sustainable development is the demand for innovative alternatives and new ways of thinking in HEIs. Thus, the management of educational institutions in a sustainable way is a priority objective in all advanced educational policy.

Despite the advantages of DT, it also has a negative impact on HE. In this sense, if the student does not engage in self-censorship, it can generate distractions in their educational development. In addition, the process of learning and teaching is less human and more impersonal; it is not completely inclusive, since not the entire population has access to digital tools; and, on the other hand, it can nullify certain skills and critical ability.

3. Materials and Methods

Bibliometry is a scientific field within Scientometrics, which applies mathematical and statistical methods to scientific literature, with the aim of studying and analyzing scientific activity [68–70]. In the mid-twentieth century, E. Garfield introduced bibliometry, and it has become widespread in scientific research in order to help revise knowledge in numerous disciplines [71,72]. Use the bibliometric indicators to measure information about the results of scientific activity in any of its manifestations.

In this study, the objective is to show and analyze research trends on the sustainable management of DT in HE globally. To achieve this, a quantitative analysis has been performed, using bibliometry. In recent decades, it has contributed to the review of scientific knowledge, and has been used successfully in different scientific fields, such as medicine, engineering, economics, administration, finance, education, biology, or ecology [73–75].

The methodology followed was to perform a complete search in the Scopus database, for its breadth of coverage and reliability [76,77], using Boolean logic connectors in the search string with the terms “digital”, “technolog*”, “higher education”, “university” and “sustainability” to examine the subfields of the title, abstract, and keywords, in the period from the publication of the first article on the subject of study, 1986, until the last full year, 2019, that is, a period of 34 years, as has been applied in other bibliometric works [78–81]. The asterisk (*) indicates any character group, including null characters. It was decided to include only articles, both in open and unopened access, because they are the only documents submitted with guarantees to the peer review process in order to guarantee their scientific quality. Thus, the final sample of articles analyzed was obtained through a search in January 2020 and included a total of 1590 articles.

The methodology has been developed to analyze the scientific communities associated with this theme. Thus, the relationships between the authors, institutions, and countries, interpreted through the co-authorship of each work, were analyzed, in addition to analyzing the relationships between the keywords of all documents based on co-occurrence.

The co-citation analysis has allowed the observation of documents with citations and cited references that can show the intellectual basis and trends in a particular area of research. Thus, the authors, institutions, and countries are determined based on the co-citations of the rest, which represent relevance in this discipline, so that these generators of scientific production can be substitutes for the ideas they represent [82,83].

On the other hand, the co-occurrence analysis has been used in order to provide a graphic visualization of the interconnection of the key terms within the analyzed documents [84,85]. Generally, co-occurrence networks are used in order to facilitate a graphic visualization of potential relationships between authors, institutions, countries, or terms in a text. Thus, the proximity relationship of two or more terms in a text unit can be observed, so that if the terms co-occur in a sentence, that is, they appear together in it, there is a probability of their semantic relationship. In short, the co-occurrence criteria allow for revealing and grouping strongly related concepts within the set of documents or records. This procedure examines documents in order to look for two or more concepts that tend to be presented together [86,87]. Thus, two or more concepts are co-occurring if they frequently appear together in a set of documents and if they are occasionally separated in the other documents. So, if co-occurring concepts are found, a category is generated.

Likewise, the indicators of the collaboration structure, which measure the links between the authors, institutions, and countries, have been analyzed by means of network processing tools and maps due to their reliability and suitability in the bibliometric analysis [88,89].

VOSviewer software tool (version 1.6.10., University of Leiden, Leiden, The Netherlands) was used as a mapping and processing tool due to its reliability and suitability in bibliometric analysis. It has allowed the processing of keywords and the analysis of grouping, with the purpose of visualizing maps, by co-authorship and co-occurrence. In addition, VOSviewer has made it possible to know the collaborative structure indicators, which measure the network links between authors, institutions, and countries, as well as the identification of research trends based on the use of keywords [90].

The results obtained in the evaluation of scientific activity in this area of research are useful for researchers, academics, analysts, managers, and the rest of the interest groups.

4. Results and Discussion

4.1. Scientific Production and Subject Area

Figure 2 shows the evolution of the 1590 articles identified in the search during the period from 1986 to 2019. This result illustrates the exponential trend in the publication of works on the management of DT in HE in the last 34 years. It is observed that, during the last five years, 2015–2019, 863 articles have been published, corresponding to 54.28% of the total, demonstrating the growing interest and

relevance of this theme. Thus, in the first year analyzed, 1986, two articles were published, while in 2019, the last year studied, a volume of 248 articles was published (15.60%).

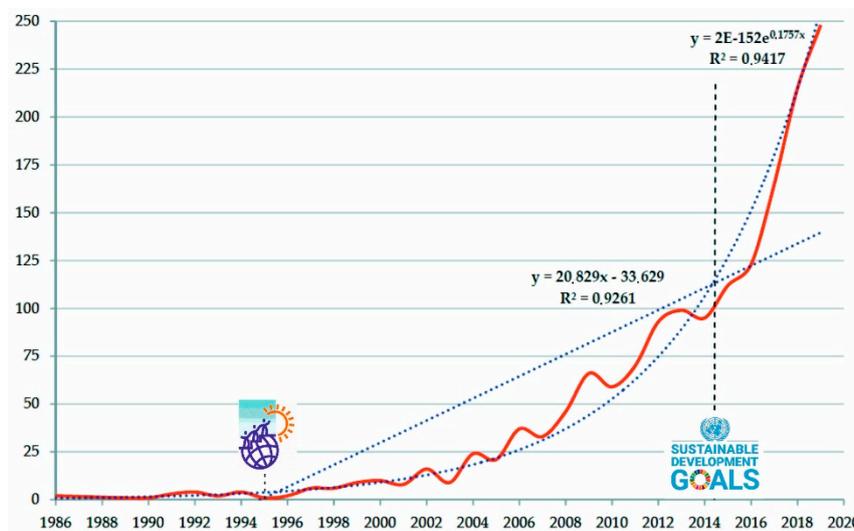


Figure 2. Evolution of the number of articles on the sustainable management of digital transformation in higher education (1986–2019).

These articles are mainly written in English (95.16%), as is common in searches in the Scopus database [91]. In addition, articles have been published in other languages, such as Spanish (1.70%), Russian (1.13%), or Portuguese (1.01%), while the rest do not exceed 1% of the total contributions.

In the period analyzed, 1986–2019, the exponential trend line shows its goodness of fit with an R^2 value of 0.9417. The curve means that the number of articles on the subject studied grows faster and faster over time. On the other hand, in the subperiod from 1995 to 2015, the trend line is also goodness of fit, with an R^2 value of 0.9261, and demonstrates the good fit of the line to the data. Thus, the linear trend line indicates that the number of items has increased at a constant rate in this period.

Both trend lines, linear and exponential, intersect at two points: first, in 1995, which corresponds to the World Summit on Social Development in Copenhagen, which called for ensuring that people living in poverty had access to production resources (credit, land, education and training, technology, knowledge, and information), as well as public services and participation in decision-making on a regulatory environment that would allow them to take advantage of economic and employment opportunities [92]; secondly, in 2015, coinciding with the adoption of the 2030 Agenda for Sustainable Development by the United Nations General Assembly [93], where the exponential nature is more pronounced in relation to the increase in scientific production on this subject. The goals related to quality education and the promotion of sustained economic growth promoted by the SDGs have meant that the international nature of publications increases.

During the time horizon analyzed, 1986–2019, works related to the sustainable management of DT in HE in various areas of knowledge have been found. According to the Scopus database, the 1590 articles analyzed are classified into 25 thematic areas. It is necessary to clarify that the same article can be classified in more than one category, subject to the interest of the author and the publisher.

Figure 3 presents how the thematic classification of articles has evolved this research topic. The Social Sciences category is the one highlighted during the entire period studied, with 24.88% of the articles published on the DT of university education. Next, the Environmental Science category follows, with 16.66%. Engineering (12.68%), Business, Management, and Accounting (8.29%), and Energy (7.69%) are the following categories in order of importance. Thus, the five most important categories represent 70.20% of the articles published on this research area from 1986 to 2019. In addition to the indicated categories, including Agricultural and Biological Sciences (4.88%), Computer Science

(4.55%), Medicine (3.11%), Economics, Econometrics, and Finance (2.84%), and Arts and Humanities (2.31%), the rest of the thematic areas do not reach 2% of published studies.

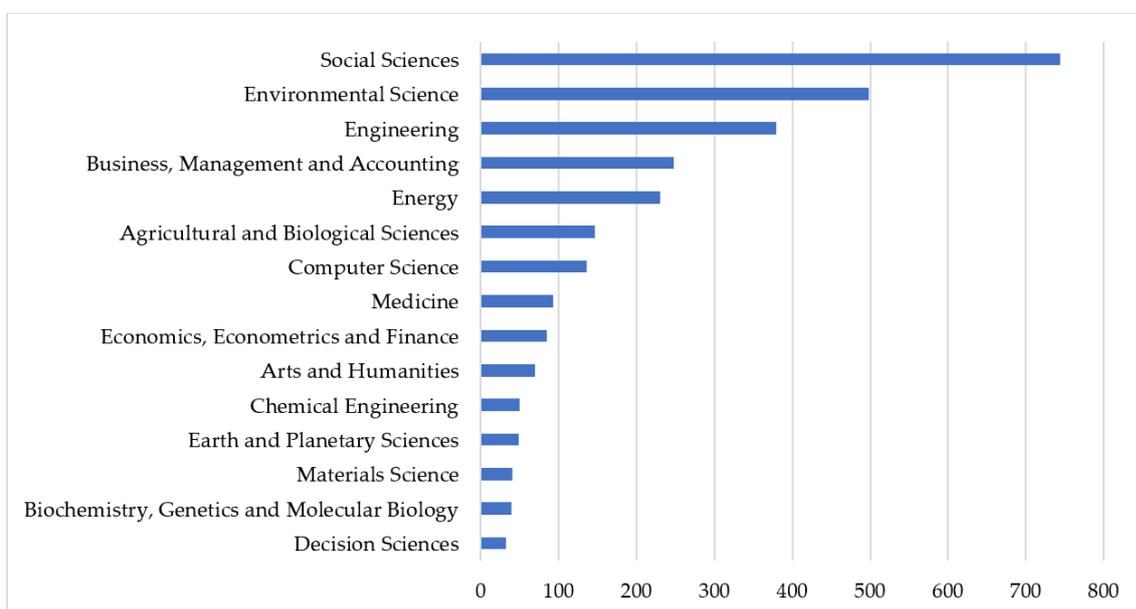


Figure 3. Main thematic areas on the sustainable management of digital transformation in higher education (1986–2019).

Most of the works in this research topic are associated with the Social Sciences category. Within this, the articles are included in their different disciplines (anthropology, sociology, geography, history, law, political science, economics, communication, pedagogy, and psychology) [94,95], that study, among other specific objectives, the organization of the HEIs, or the relationships between different stakeholders in a university that are affected by DT [96,97]. The Environmental Science category deals with issues about the environmental opportunity or challenge of digital technology, sustainability in the digital age, or the revolution of DT in organizations in relation to productivity and efficiency [98]. Another set of categories incorporates fewer studied subjects, such as Decision Science, which addresses the decisions taken within the limits of an organization, or as Biochemistry, Genetics, and Molecular Biology, which must begin to take center stage in this subject, since the results of their studies could be applicable in various areas of research [99,100].

Articles have been published in 850 journals from 1986 to 2019. Regarding the most productive scientific journals in this area, Sustainability (79, 4.97%) stands out, followed by the Journal of Industrial Ecology (66, 4.15%), International Journal of Sustainability in Higher Education (51, 3.21%), and Journal of Cleaner Production (47, 2.96%). The rest of the journals have less than 1%.

4.2. Publications by Author, Institution, and Country

The most productive authors in the sustainable management of DT in HE were Mulder, K.F. (The Hague University of Applied Sciences, The Hague, The Netherlands), Cappellaro, F. (ENEA Centro Ricerche Casaccia, Rome, Italy), Schandl, H.U. (Commonwealth Scientific and Industrial Research Organization, Canberra, Australia), and Yarime, M. (University of Tokyo, Tokyo, Japan). Among the ten most productive authors, six are of European origin, with a Dutchman (Mulder, K.F.), three Italians (Cappellaro, F.; Cotana, F.; Cumo, F.), an Austrian (Eisenmenger, N.), and a Spaniard (Ferrer-Balas, D.).

Table 2 shows the main keywords associated with the ten most productive authors in this area of research. The keywords are varied, although those that relate to the SDG and the exploitation of a certain resource below its renewal limit stand out. In this case, “sustainability”, “sustainable development”, “industrial ecology”, “developing countries”, “bioconversion”, “co-design”, or “co-creation” stand out.

A second group of keywords is in line with education, such as “active learning”, “higher education”, “pedagogy”, “active citizenship”, or “engineering education”. The term “barriers to innovation and sustainability in universities” stands out, linking the two previous groups. Finally, in a third group more numerous can be classified terms related to digital transformation and technology, such as “appropriate technologies”, “transformation”, “material flow”, “solar energy”, “alternative energy”, “acoustic performance”, “advanced technology”, “digital storage”, and “materials flow analysis (MFA)”.

Table 2. Main authors and keywords.

Author	Affiliation	City, Country	First Article *	Last Article *	Main Keywords
Mulder, K.F.	The Hague University of Applied Sciences	The Hague, The Netherlands	2004	2012	Sustainable Development, Sustainability, Active Learning
Cappellaro, F.	ENEA Centro Ricerche Casaccia	Rome, Italy	2014	2019	Active Citizenship, Appropriate Technologies, Co-design
Schandl, H.	Commonwealth Scientific and Industrial Research Organization	Canberra, Australia	2006	2018	Industrial Ecology, Developing Countries, Material Flow
Yarime, M.	University of Tokyo	Tokyo, Japan	2013	2017	Sustainability, Co-creation, Transformation
Asif, M.	King Fahd University of Petroleum and Minerals	Dhahran, Saudi Arabia	2017	2019	Sustainability, Solar Energy, Alternative Energy
Brandli, L.L.	Universidade de Passo Fundo	Passo Fundo, Brazil	2019	2019	Sustainable Development, Higher Education, Barriers to Innovation and Sustainability in Universities
Cotana, F.	Università degli Studi di Perugia	Perugia, Italy	2013	2016	Sustainable Development, Acoustic Performance, Bioconversion
Cumo, F.	Università degli Studi di Roma La Sapienza	Rome, Italy	2010	2016	Sustainable Development, Advanced Technology, Digital Storage
Eisenmenger, N.	Universität für Bodenkultur Wien	Wien, Austria	2006	2015	Industrial Ecology, Materials Flow Analysis (MFA) Sustainability
Ferrer-Balas, D.	Universitat Politècnica de Catalunya	Barcelona, Spain	2008	2012	Pedagogy, Sustainable Development, Engineering Education

(*): in this research topic.

The literature indicates that, based on the main keywords of the authors, society and the business world have accepted disruption and DT [101,102]. Different investigations point out that this began during the Great Moderation, a period that in economics refers to the reduction of the volatility of fluctuations in the economic cycle in developed nations since the mid-1980s, compared to previous periods [103–105].

Figure 4 shows the network or map of cooperation between authors who have published on the sustainability of DT in HE, based on co-authorship. The color of each cluster refers to the group of authors in the production of articles, while the size of the circle is interpreted according to the number of contributions of the author. Thus, the authors are associated in five groups.

The red group (cluster 1) presents the collaboration between Chen, L., Li, F., Li, Z., Liu, L., Shen, Z., Wang, H., Wang, L., Wang, M., Wang, X., Wang, Y., Wu, J., and Zhou, Y. Cluster 2 (green color) groups Kim, J., Li, L., Lu, Y., Scholz, R.W., Suh, S., and Yang, Y. Cluster 3 (blue color) is composed by the authors Li, H., Li, W., Liu, J., Qi, Y., and Wang, R. Group 4 (yellow) groups Wang, F., Wang, Q., Zhang, X., and Zhou, C. Finally, the fifth cluster (pink color) is made up of Li, J. and Liu, Y.

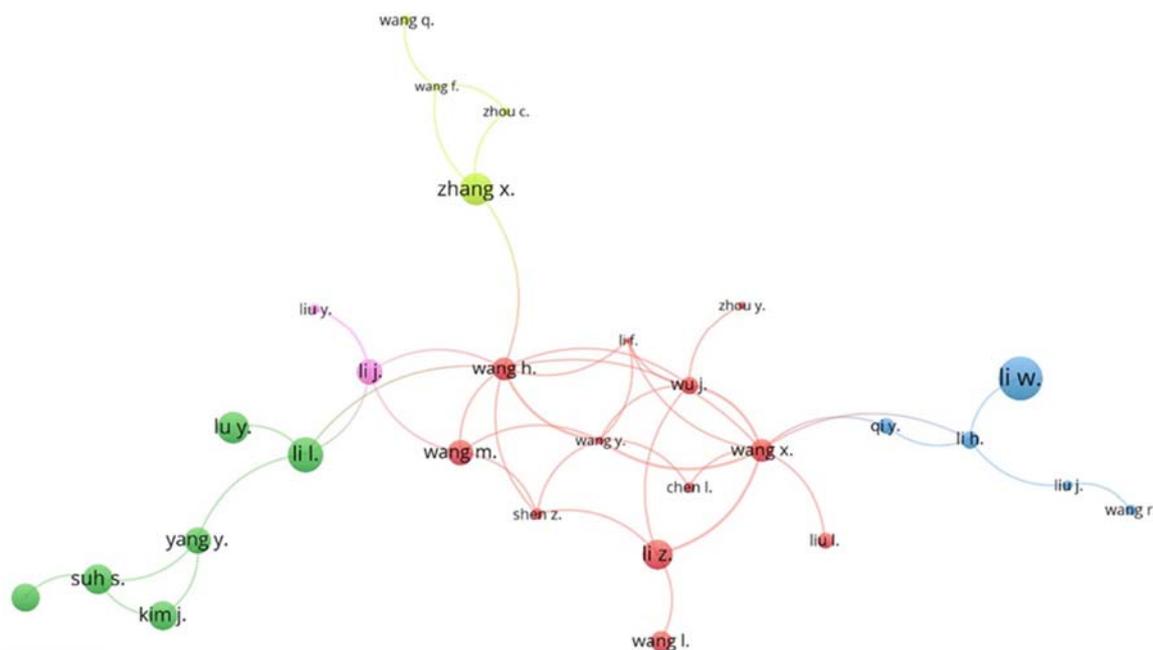


Figure 4. Cooperation network based on co-authorship between authors.

The association between authors of Asian origin is related to the strategy initiated in recent years by China, with the decision to adopt measures in order to transform information, communications, and technology as the country's central industry [106,107]. The goal of this conversion is to end the country's industrial and technological dependence with foreign companies, and become a world leader in information, communications, and culture as technological solutions to make pragmatic compensation between economic growth and social sustainability [108,109].

The total sample of articles has been written in 3668 international affiliations. The institutions with the largest number of articles on the subject of study were Delft University of Technology (the Netherlands), Arizona State University (USA), Purdue University (USA), University of Technology Sydney (Australia), and Universitat Politècnica de Catalunya (Spain). Among the top ten most productive institutions, four are American, four of European origin (The Netherlands, Spain, Switzerland, and the UK), one Australian, and one Chinese.

The global connection is a key factor in DT. Thus, research is emerging to ensure energy efficiency and the responsible use of natural resources [110,111]. Therefore, today's economies need flexible systems that allow them to evolve quickly and efficiently, in line with the speed of technology [112,113].

Table 3 shows the main keywords of the most productive institutions on the sustainable management of DT in HE, during the period analyzed, 1986–2019. Among the most used keywords, the ones related to the management of the resources associated with DT in HE stand out, without compromising the capacities of future generations, that is, “sustainable development” and “sustainability”.

Figure 5 shows the collaboration network between the main institutions that have published on the sustainable management of DT in HE, based on co-authorship. Thus, colors represent the working groups in the publication of articles, while the size of each circle indicates the number of articles of each affiliation. They have been grouped into four clusters. The red group (cluster 1) includes, among other institutions, the Allegheny College, Department of Environmental Science and Sustainability (Meadville, PA, USA); Universiti Sains Malaysia, Center for Global Sustainability Studies (CGSS) and School of Biological Sciences (Penang, Malaysia); University of Bologna, Department of Architecture (Bologna, Italy); Hamburg University of Applied Sciences, European School of Sustainability Science and Research (ESSSR) (Hamburg, Germany); Institut Mines-Télécom Business School (Évry, France). Cluster 2 (green) is composed, among others, of Jeffrey Sachs Center on Sustainable Development

(Kuala Lumpur, Malaysia); Manchester Metropolitan University (Manchester, UK); Pontifical Catholic University of Paraná (Curitiba, Brazil); Positive University (Curitiba, Brazil); International Center for Thriving—University of Chester (Chester, UK). Cluster 3 (blue) is made up, among other affiliations, by the School of Environment Enterprise and Development, University of Waterloo (Ontario, Canada); Universiti Malaysia Sabah (Sabah, Malaysia); University of Beira Interior (Covilhã, Portugal); or Thaksin University (Songkhla, Thailand). Finally, group 4 (yellow) includes the University of Belgrade (Belgrade, Serbia), University of Latvia (Riga, Latvia), University of Passo Fundo (Passo Fundo, Brazil); University of Verona (Verona, Italy), and Xavier Institute of Management and Entrepreneurship (Karnataka, India).

Table 3. Main institutions and keywords.

Institution	City, Country	Main Keywords
Delft University of Technology	Zuid-Holland, the Netherlands	Sustainable Development, Sustainability, Engineering Education
Arizona State University	Arizona, USA	Sustainable Development, Education, Digital Storytelling
Purdue University	Indiana, USA	Education, Sustainability, Technology
University of Technology Sydney	New South Wales, Australia	Higher Education, Sustainable Development, Sustainability
Universitat Politècnica de Catalunya	Barcelona, Spain	Sustainability, Sustainable Development, Education
ETH Zürich	Zurich, Switzerland	Sustainability, Sustainable Development, Environmental Impact
Open University	Milton Keynes, UK	Education, Higher Education, E-learning
Massachusetts Institute of Technology	Cambridge, USA	Sustainability, Sustainable Development, Carbon Emission
University of California	Berkeley, USA	Sustainability, Climate Change, Life Cycle Analysis
Tsinghua University	Beijing, China	Sustainable Development, Industrial Ecology, Environmental Technology

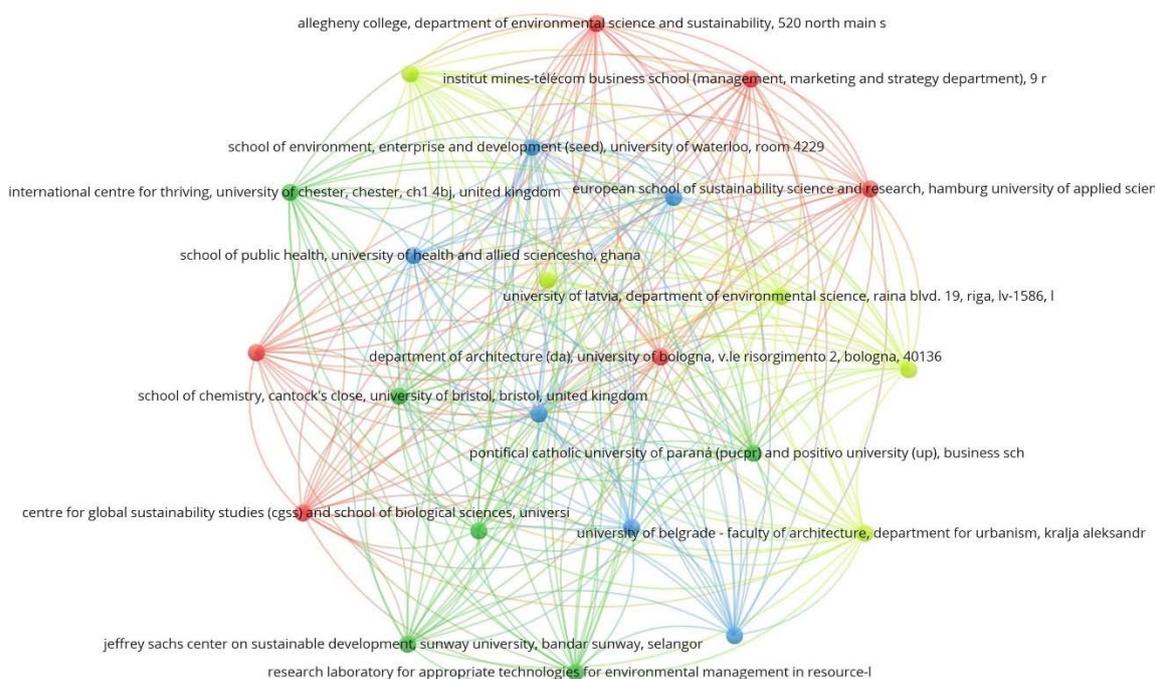


Figure 5. Network of cooperation between institutions based on co-authorship.

The link between education and SDG 4 relates the role of technological advances in HE. Likewise, sustainable development contributes to online education, so that digitalization of education means education of global quality [114–116].

The total sample of articles was written in 105 different countries. The country with the highest number of articles published on the subject of study is USA (23.52%), followed by the UK (10.13%), Australia (6.86%), China (5.22%), Italy (4.97%), The Netherlands (4.59%), Germany (4.53%), and Spain (4.09%). The rest of the countries do not exceed 4% of the total published articles.

Figure 6 shows the collaboration network between the main countries based on the co-authorship of their authors during the last 34 years. The distinct colors represent the different clusters formed by the groups of countries, while the size of the circle varies depending on the number of items in each country. Thus, the larger the circle of each country, the greater the number of articles whose authorship it represents. Countries with contributions in this area of research have been grouped into five clusters.

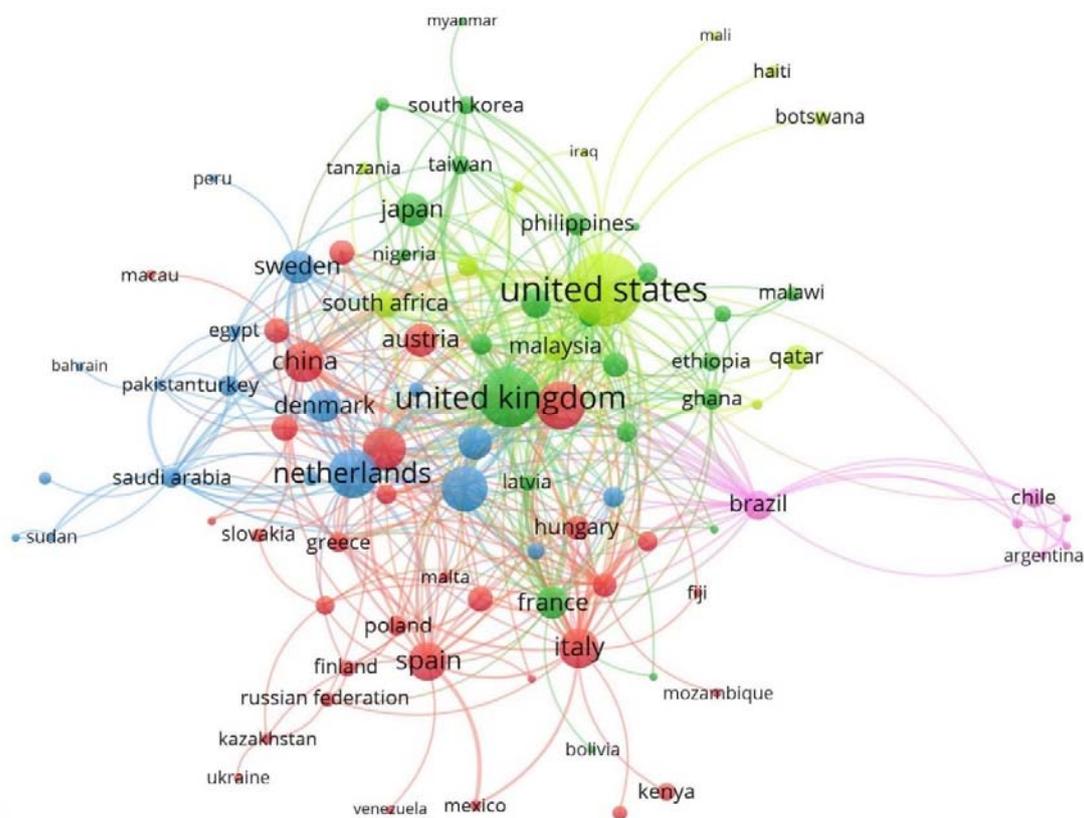


Figure 6. Network of cooperation between countries based on co-authorship.

Thus, the interest generated by the knowledge economy has implications in education as conclusive of economic growth. The ability of countries to both compete and cooperate in the global economy and respond to existing and potential challenges depends on the ability of their educational systems to develop basic skills, which enable greater learning [117,118], and this is reflected in the research collaboration.

Table 4 shows the five clusters on the thematic area of sustainable management of DT in HE, derived from cooperation between countries based on co-authorship and named by the country with the largest number of published articles.

Table 4. Clusters of countries.

Cluster Number *	Color	Cluster Name **	%	Main Countries
1	Red	Australia	34.44	China, Spain, Italy, Germany, Norway, Poland, Russia, Finland
2	Green	UK	26.67	France, Japan, Taiwan, Serbia, Ghana, Latvia, South Korea
3	Blue	The Netherlands	18.89	Canada, Switzerland, Sweden, Denmark, Turkey, Israel
4	Yellow	USA	13.33	Malaysia, Ireland, Qatar, South Africa, Bangladesh
5	Rose	Brazil	6.67	Argentina, Chile, Costa Rica, Guatemala, Panama

(*): see in Figure 6; (**): Main country; %: Network percentage.

Thus, cluster 1 (red) is the most numerous and includes 31 countries, headed by Australia, and is associated, among others, with China, Spain, Italy, or Germany. Group 2 (green) is led by the UK, and shares articles, mainly, with France, Japan, or Taiwan. Meanwhile, cluster 3 (blue) leads it, in this case, The Netherlands, and collaborates in the production of articles on the research area of the study, with Canada, Switzerland, or Sweden. Cluster 4 (yellow) is led by the USA, the country with the most publications, and forms its cooperation network, among other countries, with Malaysia, Ireland, Qatar, or South Africa. Finally, the fifth cluster (pink) is the least numerous and is led by Brazil and includes in its network mainly South American and Central American countries, such as Argentina, Chile, Costa Rica, or Panama.

In this research theme, it is observed that scientific collaboration between these countries does not respond to reliable and elementary relations of a political, cultural, economic, legal, or technological, and digital development type, but rather, they respond to an institutional or related alliances globalization process [119,120].

Along these lines, the European Commission, through the Digital Education Action Plan, considers a series of actions in order to promote the use of technology and the development of digital skills in education in the European Union member countries [121]. Thus, in relation to the open and collaborative nature of the digital society, new studies emerge about the inclusion of digital technology in HE. That is, digital education allows the student to have a shared learning through the digital platforms [122,123].

4.3. Keyword Analysis

Figure 7 shows the network of keywords on the sustainable management of DT in HE, based on co-occurrence. The analysis of the keywords with which scientific documents are classified is one of the main contributions of the bibliometric analysis [124,125]. The main keywords used in the articles of the research area are “sustainability”, “sustainable development”, “higher education”, “innovation”, “technology”, “environmental technology”, “technological development”, and “environmental management”.

Likewise, six main groups of keywords were detected when conducting a co-occurrence analysis of the articles published with this theme. Each cluster is composed of numerous related and dependent elements.

Cluster 1 (red) is the most numerous and groups 33.89% of the analyzed keywords. The main keyword, due to its greater number of co-occurrences, is “environmental impact”, which is associated with “biotechnology”, “carbon emission”, “carbon footprint”, “circular economy”, “cleaner production”, “climate”, “economic growth”, “innovate technology”, “environmental benefit”, “industrial ecology”, “social impact”, “supply chain”, “sustainability technology”, “technological advance”, “MFA” (Multi-factor authentication), or “university campus”.

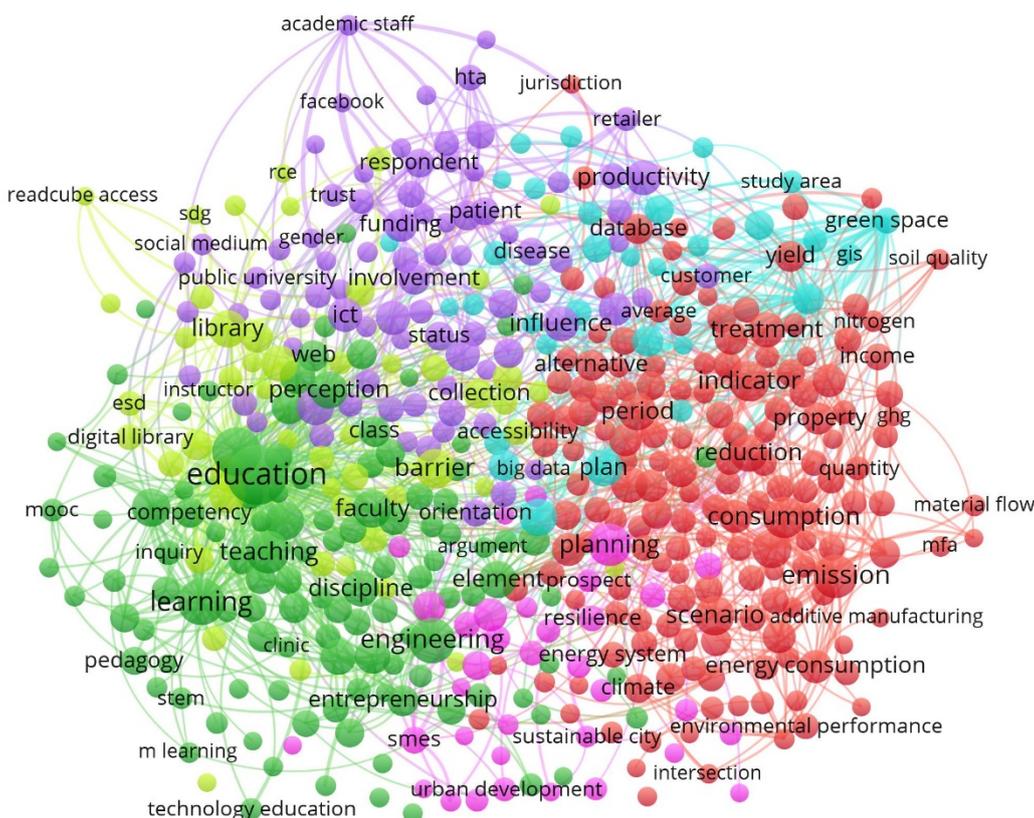


Figure 7. Network of keywords based on co-occurrence.

Cluster 2 (green) brings together 24.21% of the keywords. In this group, the main keyword is “education”, which is linked to terms such as “active learning”, “technology education”, “app (application)”, “continuous improvement”, “pedagogy”, “cultural heritage”, “distance education”, “e-learning”, “m-learning”, “ecological footprint”, “educational institution”, “future generation”, “ICM” (Information Classification and Management), “ISO” (International Organization for Standardization), “Massive open online course” (MOOC), “nanotechnology”, “STEM” (Science, Technology, Engineering and Mathematics), or “web”.

Group 3 (violet) concentrates 17.26% of the keywords on the DT of HE. The main keyword is “ICT” (Information and Communications Technology) and is associated, among others, with “academic staff”, “Big Data”, “bioinformatics”, “data analysis”, “data collection”, “digital technology”, “Protocol”, “HTA” (Health Technology Assessment), “knowledge production”, or “mobile phone”.

Cluster 4 (yellow) gathers 10.74% of the keywords. Its main keyword is “library” and is associated with terms such as “accessibility”, “cloud”, “computing”, “creativity”, “digital library”, “ESD” (Education for Sustainable Development), “HEI” (Higher Education Institution), “institutional repository”, “RCE” (Regional Centre of Expertise), “SDG” (Sustainable Development Goal), “sustainable development” or “sustainable practice”.

Cluster 5 (pink) groups 7.37% of the keywords on the subject of study. The main keyword is “computer” and is associated with “competitive advantage”, “energy performance”, “capability”, “new paradigm”, “research institution”, “simulation”, “resilience”, “SME” (small- and medium-sized enterprise), “smart city”, or “social issue”.

Cluster 6 (blue) is the least numerous and only groups 6.53% of the keywords. In this group the main keyword is “green space” and is associated with “competitiveness”, “ETC” (Education Technology Center), “major challenge”, “global change”, “GIS” (Geographic Information Systems), “information system”, “urgent need”, or “significant change”.

The contributions highlight that digital learning through the strategic and personalized approach has an inclusive impact [126,127]. Consequently, new trends in digital education allow students to acquire relevant information related to their specific needs, in addition to collective participation in the digital classroom [128]. Likewise, digital technology in the education sector multiplies the potential for collective intelligence [129,130]. In this sense, this digital stage allows students and teachers to transfer their educational efforts to educational activities and methodologies far from the traditional approach. In this sense, it is necessary to clarify that although the DT has a number of advantages, it also has a negative impact on HE, such as the distraction it can generate in learning or the digitalization of the educational process.

Table 5 shows the main keywords associated with the six clusters, named by the keyword with the most co-occurrences. The diversification and behavior of the six clusters allows us to deduce how the sustainable management of the DT of HE comprises different topics in the research activity.

Table 5. Clusters of keywords.

CNu	C	CNa	%	Main Keywords
1	Red	Environmental impact	33.89	Circular economy, Life cycle assessment, Recycling, Technology development, Social impact
2	Green	Education	24.21	Higher education, App, Distance Learning, Sustainability education, Massive open online course (MOOC)
3	Violet	ICT	17.26	Bioinformatics, Digital technology, Sustainability science, Facebook, Data analysis
4	Yellow	Library	10.74	Digital library, Accessibility, Computing, Creativity, Higher education institution
5	Rose	Computer	7.37	Simulation, Energy performance, Competitive advantage, Sustainable city, Smart city
6	Blue	Green space	6.53	Information system, Global change, Future development, Competitiveness, Geographic Information Systems (GIS)

CNu: Cluster Number; C: Color (see in Figure 7); CNa: Cluster Name; %: Network percentage.

The topic of research under study is dynamic and it is observed that the contributions are adapted to its rapid evolution [131]. In relation to the new lines of research on sustainable management, the keyword “upcycling” has emerged in response to the use of recyclable materials to create objects with a greater value than the initial [132,133], and its application in teaching and learning in HE [134–136]. In addition, among the concepts that arise associated with the DT of HE, the “digital community” stands out, in relation to groups of individuals and institutions organized virtually around a series of specific interests, whose interactions occur on the Network (discussion forums, email groups, chats, or peer-to-peer systems) [137]. In parallel, the term “netnography” is incorporated as a research method to analyze what happens in virtual communities [138].

Figure 8 shows the evolution of each keyword cluster. This graphic allows us to understand the importance of the main keywords according to the time in which they have arisen. It also indicates that the most pioneering keywords will have influence and will be a reference for the terms that have subsequently emerged. The maturity of each group of words is observed when differentiating the period in which they have been studied. Most of the keywords arose before 2017 and have been a reference for subsequent terms. Among the newest, the term “academic staff” stands out, which has been associated with this theme since 2018 [139]. This concept is defined by the International Standard Classification of Education (ISCED) 5–6, as the personnel that instructs and researches, including the personnel that has an academic rank with titles such as professor, associate professor, assistant

keywords, these authors include those related to SDG (“sustainability” and “sustainable development”), education (“active learning”), digital transformation, and technology (“appropriate technologies”).

The institutions with the largest number of articles on the subject of study were Delft University of Technology (the Netherlands), Arizona State University (USA), Purdue University (USA), University of Technology Sydney (Australia), and Universitat Politècnica de Catalunya (Spain); while the main associated keywords are “sustainable development” and “sustainability”.

The countries that have contributed the most in these areas are the USA, the UK, Australia, China, and Italy, while scientific collaboration between these countries does not necessarily respond to political, cultural, economic, legal, or technological development relationships obvious, but they do respond to institutional alliances or related to globalization.

The study by analyzing the keywords shows that there are six distinct groups around which all these works are grouped. The main keywords, due to their greater number of co-occurrences, are “environmental impact”, “education”, “ICT” (Information and Communications Technology), “library”, “computer”, and “green space”. Its temporal evolution shows a trend towards lines of research that reflect the improvements that digital technologies entail, both in the quality of HE, as in teacher training and professional development.

This study has some limitations, which could be the basis for future research. In this sense, one of these limitations refers to the intrinsic characteristics of bibliometric analysis, since it is a method of quantitative analysis. On the other hand, it is remarkable that certain authors publish few articles in a certain area of knowledge, but these have a great impact. The bibliometric method could also be expanded to analyze research trends with other quantitative or qualitative tools, which may provide a different perspective. In addition, in this study the analysis period could be limited, so that the results could vary.

Future lines in this area of research must contemplate, among others, the implications of SDG 4 in the DT of HE by regions, countries, or continents; the opportunities and challenges generated by the blockchain in the educational context; corporate vulnerability of digital threats; the link between artificial intelligence and sustainable development; the role of HE in the environment of DT; cybersecurity in HE; elucidate the future of HE in Industry 4.0; or the analysis of disruptive blockchain projects in HE.

As for the most productive journals, Sustainability points out that, although it had its first article published on the subject of study in 2013, it has become the magazine with the largest number of articles on the sustainable management of the link between DT and HE, with 79 articles, which represent 7.47% of the total articles on this subject that have been published between 2013 and 2019, a circumstance that will be reflected in the citations of these works in the coming years.

Finally, it is necessary to highlight that the growing interest of authors, institutions, and countries shown by the number of publications in recent years supposes the support of the international scientific community to the study of the different thematic lines of DT in the sector of HE and its link to sustainability.

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