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Science Mapping Research of Integration Digital Technology and Education for Sustainable Development: A Bibliometric Analysis

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ABSTRACT

The integration of digital technology into Education for Sustainable Development (ESD) has received increasing scholarly attention due to its potential to support sustainable and inclusive education. However, the development, thematic structure, and research directions of studies addressing the integration of digital technology and ESD have not been systematically mapped across the broader literature. This study aims to map publication trends, disciplinary contributions, geographical distribution, keyword relationships, and emerging research themes related to digital technology and ESD. Bibliographic data were retrieved from the Scopus database for publications from 2015 to 2025 using the search terms "Digital Technology" AND "Sustainable Development Goals." The data were processed and analyzed using VOSviewer through publication trend analysis, subject-area and country distribution analysis, keyword co-occurrence analysis, network visualization, overlay visualization, and density visualization. The results show a substantial increase in publications, particularly from 2020 onward, with Social Sciences, Computer Science, Business and Management, and Environmental Science emerging as major contributing fields. India, China, the United Kingdom, and the United States were among the leading contributors. Keyword analysis identified "Sustainable Development Goals," "digital transformation," and "sustainability" as dominant themes, while the overlay analysis indicates an increasing research focus on digital transformation, digital platforms, and technological innovation. These findings provide a science-mapping overview of the development and thematic evolution of research on digital technology and ESD and identify potential directions for future research.

Keywords : Bibliometric Analysis, Digital Technology, Education for Sustainable Development, VOSviewer.

I. INTRODUCTION

The advancement of digital technology has transformed various aspects of human life, including the education sector. Digital transformation refers to changes in the way work is carried out and managed through the utilization of information technology to improve efficiency and effectiveness [1]. his transformation is supported by the adoption of various digital technologies, including hardware, software, and enabling technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), and online learning platforms. The use of these technologies has fostered more flexible, effective, and participatory learning environments, thereby enhancing the quality of education [2]. As part of digital transformation, the development of learning platforms, interactive learning media, and digital instructional materials has become an important strategy for improving the quality of education, strengthening students' digital literacy, and enhancing their motivation and learning outcomes [3,4]. As part of digital transformation, the development of learning platforms, interactive learning media, and digital instructional materials has become an important strategy for improving the quality of education, strengthening students' digital literacy, and enhancing their motivation and learning outcomes [5]. Digital transformation has become one of the primary drivers of change within education systems, requiring the adaptation of various components of the teaching and learning process to remain relevant to the continuous advancement of science, technology, and the evolving needs of society.

Digital transformation has also driven changes across various components of the education system, one of which is the curriculum as the primary framework guiding the implementation of teaching and learning. The curriculum not only defines educational objectives, learning content, and instructional processes but also plays a crucial role in developing students' competencies to align with advancements in science, technology, and the evolving needs of society [6]. Integrating digital technology into the curriculum represents a strategic approach to fostering digital literacy, critical thinking, creativity, collaboration, and problem-solving skills, which are essential competencies for the twenty-first century [7]. Furthermore, the use of various digital learning media and platforms enables students to engage more actively in searching for, analyzing, processing, and communicating information as part of a learning process that supports sustainable living in the future [8]. The continued development of curricula that integrate digital technology further strengthens the role of education in preparing students to address a wide range of global challenges, including issues related to sustainable development through innovative and inclusive learning.

On the other hand, the Sustainable Development Goals (SDGs) represent a global commitment designed to ensure a sustainable, peaceful, prosperous, and equitable life for all people on Earth, both in the present and for future generations [9]. One of the 17 SDGs is Quality Education (SDG 4), which focuses on providing quality education and learning opportunities for all. In this context, integrating digital technology with Education for Sustainable Development (ESD) has become increasingly important as an effort to support the achievement of quality education while accelerating sustainable development. The use of digital technology in education can have an optimal impact when supported by three key components, namely content, capacities, and connectivity, thereby enabling the creation of more inclusive, high-quality, and accessible learning environments [10]. The integration of educational technology contributes to expanding access to education, improving learning quality, and supporting the achievement of SDG 4 through the utilization of various digital technologies [11].

ESD has emerged as an approach that has received widespread attention in the development of education systems. ESD aims to equip students with the knowledge, skills, values, and attitudes needed to address various sustainable development challenges. To achieve this objective, ESD needs to be integrated into the learning process across various core subjects, such as mathematics, science, social studies, and language [9]. In its implementation, digital technology enables the development of interactive and contextual learning media that support critical thinking skills within ESD [12]. Digital technology also provides students with more collaborative learning experiences while fostering the development of twenty-first-century skills that are aligned with the principles of sustainable development [13]. Integrating digital technology into the implementation of ESD represents an important strategy for achieving high-quality, sustainable, and contextually relevant learning environments that responds to the demands of the times.

Recent studies have increasingly examined the application of digital technologies in supporting ESD. For example, a bibliometric study on the integration of Augmented Reality (AR) and ESD in science education identified immersive learning, digital pedagogy, sustainability awareness, and interdisciplinary approaches as important research themes [14]. Other studies have explored the use of AI, IoT, Virtual Reality (VR), learning analytics, mobile learning, and gamification to support sustainable learning and ESD [15]. Digital technologies have also been associated with broader educational access, learning flexibility, and inclusive education [16]. These studies demonstrate the growing diversity of technology-supported ESD research; however, they mainly focus on specific technologies or particular aspects of ESD rather than providing a comprehensive science map of the broader research field.

Although previous studies have provided valuable insights into specific digital technologies and their applications in ESD, the broader development of research integrating digital technology and ESD has not been comprehensively mapped. Limited attention has been given to the simultaneous examination of publication trends, disciplinary contributions, country distribution, keyword relationships, and the temporal evolution of research themes. Consequently, the overall knowledge structure and dominant themes of this interdisciplinary field remain insufficiently understood. A comprehensive bibliometric mapping is therefore needed to identify emerging research directions and clarify future opportunities in digital technology-supported ESD.

To address this gap, the present study employs a bibliometric science-mapping approach to examine Scopus-indexed publications on digital technology and ESD from 2015 to 2025. The novelty of this study lies in integrating publication trend analysis, subject-area distribution, country contributions, keyword co-occurrence, temporal development, and density visualization to provide a comprehensive overview of the evolution and knowledge structure of the field. Specifically, this study aims to identify publication trends, major contributing disciplines and countries, dominant research themes, emerging topics, and potential directions for future research. The findings

are expected to provide a systematic reference for researchers and educators in understanding the development of digital technology-supported ESD research.

II. METHOD

This study employed a bibliometric analysis using a science-mapping approach to examine the development of research related to the integration of digital technology and ESD. Bibliometric analysis provides a systematic approach for examining the intellectual structure, emerging trends, and relationships among research themes within a particular field [17]. Bibliometric analysis is a quantitative approach that can be used to examine publication patterns, research trends, collaboration networks, and the development of a research field [18]. It also enables researchers to systematically identify research trends and map the development of topics within a particular field [19]. In this study, bibliometric analysis was used to identify publication trends, disciplinary and geographical contributions, keyword relationships, and the development of research themes related to digital technology and ESD across different research contexts and periods.

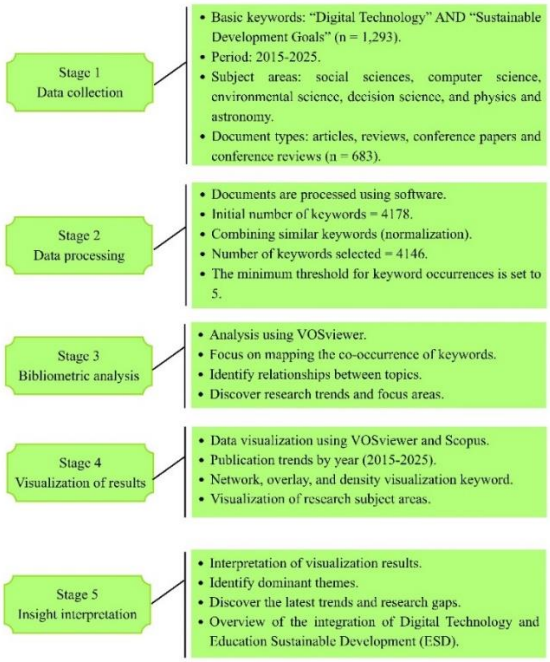

Fig 1. Stages in Bibliometric Analysis Research

The data were obtained from the Scopus database, which was selected because of its broad coverage of internationally published scientific literature and the availability of comprehensive bibliographic metadata. The search was limited to publications published between 2015 and 2025 to capture the development of research during the selected period. The document types considered in the study included articles, review articles, conference papers, and conference reviews. The initial search retrieved 1,293 records, which were subsequently screened according to the predetermined selection criteria. After the selection process, 683 documents were retained for further data processing and bibliometric analysis.

The search strategy was developed to identify publications addressing the relationship between digital technology and sustainable development within an educational context. The search query used the keywords "Digital Technology" AND "Sustainable Development Goals." The Boolean operator AND was applied to retrieve publications containing both concepts. The retrieved records were subsequently screened for their relevance to the research focus. This keyword strategy was intended to obtain literature representing the intersection of digital technology, education, and sustainable development and to provide an appropriate dataset for the subsequent bibliometric analysis.

The research procedure consisted of several stages, including data collection, article selection, data processing, bibliometric analysis, visualization, and interpretation. These stages were adapted from the bibliometric analysis framework proposed in previous research [18]. During the data collection stage, relevant bibliographic records were retrieved from Scopus based on the predetermined search strategy and selection criteria. The retrieved records were then screened and processed before being analyzed. The overall research procedure is presented in Figure 1 to provide a systematic overview of the stages followed in the study.

Before the bibliometric analysis, the retrieved bibliographic data were processed to improve consistency and accuracy. Microsoft Excel and Notepad were used to examine and standardize the bibliographic records, particularly the keyword data. Keywords with equivalent meanings or different forms of expression were combined or standardized to reduce redundancy in the analysis. The initial keyword set was subsequently filtered using a minimum keyword-occurrence threshold of five. The processed dataset was then prepared for analysis and visualization using VOSviewer.

VOSviewer was used to conduct keyword co-occurrence analysis and to identify relationships among the keywords within the selected publications. The analysis focused on the relationships and co-occurrence patterns among keywords to reveal the conceptual structure and thematic development of the research field. Network visualization was used to identify keyword relationships and thematic clusters. In this visualization, the size of a node represents the frequency of keyword occurrence, while the links represent co-occurrence relationships among keywords within the analyzed research network.

Three types of visualization were generated using VOSviewer: network, overlay, and density visualization. Network visualization was used to identify the relationships and clusters among research themes, overlay visualization was used to examine the temporal development of research topics based on the average publication year, and density visualization was used to identify highly concentrated and dominant research themes. The resulting visualizations were interpreted descriptively to identify dominant themes, emerging research directions, and potential areas for future research. The findings were then used to provide an overview of the development and knowledge structure of research on the integration of digital technology and ESD.

III. RESULTS AND DISCUSSION

Results

Bibliometric analysis is one of the methods widely used to examine publication patterns, research collaboration networks, and the distribution of emerging topics within a particular field of study. Through this approach, countries, institutions, and authors that have made significant contributions to the development of research on digital technology and sustainable development can be identified. Thus, the results of the analysis are expected to provide a comprehensive understanding of research trends, developments, and dynamics, thereby serving as a foundation for advancing future research. In addition, bibliometric analysis enables the mapping of knowledge structures through relationships among keywords, citations, and interconnected publications. The resulting maps can reveal dominant research themes, emerging topics, and areas that require further investigation. This information can support researchers in determining research directions, identifying opportunities for collaboration, and formulating future research agendas.

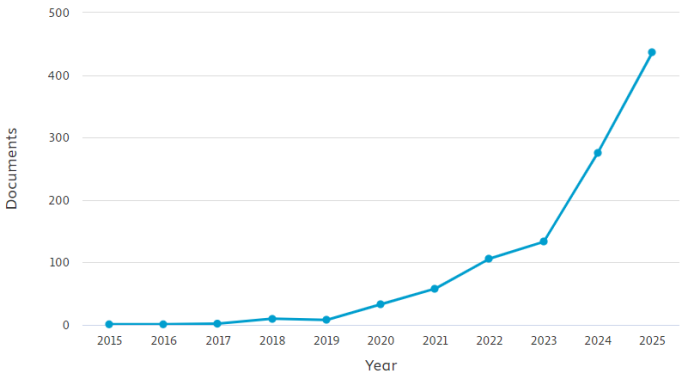

Fig 2. Distribution of Publication Trends 2015 to 2025 on the Integration of Digital Technology and ESD

Figure 2 presents the annual publication trend on the integration of digital technology and ESD from 2015 to 2025. The number of publications remained relatively low during the early years of the observation period, with a gradual increase beginning in 2018. A slight decline was observed in 2019, followed by a continuous increase from 2020 onward. The growth became more pronounced from 2022, and the highest publication output was recorded in 2025. Overall, the annual distribution shows a clear upward trend in publications during the 2015–2025 period, reflecting growing research attention to this interdisciplinary field.

The distribution of subject areas provides an overview of the academic disciplines contributing to research on a particular topic. This analysis identifies the disciplines with the largest contributions and illustrates the relative involvement of each field in shaping the research landscape. The distribution also demonstrates the extent of

interdisciplinary integration and the emergence of cross-disciplinary research over time. These findings provide a broader understanding of the academic scope of the topic and demonstrate how its development is supported by contributions from multiple disciplines.

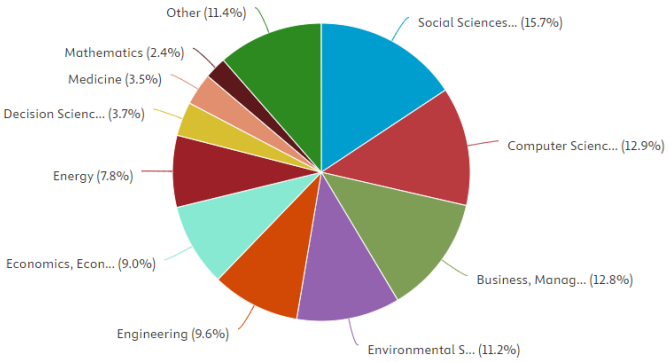

Fig 3. Distribution of Research Fields on the Integration of Digital Technology and ESD

Figure 3 presents the distribution of research fields related to digital technology and ESD. Social Sciences represented the largest proportion of publications at 15.7%, followed by Computer Science at 12.9% and Business and Management at 12.8%. Environmental Science accounted for 11.2% of the publications. Other contributing fields included Engineering, Economics, Energy, Decision Sciences, Medicine, and Mathematics, although their proportions were lower than those of the four dominant fields. Overall, the distribution demonstrates that research on digital technology and ESD spans multiple academic fields, with Social Sciences, Computer Science, Business and Management, and Environmental Science representing the largest contributions.

The analysis of country distribution provides an overview of the geographical contributions to the development of research in a particular field. This analysis makes it possible to identify countries with the highest publication productivity as well as patterns of international collaboration among researchers from different regions. The distribution of countries also reflects the extent of their involvement in advancing scientific knowledge and the development of research networks across regions. Furthermore, it provides valuable insights into the dissemination of knowledge, the strength of international research connections, and potential opportunities for future collaboration.

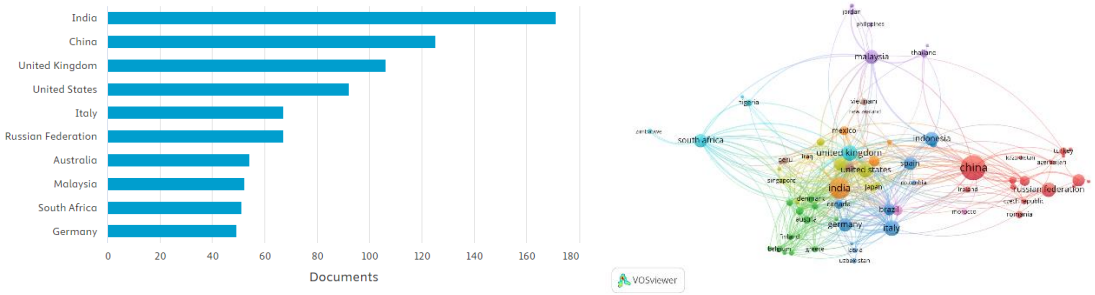

Fig 4. Distribution of Country Publications on the Integration of Digital Technology and ESD

Figure 4 presents the distribution of publications by country on the integration of digital technology and ESD. India, China, the United Kingdom, and the United States were the leading contributing countries in the analyzed publications. Other countries represented in the distribution included Italy, Russia, Australia, Malaysia, South Africa, and Germany. Among Southeast Asian countries, Malaysia was the only country represented among the ten leading contributors, while Indonesia was not included in the top ten. The visualization also shows relatively prominent nodes for India, China, the United Kingdom, and the United States, indicating their substantial contributions to the publication landscape. Overall, the country distribution demonstrates broad international participation in research on digital technology and ESD.

Network visualization is employed in bibliometric research to map the connections among different research components, including authors, keywords, institutions, and documents. This approach provides a graphical representation of how research elements are interconnected and enables the identification of collaboration patterns, thematic clusters, and the intellectual structure of a research field. The visualization also indicates the strength of relationships between elements and helps determine topics that occupy central positions within the research network. In addition, the resulting network can be used to examine relationships between research themes and

identify groups of topics that share strong conceptual associations, thereby providing insights into the development and direction of research.

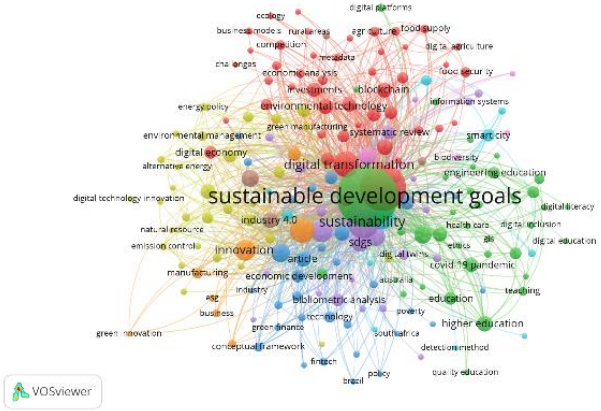

Fig 5. Network Visualization of the Integration of Digital Technology and ESD

Figure 5 presents the keyword co-occurrence network of research on digital technology and ESD. "Sustainable Development Goals" appears as the largest and most prominent keyword in the network, with strong connections to digital technology-related terms. The keywords "sustainability," "technological transformation," and "education" also show prominent connections within the network. Other keywords, including "digital literacy," "digital education," "students," "e-learning," "quality education," and "teaching," contribute to the broader network and indicate the presence of several interconnected research topics. Overall, the network visualization shows that research in this field is organized around interconnected themes involving sustainable development, digital transformation, and education.

Overlay visualization analysis in bibliometric studies is used to illustrate the development of research topics based on the temporal dimension. This approach enables researchers to identify topics that emerged during earlier periods as well as those that have developed more recently through color gradients representing publication years. The overlay visualization generated using VOSviewer illustrates the development of research on digital technology and ESD during the 2023–2025 period. In this visualization, each node represents a keyword, while the color gradient indicates the average publication year. Blue represents topics that emerged earlier, whereas green to yellow indicates topics that have developed more recently. Thus, overlay visualization helps identify research dynamics, shifts in research focus, and directions of research development in a more comprehensive manner.

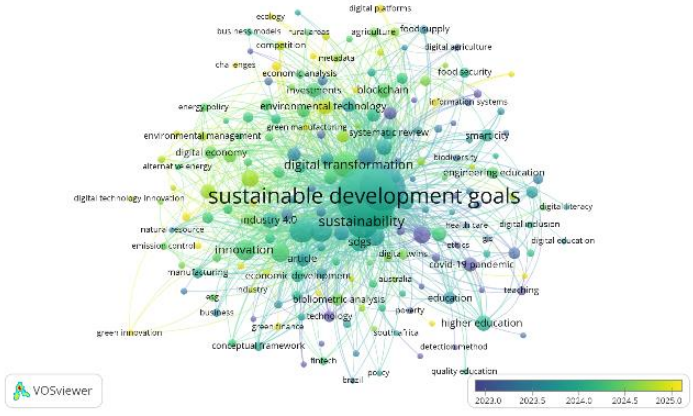

Fig 6. Overlay Visualization of the Integration of Digtisl Technology and ESD

Figure 6 presents the temporal development of research themes related to digital technology and ESD based on keyword co-occurrence. "Sustainable Development Goals" appears as the largest and most central keyword, while "digital transformation" and "sustainability" show strong connections with other keywords in the network. The visualization also shows connections among "education," "higher education," "digital education," "digital literacy," and "teaching," as well as keywords such as "information systems," "digital platforms," and "smart city." The temporal distribution indicates that earlier research was more closely associated with education and digital

literacy, whereas more recent research has increasingly involved digital technology innovation and digital platforms. Overall, the overlay visualization shows a shift in research themes toward broader applications of digital technology in supporting ESD.

Density visualization analysis in bibliometric studies is used to illustrate the density of keyword or research topic occurrences within a particular field of study. Through this visualization, areas with a high occurrence intensity can be identified as themes that have received the most attention in research. In addition, density visualization enables researchers to distinguish between topics that have been extensively developed and those that remain relatively underexplored. Thus, this visualization can serve as a reference for identifying research opportunities and determining directions for future research development.

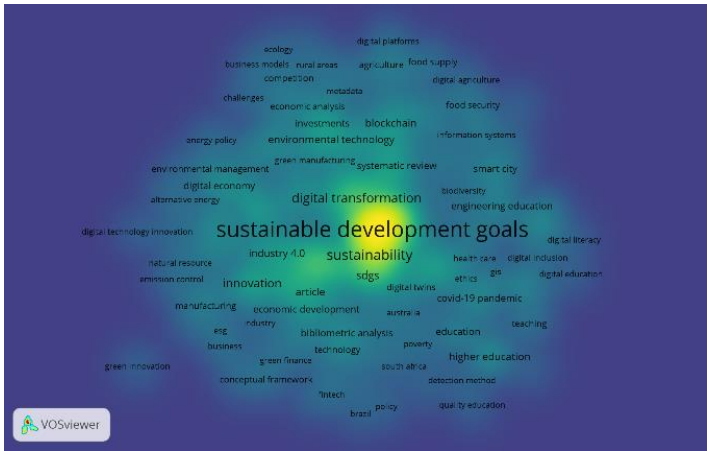

Fig 7. Density Visualization of the Integration of Digital Technology and ESD

Figure 7 presents the density visualization of research themes related to digital technology and ESD. The highest-density area is centered on the keyword "Sustainable Development Goals," which is closely associated with "digital transformation" and "sustainability." These keywords form the most concentrated areas in the research landscape. Other keywords, including "education," "Industry 4.0," "environmental technology," and "innovation," appear in surrounding areas with relatively lower density. Overall, the density visualization identifies "Sustainable Development Goals," "digital transformation," and "sustainability" as the most prominent and frequently occurring themes within the analyzed literature.

Discussion

The increasing publication trend related to the integration of digital technology and ESD during the 2015–2025 period indicates that this topic has become an increasingly important area of academic research. The stronger growth observed after 2020 suggests that research attention has expanded alongside the increasing need to utilize digital technology in educational and sustainability contexts. However, the growth of scholarly publications does not necessarily indicate that the implementation of digital technology in education is already equitable or effective. Evidence from educational settings indicates that the use of technology in schools remains uneven [20]. This disparity is influenced by technological infrastructure, internet access, availability of digital devices, and educators' competencies in integrating technology into learning [21]. Therefore, the increasing research activity identified in this study should be understood alongside the continuing implementation challenges, particularly in ensuring equitable access and strengthening the capacity of educators to use digital technology in support of ESD.

The distribution of subject areas demonstrates that research on digital technology and ESD has developed as a multidisciplinary field rather than being confined to education or technology alone. The strong contributions of Social Sciences, Computer Science, Business and Management, and Environmental Science indicate that the development of technology-supported ESD involves pedagogical, technological, organizational, and sustainability perspectives. This finding is consistent with previous research describing ESD as an interdisciplinary field that integrates social, economic, environmental, and technological dimensions in addressing sustainable development challenges [22]**.** UNESCO also emphasizes that the implementation of ESD requires collaboration among disciplines and stakeholders to support the achievement of the SDGs [23]. Furthermore, previous bibliometric research has shown the importance of cross-disciplinary connections in the development of ESD research [24]. Thus, the multidisciplinary distribution observed in this study reflects the broad scope of ESD and suggests that digital technology is being examined not only as a technological tool but also as part of wider educational, organizational, and sustainability systems.

The country distribution indicates that research on digital technology and ESD has developed internationally, although publication contributions are concentrated in countries with relatively strong research and innovation capacities. The leading contributions from India, China, the United Kingdom, and the United States suggest that research capacity and technological development may play an important role in shaping the geographical distribution of publications. This pattern is consistent with previous bibliometric findings showing that ESD research productivity has been dominated by countries such as China, Spain, and Germany, which have established research and innovation ecosystems [25]. The absence of Indonesia from the leading contributors is also noteworthy, particularly because Southeast Asian representation remains relatively limited in the analyzed publication landscape. Previous research has similarly reported the dominance of developed countries in ESD research and highlighted the need to strengthen research capacity and international collaboration among developing countries [26]. In this context, increasing research participation from countries with lower publication output could contribute to a more geographically diverse knowledge base on digital technology and ESD.

The keyword network reveals that research on digital technology and ESD is structured around strong relationships among sustainable development, digital transformation, and education. The prominence of "Sustainable Development Goals" indicates that the SDGs provide an important conceptual orientation for research in this field [23]. The strong connections among digital transformation, sustainability, and education further suggest that digital technology is increasingly considered in relation to broader sustainability objectives rather than as an isolated educational tool. This pattern is consistent with Parmaxi et al., who highlighted the growing integration of digital technology and emerging technologies in ESD-oriented educational innovation [27]. It is also consistent with Tafese and Kopp, who identified digital transformation, learning innovation, and sustainable development goals as important themes in the development of ESD research [28]. Thus, the keyword relationships observed in this study indicate an increasingly interconnected research landscape in which digital technology, education, and sustainability are examined as related dimensions of sustainable development.

The overlay visualization indicates a temporal shift in research attention from education and digital literacy toward digital transformation, digital platforms, and technological innovation. This shift suggests that the role of digital technology in ESD research has expanded beyond its use as a learning medium toward broader considerations of technological transformation within education and sustainability contexts. The finding is consistent with Parmaxi et al., who emphasized the increasing role of emerging technologies and digitalization in education for sustainable development [27]. UNESCO likewise emphasizes that digital technology is increasingly viewed not merely as a learning medium but as a driver of educational transformation and a means of supporting the achievement of the SDGs [21]. The temporal development identified in this study therefore indicates a broadening research agenda, in which digital technology is increasingly examined as part of wider educational and sustainability transformation processes.

The density visualization further confirms that "Sustainable Development Goals," "digital transformation," and "sustainability" constitute the core themes within the analyzed literature. The high concentration of these themes indicates that research on digital technology and ESD is strongly oriented toward connecting technological development with broader sustainability objectives. This finding is consistent with previous studies, which identified SDGs, educational transformation, and sustainability as major themes in ESD research [29]. Similarly, the increasing integration of digital technology and emerging technologies has been emphasized as an important driver of educational innovation for sustainable development [27]. In addition, UNESCO highlights the importance of integrating digital transformation with innovation and cross-sectoral collaboration in addressing sustainability challenges through education [21]. The presence of supporting themes such as innovation, environmental technology, and Industry 4.0 suggests that the research field also has potential to expand toward broader technological and interdisciplinary applications.

IV. CONCLUSION

This study provides a bibliometric overview of research on the integration of digital technology and ESD based on Scopus-indexed publications from 2015 to 2025. The findings reveal an overall increase in publication activity, with Social Sciences, Computer Science, Business and Management, and Environmental Science emerging as the major contributing fields, while India, China, the United Kingdom, and the United States were among the leading contributing countries. The keyword co-occurrence analysis identifies "Sustainable Development Goals," "digital transformation," and "sustainability" as prominent themes within the research landscape. The overlay visualization indicates a temporal shift from earlier research emphasizing education and digital literacy toward more recent attention to digital transformation, digital platforms, and technological innovation. Overall, the findings demonstrate that research connecting digital technology and ESD has developed into a multidisciplinary and increasingly interconnected field, while the science map provides a systematic overview of its development and thematic structure. Future studies may further investigate the implementation of

specific digital technologies across diverse educational contexts and strengthen research representation from regions and countries that remain underrepresented in the existing literature.

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