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Artificial Intelligence in Sustainable Education: A Bibliometric Analysis and Future Research Directions

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Abstract: This study investigates the role of Artificial Intelligence (AI) in sustainable education through a bibliometric analysis, aiming to explore research trends, key contributors, citation analysis, co-authorship, and thematic developments in the field. As AI becomes increasingly integrated into Education, it is crucial to understand its impact on learning personalization, institutional efficiency, and sustainability. The study also identifies research gaps and provides recommendations for future exploration. The study employs a bibliometric and content analysis methodology using Scopus data. Two hundred seventy-six documents (2016-2025) were analyzed through descriptive statistics, citation analysis, co-word analysis, and co-authorship networks, utilizing VOSviewer and Biblioshiny for data visualization. The analysis examines publication trends, top-cited articles, leading institutions, and international collaborations to map the intellectual landscape of AI in sustainable education. The findings indicate a significant increase in AI-related publications after 2019, reflecting growing global interest. India, the USA, and China lead research output, while Sustainability (Switzerland) and Lecture Notes in Networks and Systems are the most prominent publication sources. The co-authorship analysis highlights strong global research collaborations, with the UK, Brazil, and China playing key roles. Thematic clustering reveals four major research areas: AI-driven Environmental Education, AI in Education, sustainable education frameworks, and AI's technical advancements in learning systems. This study provides a comprehensive, macro-level bibliometric analysis that maps global research dynamics, identifies intellectual structures, and visualizes collaborative networks in AI and sustainable education. Despite its contributions, the study has several limitations. First, while Scopus offers broad and reputable coverage of peer-reviewed literature, the exclusive reliance on this database limits the inclusion of potentially relevant studies indexed in other databases such as Web of Science (WoS). This may restrict the diversity and comprehensiveness of the findings. Future research should consider cross-validating results using multiple databases to ensure a more holistic understanding of AI in sustainable education. Second, the exclusion of non-English publications may limit the diversity of perspectives. Third, the study primarily focuses on journal articles and conference papers, excluding books and institutional reports that might offer more profound insights.

Keywords: Artificial Intelligence; Machine learning; Deep learning; Environmental education; Sustainable education; Bibliometric analysis; VOS viewer; Biblioshiny

1. Introduction

The Artificial Intelligence (AI) is rapidly transforming how systems operate, enabling machines to perform tasks that traditionally require human intelligence. With its ability to process vast amounts of data, recognize patterns, and make autonomous decisions, AI has become a key driver of technological advancement (Gulenko et al., 2020). The continuous development of AI techniques, including machine learning and deep learning, has led to more sophisticated and efficient systems capable of improving decision-making, optimizing processes, and enhancing overall efficiency (Malik et al., 2023). AI-driven automation has redefined workflows, reducing human effort in repetitive tasks and allowing for greater precision and speed in complex problem-solving (Zhang & Wen, 2021). While AI offers numerous benefits, its widespread adoption also presents challenges related to ethical considerations, data security, and algorithmic biases (Elendu et al., 2023). As AI systems increasingly influence decision-making, concerns about transparency, accountability, and the potential unintended consequences of autonomous technologies have become critical discussion areas (Gordon-Murnane, 2018). Furthermore, integrating AI into various domains raises questions about its long-term impact on human roles, requiring ongoing Research and regulatory measures to ensure its responsible development and use (Khogali & Mekid, 2023). As AI continues to evolve, balancing its potential with ethical and societal considerations remains essential for harnessing its benefits while mitigating associated risks.

Artificial Intelligence (AI) is changing the future of Education by enhancing efficiency, promoting accessibility, and fostering sustainability. As educational institutions embrace digital transformation, AI-driven tools are being integrated to personalize learning, automate administrative processes, and optimize resource utilization, thereby contributing to more sustainable and inclusive educational ecosystems (Bültemann et al., 2023). By reducing the reliance on physical infrastructure, minimizing resource wastage, and expanding educational opportunities beyond traditional classrooms, AI plays a crucial role in making Education more accessible, cost-effective, and environmentally friendly (Lin et al., 2023). One of the most significant contributions of AI to sustainable education is its ability to personalize learning experiences based on individual student needs. Traditional education models often follow a standardized approach that may not cater to students' diverse learning paces and preferences. AI-powered adaptive learning platforms address this challenge by analyzing students' performance, learning patterns, and engagement levels to deliver customized content and real-time feedback (Kamruzzaman et al., 2023). This improves learning outcomes and ensures that students receive the support they need, reducing dropout rates and enhancing overall academic success. AI fosters a more inclusive and efficient educational environment by allowing learners to progress at their own pace. In addition to enhancing learning experiences, AI significantly improves the efficiency of educational institutions by automating administrative tasks. AI-powered systems can handle repetitive and time-consuming duties such as grading assignments, managing student records, scheduling classes, and monitoring attendance (Bucăţa & Tileagă, 2024). This automation reduces the workload for educators and administrative staff and allows them to focus on higher-value tasks such as mentoring and curriculum development. By optimizing resource allocation, AI-driven automation contributes to more cost-effective and sustainable education management.

AI also plays a key role in reducing the environmental impact of Education by promoting digital learning and reducing reliance on physical materials. Traditional educational systems rely heavily on printed textbooks, paper-based exams, and extensive physical infrastructure, leading to significant resource consumption and waste generation (Caird et al., 2013). AI-powered e-learning platforms, virtual classrooms, and digital libraries provide alternatives that significantly reduce paper usage, lower carbon footprints, and minimize energy consumption associated with maintaining extensive educational facilities. Additionally, AI-driven energy management systems in smart classrooms optimize lighting, heating, and electricity usage, further contributing to sustainability efforts (Park et al., 2020). Beyond improving operational efficiency, AI enhances the accessibility of Education, breaking geographical and socioeconomic barriers that have historically limited learning opportunities. AI-powered virtual learning environments, automated translation tools, and intelligent tutoring systems enable students from diverse backgrounds to access high-quality educational resources, regardless of location or financial constraints (Gligorea et al., 2023). This is particularly important for learners in remote and underserved regions, where access to qualified teachers and educational infrastructure is limited. AI-driven language processing technologies also facilitate multilingual Education, allowing non-native speakers to engage with learning materials in their preferred language, thereby improving comprehension and inclusivity.

In recent years, extensive empirical research has been conducted on AI and higher education, such as *Artificial Intelligence in Education: Challenges and Opportunities for Sustainable Development*, *Artificial Intelligence in Education,* and *Impact of Artificial Intelligence on Students' Sustainability Education and Career Development Using the Extended TOE Framework* (Hamal et al., 2022; Tan et al., 2014). This has resulted in a significant body of literature on Artificial Intelligence in sustainable education. Through an extensive literature analysis, researchers can thoroughly understand how AI supports sustainable education development. Holmes & Tuomi (2022), State of the Art and Practice in AI in Education, the study aims to provide a comprehensive overview of the current state of AI in Education, focusing on efficacy, independent Research, cognitive impacts, socio-political challenges, and the realism of optimistic claims surrounding AI technologies. The study results reveal a complex landscape of AI in Education, characterized by a need for more independent research, skepticism towards existing claims, and a focus on understanding the cognitive impacts of technology on learners.

Given the rapid expansion of research on Artificial Intelligence in sustainable education, a bibliometric approach offers distinct advantages in mapping the intellectual structure and identifying influential trends, contributors, and collaborations across the field. Unlike systematic reviews, which focus on evaluating and synthesizing evidence from a narrow selection of studies, bibliometric analysis provides a macro-level perspective by quantitatively analyzing large volumes of scientific output. This method allows researchers to visualize research productivity, citation patterns, and thematic clusters over time. Therefore, a bibliometric analysis was selected to provide both quantitative insights and qualitative interpretations of the emerging research landscape, enabling a comprehensive understanding of how AI is shaping sustainable education globally.

In previous bibliometric studies of Artificial Intelligence in higher Education, such as the study by Bhagat et al. (2022), the primary aim of the study is to fill the existing gap in the literature regarding the bibliometric analysis of AI in sustainable agriculture, particularly from 2000 to 2021. The study employs a comprehensive bibliometric analysis to evaluate the literature on AI in sustainable agriculture from 2000 to 2021. This method allows for quantitative and empirical examination of published works in the field. In another study by Prahani et al. (2022), the main aim of the study is to conduct a bibliometric analysis of Artificial Intelligence in Education (AIED) research over the last ten years (2011-2021). The study employs a descriptive research method, utilizing bibliometric analysis to examine the metadata from the Scopus database. These studies mainly use a few bibliometric methods to analyze current trends in AIED. The current study is both descriptive, network analysis and content analysis, giving directions for future studies. This study investigates the following questions.

RQ: What are the publication trends in Artificial Intelligence in sustainable education?

RQ: Who are the top contributing authors, institutions, journals, and countries in Artificial Intelligence in sustainable education?

RQ: Which are the top-cited articles on Artificial Intelligence in sustainable education?

RQ: What are the major themes and topics in the intellectual structure of Artificial Intelligence in sustainable education?

RQ: Which are the top collaborative countries in Artificial Intelligence and sustainable education?

RQ: Where else can future Research contribute to Artificial Intelligence in sustainable education?

This study's primary purpose is to delineate the intellectual progression and knowledge framework predicated on publication quantity and examine the research patterns of sources, documents, authors, institutions, and countries. Moreover, its goal is to explore the major topics in the intellectual structure of Artificial Intelligence in sustainable education, impactful research papers, collaboration among nations, and contribute to future research in sustainable education.

This study will significantly contribute in various ways that align with the anticipated outcomes of a bibliometric evaluation. This study will provide fundamental insights into the latest developments in Artificial Intelligence, emphasizing the relationship between Artificial Intelligence and sustainable education, which is the leading publication in the field. This Research will address insights shown by the performance (including publication trends, leading institutions, authors, articles, countries, and highly cited articles), intellectual structure (including key concepts and topics, citation, and co-authorship), and content analysis related to Artificial Intelligence in sustainable education. This study will enhance future Research by allowing for more efficient identification and integration of new contributions with existing ones. This study will encourage future Research by using the insights obtained from the present review to its recommended agenda. This study will highlight critical gaps in existing Research that future investigations may address to ensure the importance and relevance of Artificial Intelligence in sustainable education.

2. Research Methodology

A bibliometric analysis of the literature approach (also referred to as a hybrid review), was conducted to illustrate the best practices in scientific knowledge, particularly in Artificial Intelligence in sustainable education disclosure (Ivanova et al., 2024). This combined approach demonstrates the progression of scientific knowledge in a specific field using quantitative bibliometric tools while incorporating detailed content analysis through a qualitative systematic review (Kavitha et al., 2024). The Research used quantitative and qualitative methods to analyze the literature on AI in higher education disclosure based on Scopus data.

2.1 Data Collection Method

This bibliometric analysis study used Scopus, a scientific database recognized for offering one of the most comprehensive collections of peer-reviewed literature (Guz & Rushchitsky, 2009). Moreover, Scopus is known for its extensive coverage, indexing peer-reviewed journals across multiple disciplines. It also provides strong citation metrics, making it a valuable tool for bibliometric analysis. Its strict editorial criteria also ensure that only reputable journals are included, reducing the chances of low-quality sources (Singh et al., 2021). Scopus was chosen over other databases due to its extensive coverage of peer-reviewed journals across multiple disciplines, ensuring a more comprehensive dataset. It offers advanced citation analysis tools, detailed author profiles, and structured metadata, which enhance research tracking and bibliometric studies; as compared to Google Scholar, which includes non-peer-reviewed sources, Scopus provides more curated and reliable data. While the Web of Science is prestigious, its journal selection is more limited, particularly in non-English publications (Vieira & Gomes, 2009). The search keywords Artificial Intelligence, AI, and sustainable education were included in the title article search on January 4, 2025, resulting in 422 documents published between 2016 and 2025. While compiling the dataset, editorials, notes, and reports were excluded to ensure the analysis focused on peer-reviewed, research-based academic contributions. These document types were omitted primarily because they typically lack empirical data, methodological rigor, and standardized peer-review processes, which are essential for bibliometric consistency and reliability. Editorials and notes often represent opinion pieces or brief commentaries, while institutional reports may vary widely in structure, scope, and academic validation. I refined the dataset to 276 documents comprising articles and conference articles.

2.2 Data Analysis Method

This Research used two principal bibliometric analysis methods: descriptive (Publication trend, contributing countries, affiliations, authors, and journals) and network analysis (Co-word, citation, co-authorship) and content analysis of the top five most cited articles in AI in sustainable education.

This study examines performance through descriptive analysis regarding publication trends, top contributing countries, authors, journals, and affiliations. Moreover, this study examines the primary themes and topics within the intellectual structure through science mapping using co-word analysis, citation analysis, co-authorship analysis, and content analysis of the top five most cited articles in AI in the higher education sector. We utilize the VOSviewer software application and bibliophily for data analysis and visualization. VOSviewer is a robust visualization tool that employs a distance-based mapping technique to display items (van Eck & Waltman, 2010). It presents results as networks and clusters in various colors, reflecting linkages, link strength, and total link strength among articles (Orduña-Malea & Costas, 2021). Figure 1 presents the Data collection and analysis procedure.

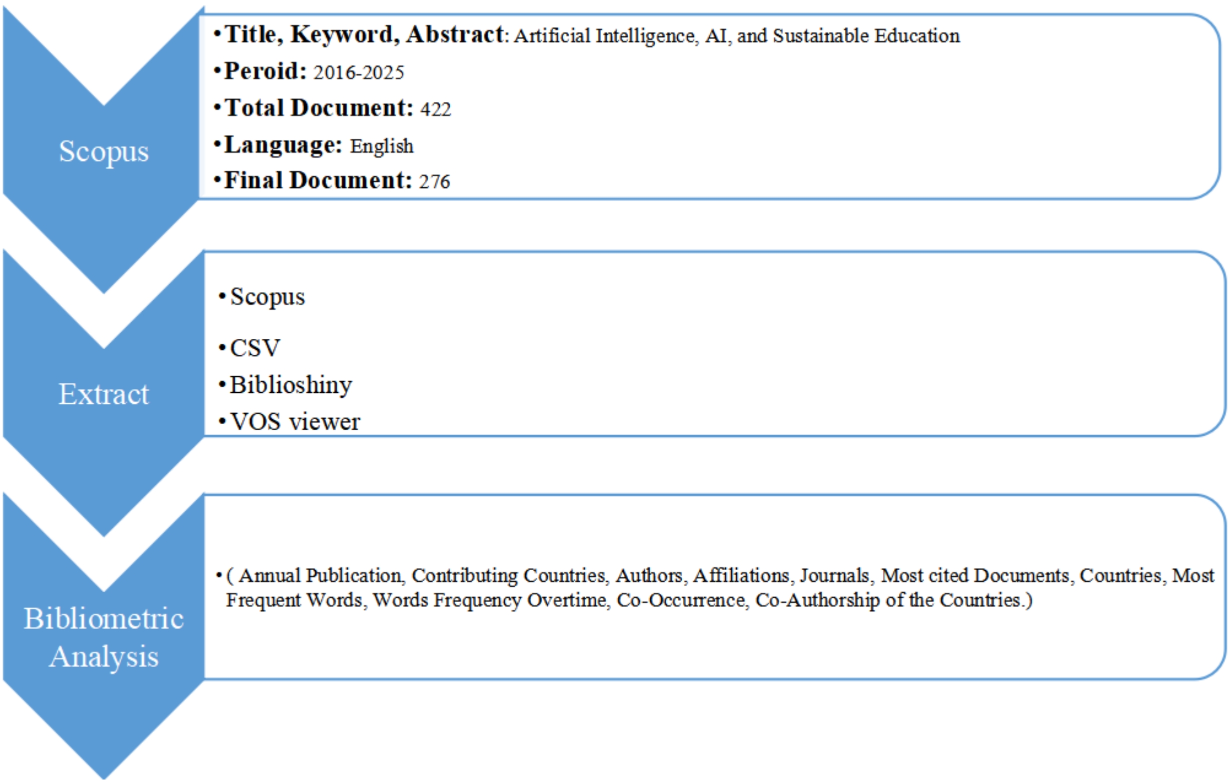

Figure 1. Data collection and analysis procedure

3. Result and Discussion

3.1 Annual Publication

Figure 2 illustrates the yearly research output about Artificial Intelligence (AI) in sustainable education. The data indicates a consistent rise in publication, with little variation in the first years. A considerable increase in the volume of publications has been seen since 2019, indicating heightened interest and progress in the field. The surge in publications after 2019 can be attributed to the global digital transformation accelerated by the COVID-19 pandemic. As educational institutions rapidly shifted to online learning, interest in AI-driven solutions for remote instruction, learning analytics, and educational sustainability increased significantly. This urgency likely fueled a spike in research output focused on AI in education.

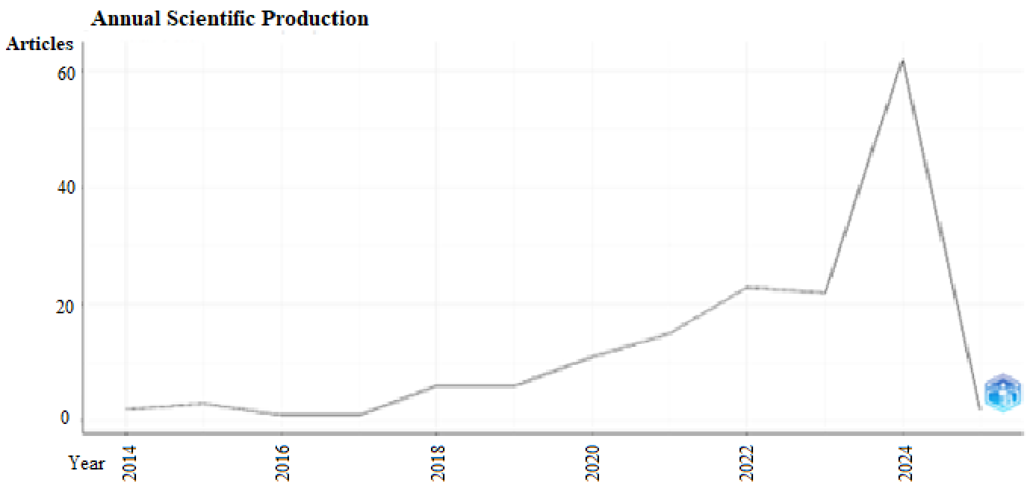

Figure 2. Annual publication

The most significant increase happened in 2023 when the number of articles reached its highest point. The substantial rise indicates that AI's contribution to sustainable education has garnered considerable academic interest, perhaps attributable to technology innovations, legislative modifications, or more financing for research projects (Conde-Zhingre et al., 2022). In 2024, publication output will be significantly reduced due to changes in research emphasis, financial constraints, or saturation in specific fields of study (Shelton, 2008). The trend indicates that while AI in sustainable education has significantly developed, the variations underscore the need for sustained research initiatives and financing to preserve advancement in this multidisciplinary domain (Lin et al., 2023).

3.2 Top Contributing Countries

Figure 3 shows the several countries have made significant contributions to studying Artificial Intelligence in sustainable education. India averages 74 articles, indicating its increasing emphasis on using AI in educational institutions to improve learning results and accessibility. The United States ranks second with 69 publications, underscoring its sustained leadership in AI-enhanced educational progress. Likewise, with 68 articles, China has highlighted AI's promise in transforming Sustainable and creative teaching methodologies.

The United Kingdom and Spain produced 41 and 32 papers, respectively, highlighting their involvement in investigating AI-driven sustainability solutions in Education. With 24 publications, Saudi Arabia demonstrates its dedication to incorporating AI into its developing educational systems. Brazil and Malaysia contribute 21 papers, indicating a mutual focus on using AI to enhance sustainable learning settings. Portugal and Romania, each contributing 20 papers, further underscore the worldwide influence of AI on Education. These efforts together underscore the growing acknowledgment of AI's significance in promoting educational sustainability across many locations (Leal Filho et al., 2024). The map presents the publication of the countries.

3.3 Top Contributing Affiliations

Just Table 1 shows the top ten research affiliations that have published the most papers on Artificial Intelligence and sustainable education. Numerous academic institutions worldwide have significantly contributed to Research on using Artificial Intelligence in sustainable education. Kent State University in the United States averages eight publications, underscoring its strong academic emphasis on AI-driven educational advances. Near East University in Turkey and the University of Liverpool in the United Kingdom both have seven publications, ranking closely together. Their contributions indicate an increasing interest in examining AI's revolutionary educational effects.

The University Health Network in the United States has published seven publications highlighting the significance of AI in improving educational sustainability in healthcare and other fields. Simultaneously, the Catholic University Center of Eastern Minas Gerais in Brazil, City University Ajman in the UAE, Fundación Universitaria Konrad Lorenz in Colombia, King Abdulaziz University in Saudi Arabia, and Mohammed VI Polytechnic University in Morocco have each produced six publications. This varied representation reflects a worldwide dedication to using AI in sustainable educational methodologies. North Carolina State University in the United States has six publications, adding to the country's leading status in AI-related Research in Education. The extensive geographic range of participating schools signifies a collaborative academic endeavor to investigate AI's potential to promote long-term sustainability in Education across many locations (Leal Filho et al., 2024).

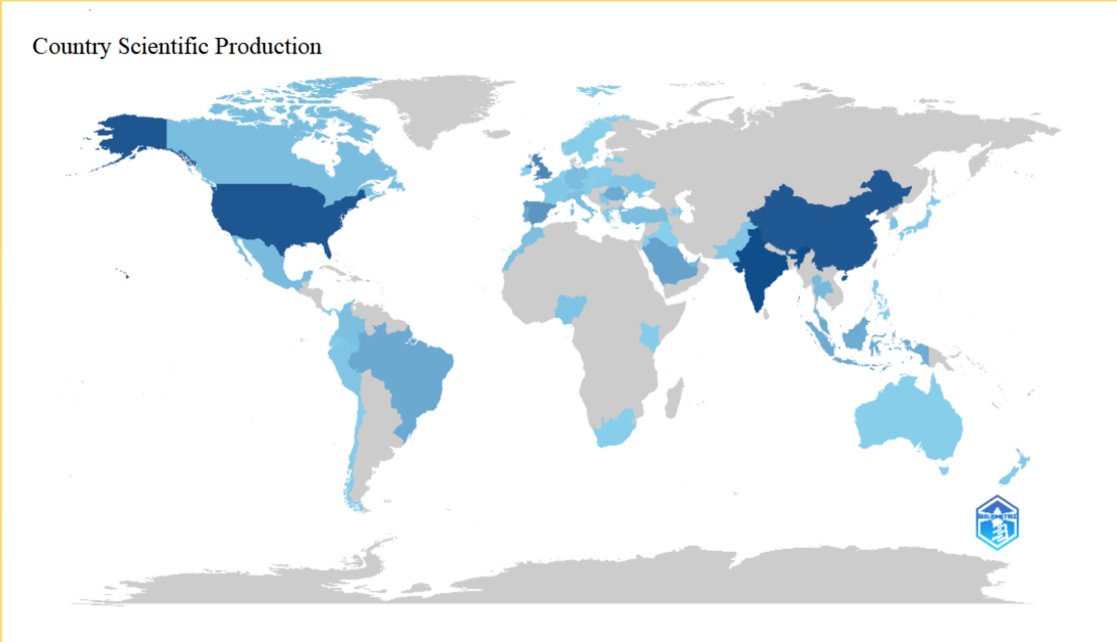

Figure 3. Top contributing countries

3.4 Top Contributing Authors

Table 2 presents the top 10 authors with the most publications on Artificial Intelligence and sustainable education. The analysis of significant authors in AI-driven sustainable education research underscores significant contributions from academics in many countries. Bucea-Manea-Ţoniş has authored four papers, demonstrating a practical and persistent research emphasis on the topic. Their elevated publication count indicates an important impact on the progression of AI applications in Education.

Table 1. Top contributing affiliations

Affiliation		No. of Publication
Institution/ University	**Country**	
Kent State University	USA	8
Near East University	Turkey	7
University of Liverpool	UK	7
University Health Network	USA	7
Catholic University Center of Eastern Minas Gerais (MG)	Brazil	6
City University Ajman	UAE	6
Fundacion Universitaria Konrad Lorenz	Colombia	6
King Abdulaziz University	Saudi Arabia	6
Mohammed VI Polytechnic University	Morocco	6
North Carolina State University	USA	6

Source: Author (Scopus Database & Biblioshiny)

Aljohani Nr, Arnold O, Hassan S-U, Jantke KP, Zhang W, and Zhu W each own three publications. Their contributions signify an increasing academic focus on merging AI and Education. The existence of several authors with similar publication counts indicates a collaborative research context whereby diverse viewpoints enhance the current conversation. Furthermore, Alshahrani A, Dadhich M, and Greller W each own two publications. Despite a smaller publication count, their contributions influence the discipline. Beginning researchers often provide significant insights that enhance the discoveries of more established writers, promoting a more thorough comprehension of AI's function in Education (Doroudi, 2023).

Table 2. Top contributing authors

Authors	No. of Publication
Bucea-Manea-Țoniș, R.	4
Aljohani, Nr.	3
Arnold, O.	3
Hassan, S. U.	3
Jantke, K. P.	3
Zhang, W.	3
Zhu, W.	3
Alshahrani, A.	2
Dadhich, M.	2
Greller, W.	2

Source: Author (Scopus Database & Biblioshiny)

3.5 Top Contributing Journals

Table 3 presents the 10 leading journals with the most published papers on Artificial Intelligence and sustainable education over recent years. An analysis of academic publications distributing Research on the role of Artificial Intelligence in sustainable education identifies significant outlets for scholarly contributions to this developing domain. Sustainability (Switzerland) averages 31 publications, signifying its relevance in extending Research on AI-driven educational sustainability. The journal's significant publishing volume indicates its extensive multidisciplinary emphasis on educational sustainability's environmental, social, and technical dimensions (Donthu et al., 2021).

Other publications have also provided significant contributions. Integrating Generative AI in Education aims to fulfill the Sustainable Development Goals, whereas Lecture Notes in Networks and Systems comprises four publications. These sources emphasize the evolving discourse on the role of AI-driven technologies in enhancing educational frameworks that correspond with sustainability goals (Lin et al., 2023). The IEEE Global Engineering Education Conference (Educon) and the Journal of Physics: Conference Series each include three articles, indicating an increasing interest in AI applications in engineering and technical Education. These contributions indicate that the role of AI in sustainable education is being examined in both educational settings and in the fields of science and technology (Saheb et al., 2022). Numerous other journals, including Advances in Intelligent Systems and Computing, Discover Sustainability, E3S Web of Conference, Humanities and Social Sciences Communications, and Journal of Cleaner Production, each including two articles, enhance a vast body of Research. Their participation highlights the extensive value of AI in sustainability, including environmental, social sciences, and computational viewpoints (Schoormann et al., 2021). The distribution of articles across various journals illustrates the multidisciplinary character of AI-driven sustainable education research. Some publications concentrate on scientific breakthroughs, while others highlight sustainability, policy, and social aspects, so ensuring a thorough examination of the topic.

3.6 Most Global Cited Documents

Citations are used to evaluate the influence and importance of academic Research in scholarly contexts (Noyons et al., 1999). A research article with a high citation index often indicates its significant impact within a discipline. Furthermore, the citation patterns of a publication might indicate the Research's impact on academics (Tan et al., 2014).

Table 4 presents the top ten articles based on the total citation of citation analysis and citation index. Waheed et al. (2020), Predicting Academic Performance of Students from VLE Big Data using Deep Learning Models. The study utilizes the Open University Learning Analytics (OULA) dataset, which includes demographic, clickstream, and assessment data from 32,593 students over 9 months across 7 courses. The results show that the ANN model achieved an overall accuracy of 84% in predicting at-risk students, with significant features identified from demographics and clickstream data. For predicting students with distinction, the model showed varying accuracy due to class imbalance, while withdrawal prediction accuracy improved from 78% to 93% over the quarters. The study emphasizes the importance of early prediction, enabling timely intervention to support students at risk of low performance or withdrawal. Another study by Ramlowat & Pattanayak (2019) explores the Internet of Things (IoT) in Education: A review of Fifth International Conference India 2018 volume 2. Results present the experimental work indicated that PCA is a powerful tool for simplifying data analysis across various fields, from neurobiology to computer graphics. The result suggests that PCA can effectively reduce the dimensionality of complex datasets, allowing for better operational equivalence among services. This reduction in complexity aids in selecting services that can replace each other operationally, thus improving the overall efficiency of service utilization in Service-Oriented Architecture.

Table 3. Top contributing journal

Journal	Publication
Sustainability (Switzerland)	31
Integrating Generative AI in Education to Achieve Sustainable Development Goals	4
Lecture Notes in Networks and Systems	4
IEEE Global Engineering Education Conference, Educon	3
Journal of Physics: Conference Series	3
Advances in Intelligent Systems and Computing	2
Discover Sustainability	2
E3s Web of Conference	2
Humanities and Social Sciences Communications	2
Journal of Cleaner Production	2

Source: Author (Scopus Database & Biblioshiny)

Table 4. Most cited documents

Total Citations	Author and Year	Article Title	DOI Number	Source Journal
356	Waheed et al. (2020)	Predicting Academic Performance of Students from VLE Big Data using Deep Learning Models	10.1016/j.chb.2019.106189	Computers in Human Behavior
91	Ramlowat & Pattanayak (2019)	Exploring the Internet of Things (IoT) in Education: A Review	10.1007/978-981-13-3338-5_23	Advances in Intelligent Systems and Computing
65	Bucea-Manea-Ţoniş et al. (2021)	Blockchain Technology Enhances Sustainable Higher Education	10.3390/su132212347	Sustainability
63	Gupta et al. (2021)	Data Analytics for Environmental Science and Engineering Research	10.1021/acs.est.1c01026	Environmental Science & Technology
63	Aljohani et al. (2019)	Predicting At-Risk Students Using Clickstream Data in the Virtual	10.3390/su11247238	Sustainability
61	Alshahrani (2023)	The Impact of ChatGPT on Blended Learning: Current Trends and Future Research Directions	10.5267/j.ijdns.2023.6.010	International Journal of Data and Network Science
52	Han & Xu (2021)	Ecological Evolution Path of Smart Education Platform Based on Deep Learning and Image Detection	10.1016/j.micpro.2020.103343	Microprocessors and Microsystems
52	O'Brien & Sarkis (2014)	The Potential of Community-Based Sustainability Projects for Deep Learning Initiatives	10.1016/j.jclepro.2013.07.001	Journal of Cleaner Production
50	Cavus et al. (2021)	Determinants of Learning Management Systems during COVID-19 Pandemic for Sustainable Education	10.3390/su13095189	Sustainability
43	Carbonell-Carrera et al. (2018)	Teaching with AR as a Tool for relief Visualization: Usability and Motivation Study	10.1080/10382046.2017.1285135	International Research in Geographical and Environmental Education

Source: Author (Scopus Database & Biblioshiny)

The study “Blockchain Technology Enhances Sustainable Higher Education” by Bucea-Manea-Toniş et al. (2021) employed a mixed-methods approach, including document analysis, literature review, content analysis of blockchain platforms, case studies, and surveys. The findings indicated that student motivation significantly and positively influenced the quality of collaborative work, which enhanced learning performance. The analysis revealed strong correlations between collaborative work, motivation, engagement, and various educational technologies, such as MOOCs, augmented reality (AR), and gamification, all contributing to improved learning outcomes: Gupta et al. (2021), Data Analytics for Environmental Science and Engineering Research. The study discusses three case studies showcasing ML applications, metagenomics data analysis for antimicrobial resistance, nontarget analysis for pollutant profiling, and anomaly detection in EWS. These applications demonstrate the potential of data analytics in enhancing environmental monitoring and management. The study “Predicting At-Risk Students Using Clickstream Data in the Virtual Learning Environment” by Aljohani et al. (2019) utilized a deep, long, short-term memory (LSTM) model to analyze clickstream data from students in a Virtual Learning Environment (VLE). The results underscore the effectiveness of clickstream data in enhancing the early prediction of students' academic performance in virtual learning environments.

Technical Advancements in AI for Education: Several highly cited studies focus on the application of deep learning and predictive analytics in virtual learning environments. For instance, Waheed et al. (2020) and Aljohani et al. (2019) developed models to predict student performance using big data and clickstream analysis, demonstrating the practical utility of AI in improving educational outcomes. Similarly, Han & Xu (2021) explored deep learning and image detection in smart education platforms.

AI and Educational Sustainability: Works such as Bucea-Manea-Toniş et al. (2021) and Cavus et al. (2021) highlight AI’s role in promoting sustainability in higher education through technologies like blockchain and LMSs. These studies emphasize AI’s potential to optimize institutional processes, reduce resource consumption, and enhance long-term educational resilience.

Emerging Technologies and Learning Design: Ramlowat & Pattanayak (2019) focused on the Internet of Things (IoT) in education, while Carbonell-Carrera et al. (2018) examined Augmented Reality (AR) for geographic learning. These works showcase the integration of novel technologies aimed at improving student engagement and visualization in learning.

AI Ethics, Equity, and Societal Impact: Alshahrani (2023) discussed the implications of ChatGPT in blended learning, particularly around personalization, engagement, and ethical considerations. O’Brien & Sarkis (2014) looked at community-based sustainability projects, underscoring the need for ethical and socially aware educational frameworks supported by AI.

Data-Driven Environmental and Interdisciplinary Research: Gupta et al. (2021) presented case studies of machine learning applications in environmental science and engineering education, reflecting the interdisciplinary expansion of AI research into environmental and sustainability domains.

Table 5. Most cited countries

Country	Total Citation	Average Article Citations
Pakistan	419	209.50
China	166	11.10
USA	160	13.30
Saudi Arabia	108	18.00
Serbia	93	46.50
Mauritius	91	91.00
Spain	76	10.90
UK	66	22.00
India	51	4.20
Cyprus	50	25.00

Source: Author (Scopus Database & Biblioshiny)

3.7 Most Cited Countries

Table 5 presents the top ten countries based on the total citation analysis and index. The analysis of the top-cited countries in AI-oriented sustainable education research highlights the varied academic impact of various locations. Pakistan ranks first with 419 citations and an average of 209.50 citations per article, indicating that its research output is significantly influential and extensively cited in the domain (Tan et al., 2014).

China, the United States, and Saudi Arabia had 166, 160, and 108 citations, respectively. Although China and the USA have similar overall citation counts, their average citations per article—11.10 and 13.30—indicate consistent contributions to the research domain. Saudi Arabia has robust AI and education research involvement, averaging 18.00 citations per paper, contributing to the global conversation. Although Serbia and Mauritius possess lower overall citation counts, they have very high average citations per article, at 46.50 and 91.00, respectively. This indicates that despite producing fewer publications, these countries' Research is essential and often acknowledged by researchers. Spain and the UK show significant contributions, with the UK attaining an average of 22.00 citations per piece. This indicates substantial academic acknowledgment and the existence of extensively referenced Research in Artificial Intelligence and sustainable education. India and Cyprus complete the list, with India recording 51 total citations and an average of 4.20 citations per piece, indicating emerging contributions. With 50 citations and an average of 25.00 per piece, Cyprus underscores the significance of targeted, high-caliber research in the field.

Table 6. Most frequent words

Keyword	Occurrence
Sustainable Education	37
Artificial Intelligence	34
Environmental Education	15
Education	12
Sustainability	12
Deep Learning	11
Machine Learning	11
AI	10
Higher Education	9
IoT	6

Source: Author (Scopus Database & Biblioshiny)

3.8 Most Frequent Word

Table 6 presents the top ten most frequent words in Artificial Intelligence and sustainable education. Analyzing frequent terms in AI-enhanced sustainable education research underscores significant topics and trends within the discipline. Sustainable education is the most frequent word, appearing 37 times, indicating a primary emphasis on incorporating Artificial Intelligence to enhance long-term educational sustainability. Artificial Intelligence has been used 34 times, highlighting its increasing significance in revolutionizing Education via novel technology and data-driven learning methodologies.

Environmental Education and sustainability are mentioned 15 and 12 times, respectively, highlighting the growing recognition of AI's capacity to enhance eco-friendly educational practices and advance global sustainability objectives in Education. The word education appears 12 times, indicating extensive discourse on the impact of AI on learning approaches. Deep learning and machine learning, appearing 11 times, underscore the technical foundation of AI applications in Education. Advanced AI approaches are extensively used to customize learning experiences and enhance decision-making in educational systems (Akavova et al., 2023). Likewise, AI is referenced 10 times, underscoring the field's focus on breakthroughs in Artificial Intelligence. Higher Education appears 9 times, indicating that AI applications in sustainable education are especially pertinent to universities and research institutes. Furthermore, IoT (Internet of Things) is referenced 6 times, indicating a growing interest in the potential of linked devices to improve sustainable educational practices.

Figure 4. Word cloud
Source: Author (Scopus Database & Biblioshiny)

Figure 4 represents the most often-used word in AI-driven sustainable education research. The main terms, sustainable education and Artificial Intelligence are shown in the largest font size, signifying their significance in the argument. This underscores the strong relationship between AI technology and initiatives to foster long-term educational sustainability. Words like environmental Education, sustainability, and higher Education indicate an increasing emphasis on incorporating AI into environmentally mindful teaching methodologies and Higher Education. The expanding importance of deep learning and machine learning suggests a growing dependence on advanced AI approaches to improve educational practices (Ouahi et al., 2024). Moreover, words like IoT (Internet of Things) and Education suggest emerging discussions around innovative technology to foster sustainable learning settings (Kanan et al., 2023). The word cloud quickly summarizes the principal topics motivating current studies in AI and sustainable education, highlighting this advancing domain's technical, environmental, and institutional dimensions.

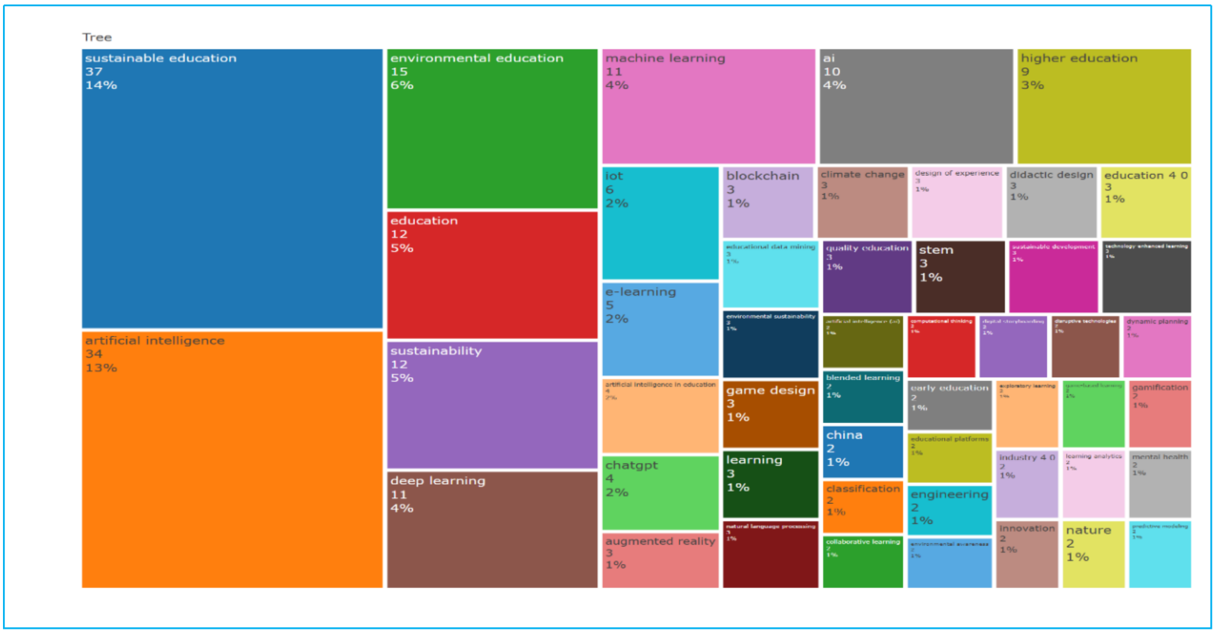

Figure 5. Tree map
Source: Author (Scopus Database & Biblioshiny)

Figure 5 shows the most used terms in AI-driven sustainable education research, offering insights into the main focus areas. Sustainable education and Artificial Intelligence dominate visualization, comprising the most significant segments with 14% and 13% occurrences, respectively. This underscores the increasing significance of AI in promoting long-term educational sustainability.

Other notable words include environmental Education (6%), Education (5%), and sustainability (5%), indicating a strong link between AI and eco-conscious educational methods. Deep learning and machine learning, both at 4%, underscore the technical progress impacting AI applications in Education. Keywords like IoT, blockchain, STEM, and climate change indicate new research topics centered on innovative technologies, digital innovation, and science-based Education. The generalization of higher Education (3%) emphasizes using AI in universities and research institutes. Minor segments, such as ChatGPT, game design, augmented reality, and engineering, illustrate the variety of AI applications in Education, ranging from interactive learning instruments to immersive digital experiences. The tree map clearly shows the changing dynamics of AI-driven Education, highlighting the relationships among sustainability, advanced technology, and creative learning methodologies.

3.9 Word Frequency Overtime

The word frequency in Figure 6 illustrates the increasing number of essential words associated with AI and sustainable education over time. The growing use of terminology like Artificial Intelligence, machine learning, and sustainable education signifies an increasing interest in integrating technology into educational sustainability. Between 2014 and 2018, the use of these words was comparatively low, indicating the early stage of AI integration in Education. Post-2019, a clear increasing trend is seen, especially in Artificial Intelligence and sustainable education, indicating a change in academic and Research goals. This expansion corresponds with the rising worldwide focus on AI-driven educational solutions and environmental efforts. The notable increase in words like sustainability, teaching, and Education post-2020 underscores AI's impact on revolutionizing conventional learning methods while ensuring enduring educational advantages. The significance of machine learning and deep learning supports the assertion that advanced computational methods impact sustainable education's future. The overarching trend of these words indicates that AI's influence in Education will continue expanding, enhancing its capacity to foster innovation, efficiency, and sustainability in educational settings.

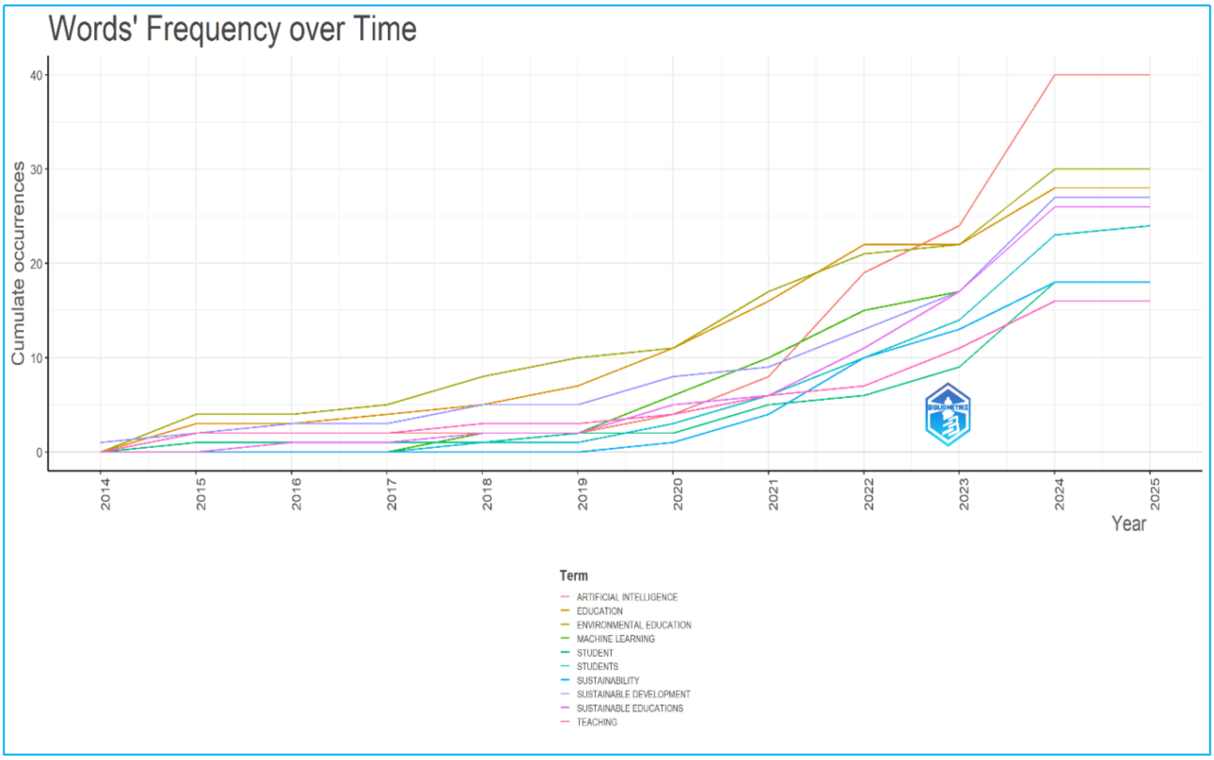

Figure 6. Word frequency over time

3.10 Co-Occurrence Network

Figure 7 and Figure 8 show the network visualization of popular keywords derived from co-word analysis. Consistent with the findings in Table 6. The network visualization of keyword clusters illustrates the interconnectedness of key research areas, with sustainable education**,** Artificial Intelligence**,** and environmental Education emerging as dominant clusters. The strong connections between these fields highlight their increasingly interdisciplinary nature and relevance in contemporary Research.

Red Cluster: Environmental Education and AI-Driven Learning: This cluster is centered around environmental Education, with strong links to Artificial Intelligence, user experience, interface design, and dynamic learning. The connections suggest that researchers explore how AI and interactive technologies can improve environmental awareness and Education. Topics such as Artificial Intelligence in Education and digital learning experience indicate that modern tools like AI-driven simulations, augmented reality, and adaptive learning platforms are being used to enhance environmental Education. This cluster signifies a growing interest in using digital technologies to make ecological learning more engaging, interactive, and effective.

Green Cluster: Artificial Intelligence in Education: The green cluster focuses on the role of Artificial Intelligence in improving educational experiences. It includes terms like quality education, virtual reality, machine learning, renewable energy, and environmental sustainability. The connections within this cluster suggest that AI is not just being studied as a tool for teaching but also as a means to promote sustainable practices. Quality education and AI-driven personalized learning show that AI enhances the way students' access and interact with educational content. Virtual reality and machine learning indicate the integration of immersive technologies into AI-driven education systems, making learning more effective and engaging. Additionally, including renewable energy and environmental sustainability suggests that AI is being explored in the context of sustainable education and green technology.

Brown & Yellow Clusters: Sustainable education as a Bridge: The brown and yellow clusters focus on sustainable education, which bridges Artificial Intelligence and environmental Education. These clusters contain keywords such as educational data mining, critical thinking, innovation, climate change, and disruptive Education. The emphasis on critical thinking and climate change suggests that Research explores how Education can promote sustainability and environmental responsibility. The presence of innovation and disruptive Education indicates that

AI-powered educational approaches are changing traditional learning models, making them more adaptable to sustainability goals. These clusters highlight the increasing importance of using AI to develop sustainable educational frameworks that promote global environmental awareness.

Blue Cluster: Technical Aspects of AI in Education: The blue cluster represents the technical and analytical side of AI applications in Education. Keywords such as prediction models, educational data mining, and deep learning suggest a focus on how AI can optimize learning processes through advanced analytics. Disruptive Education indicates that AI-powered tools transform traditional educational methodologies, making them more data-driven and adaptive. The presence of deep learning and prediction models shows that researchers are exploring AI's ability to analyze student learning behaviors, predict educational outcomes, and personalize content delivery.

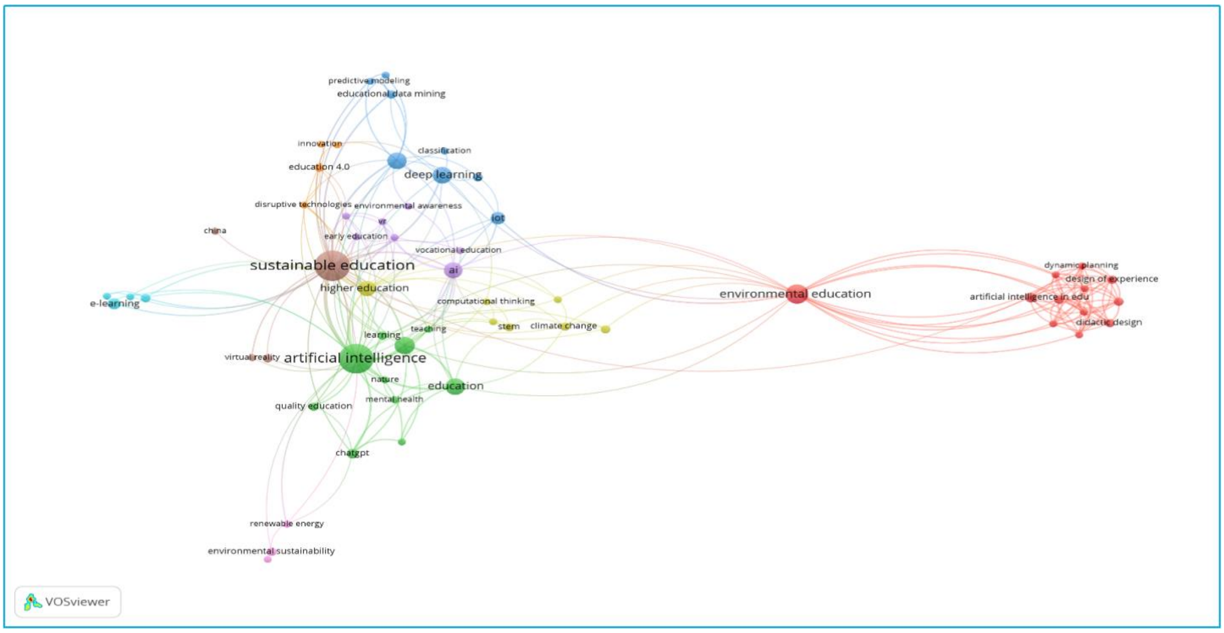

Figure 7. Network visualization of keyword
Source: Author (Scopus Database & VOS viewer)

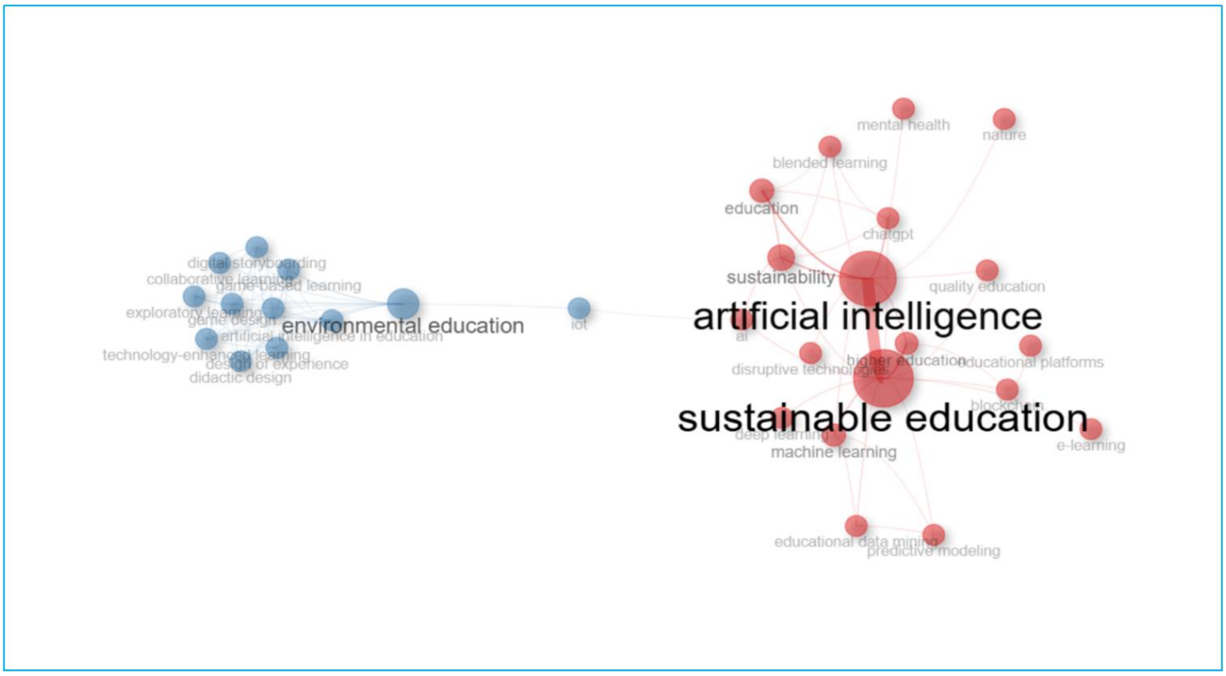

Figure 8. Network visualization of keyword
Source: Author (Scopus Database & Biblioshiny)

3.11 Co-Authorship Analysis

Co-authorship occurs when two or more authors collaborate to produce a research publication. Bibliometric tools may examine co-authorship networks (Mourao & Martinho, 2020). The growing collaboration among academics in recent years necessitates understanding the degree of cooperation and network patterns within the Artificial Intelligence and sustainable education domains. The examination of co-authorship highlights the strong social ties among scholars from diverse backgrounds (Ponomariov & Boardman, 2016). Moreover, it demonstrates the outcomes of partnerships and provides insights into the factors influencing the degree of co-authorship (Khan et al., 2021).

Figure 9 presents the network mapping of countries based on co-authorship analysis. The United Kingdom, Brazil, China, and India are major hubs, indicating their strong engagement in international research partnerships.

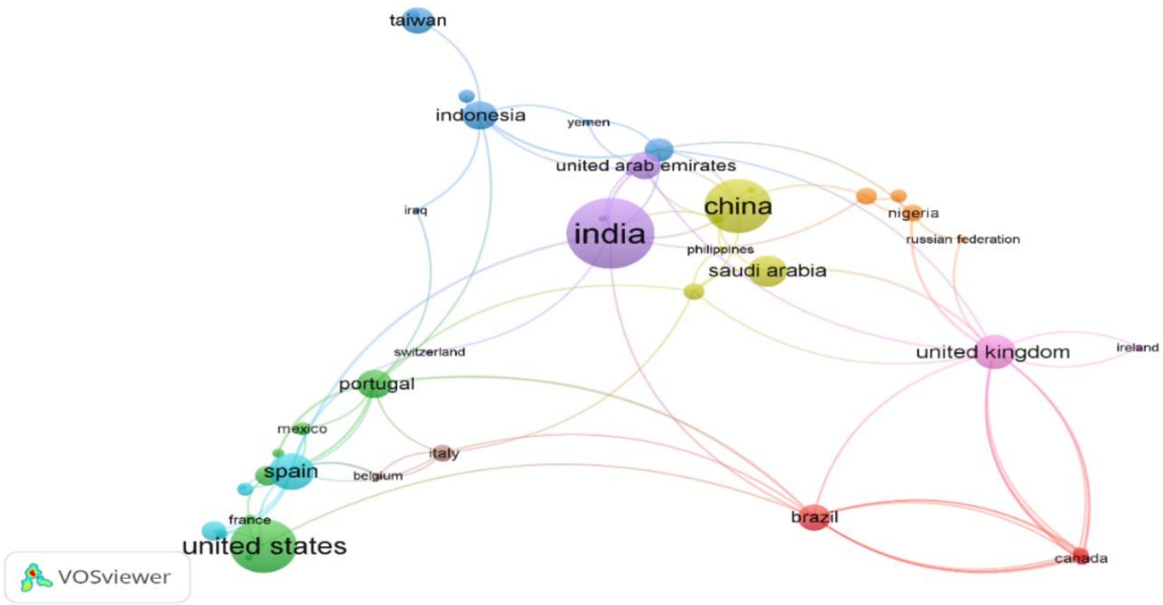

Figure 9. Co-authorship network visualization

Purple Cluster (India-Centered Network): India emerges as a central hub in this cluster, actively collaborating with countries such as China, Saudi Arabia, the United Arab Emirates, Indonesia, and the Philippines. This strong network indicates that India plays a crucial role in global academic Research, particularly in fields such as information technology, engineering, business, and environmental sciences. The collaboration with Saudi Arabia and the UAE suggests a connection in areas like energy, sustainability, and economic Research, while ties with China and Indonesia may reflect shared interests in Artificial Intelligence, Education, and public health studies.

Green Cluster (United States, Spain, and Portugal): This cluster represents a Western research network dominated by the United States, Spain, and Portugal, with substantial contributions from Mexico, Belgium, and Switzerland. The United States, being a major player in global Research, acts as a bridge for European and Latin American collaborations. Spain and Portugal's strong connections indicate research cooperation in areas such as renewable energy, social sciences, and health sciences. The presence of Mexico suggests involvement in cross-border Research, likely in technology, environmental studies, and trade-related disciplines.

Red Cluster (United Kingdom and Brazil-Centered Network): The United Kingdom and Brazil form the core of this cluster, maintaining strong research ties with Canada and Iceland. This network suggests a focus on environmental sciences, public health, and agricultural Research, to which Brazil is a key contributor. The connection between the UK and Canada reflects ongoing collaborations in climate change studies, Medical Research, and Higher Education. Including Iceland may indicate Research in sustainability and oceanic studies, areas where Iceland has a strong academic presence.

Yellow Cluster (China, Saudi Arabia, and the Philippines): China leads this cluster, collaborating with Saudi Arabia and the Philippines, highlighting a research focus on infrastructure development, technological advancements, and educational policies. Saudi Arabia's involvement suggests energy, Artificial Intelligence, and higher education research interests. On the other hand, the Philippines may engage in research related to climate change adaptation, digital transformation, and healthcare innovations, with China having a significant influence.

Blue Cluster (Indonesia, Taiwan, and the United Arab Emirates): This cluster includes Indonesia, Taiwan, the United Arab Emirates, Iraq, and Yemen, suggesting a research focus in Southeast Asia and the Middle East. Indonesia's connections indicate strong contributions to sustainability, digital Education, and business research. Taiwan's involvement suggests focusing on semiconductor technology, Artificial Intelligence, and innovation-driven studies. The presence of the UAE, Iraq, and Yemen highlights a developing research network in the Middle East, likely covering fields such as energy, security studies, and urban development.

3.12 Directions for Future Studies

Table 7 shows future studies directions. This study of Waheed et al. (2020) investigates using deep learning models to predict student academic performance based on data generated from Virtual Learning Environments (VLEs). The primary aim is to measure the effectiveness of VLEs in predicting student performance, allowing for timely interventions by instructors to provide necessary support and guidance. The findings underscore the importance of leveraging VLE data and deep learning techniques to enhance educational outcomes and inform institutional policies to support student success. The study conducted by Ramlowat & Pattanayak (2019) aims to create a robust framework for service selection in SOA, focusing on efficiency, service independence, and applying advanced analytical techniques to improve decision-making processes. The methodology integrates qualitative and quantitative approaches, utilizing ethnography, content analysis, surveys, and case studies to effectively explore consumer behavior and service selection. The results indicate that the proposed architecture and methodologies effectively classify sources, monitor traffic conditions, and enhance road safety through real-time alerts and data logging. The study by Bucea-Manea-Toniş et al. (2021) aims to bridge the gap between blockchain technology and educational practices by demonstrating how motivation and collaborative work can enhance learning outcomes in higher education settings. This robust study combines qualitative and quantitative approaches to comprehensively understand how blockchain technology can improve collaborative work and learning outcomes in higher Education. The study highlights the importance of motivation, engagement, and blockchain technology in enhancing collaborative work and learning outcomes in higher Education. The results suggest that integrating blockchain tools can significantly benefit students' educational experiences.

The study, Data Analytics for Environmental Science and Engineering Research conducted by Gupta et al. (2021), aims to enhance the understanding and management of environmental systems by applying advanced data analytics and machine learning techniques, ultimately contributing to human and ecological health protection. The study emphasizes a systematic approach to data analysis, encompassing data acquisition, exploration, preprocessing, model building, and interpretation, all aimed at enhancing the understanding of environmental systems through data-driven insights. The study's results emphasize the transformative potential of data analytics and ML in enhancing environmental Research, providing practical examples through case studies and outlining future directions for integrating these approaches into ESE practices. The study, Predicting At-Risk Students Using Clickstream Data in the Virtual Learning Environment of Aljohani et al. (2019), aims to utilize clickstream data to predict at-risk students effectively, enabling timely interventions and improved educational strategies. This study combines data collection, processing, model architecture, training, and evaluation to effectively predict at-risk students using clickstream data in a virtual learning environment. The study's results highlight the effectiveness of deep learning models, particularly LSTM, in predicting at-risk students based on their engagement with virtual learning environments, ultimately contributing to improved educational outcomes. As for The impact of ChatGPT on blended learning: Current trends and future research directions of Alshahrani (2023), this study emphasizes the importance of AI, particularly ChatGPT, in creating a more effective, personalized, and sustainable educational environment. This study combines qualitative and quantitative approaches to provide a comprehensive understanding of the impact of ChatGPT on blended learning, aiming to inform future Research and practice in the field of Education. The results show that Integrating ChatGPT into blended learning systems can lead to improved learning outcomes, enhanced student engagement, and more personalized learning experiences. Tools like ChatGPT can make blended learning systems more sustainable, efficient, and accessible for learners globally. Integrating AI chatbots like ChatGPT into Education can promote student engagement, motivation, and self-directed learning through immediate feedback and assistance.

The study of Han & Xu (2021) aims to create a robust framework for innovative Education that integrates advanced technologies while considering ecological impacts, ultimately enhancing personalized learning experiences and improving educational outcomes. The study methodology focuses on leveraging advanced technologies, conducting comparative analyses, and developing personalized learning models while ensuring ecological sustainability in the academic context. The study's results highlight the effectiveness of deep learning and image detection in enhancing innovative education platforms, demonstrating significant improvements in processing times, ecological effectiveness, and overall learning outcomes: O'Brien & Sarkis (2014), The potential of community-based sustainability projects for deep learning initiatives. The study aims to develop a comprehensive framework for deep learning in sustainability education, evaluate its effectiveness, and provide insights for future curriculum development and Research in this field. This study is structured around a case study approach, utilizing various data collection methods to evaluate the impact of community-based sustainability projects on deep learning in higher Education. The study highlights the potential of community-based sustainability projects to enhance deep learning in higher education, emphasizing the need for further research to validate and expand upon these findings. The study by Cavus et al. (2021) investigates the factors influencing the success and adoption of Learning Management Systems (LMS) in Nigeria, particularly during the COVID-19 pandemic. This structured methodology allows for a robust analysis of the determinants of LMS usage, providing valuable insights into enhancing educational sustainability during the COVID-19 pandemic. The findings provide useful insights into the factors that can facilitate the successful implementation of LMS, which is essential for maintaining academic standards during challenging times like the COVID-19 pandemic. Teaching with AR as a tool for relief visualization: usability and motivation study by Carbonell-Carrera et al. (2018) aims to demonstrate that integrating AR technology into geographical Education can enhance academic performance, usability, and student motivation, providing a more effective learning experience. This study combined a hands-on workshop with structured assessments to evaluate the impact of AR on students' learning experiences in geographical Education, focusing on usability and motivation. The study demonstrated that AR is a powerful tool for relief visualization, enhancing both usability and motivation among students while contributing to academic improvement in geographical Education.

Table 7. Directions for future studies

No. of Citations	Author Name and Year	Publication Titles	Future Research Directions
356	Waheed et al. (2020)	Predicting Academic Performance of Students from VLE Big Data using Deep Learning Models	1. Data-driven studies are needed to help formulate effective pedagogical policies and guidelines, ensuring educational stakeholders can better support students. 2. Further Research should examine how demographic factors, such as age and region, affect student performance, particularly their engagement with virtual learning environments (VLEs). 3. Conducting longitudinal studies to track student performance over time can help understand the long-term effects of VLE interactions and interventions.
91	Ramlowat & Pattanayak (2019)	Exploring the Internet of Things (IoT) in Education: A Review	1. Future studies could focus on improving the selection process of abstract and concrete services by further exploring quality of service (quality of service) attributes. 2. There is a need to explore the integration of big data analytics in social networks to enhance real-time decision-making processes. 3. Future studies should consider interdisciplinary approaches that combine insights from various fields, such as marketing, information technology, and customer behavior.
65	Bucea-Manea-Toniș et al. (2021)	Blockchain Technology Enhances Sustainable Higher Education	1.the study indicates a need for ongoing exploration of innovative ways to implement blockchain technology in higher education institutions (HEIs). 2. Future Research should focus on developing strategies to improve digital literacy. 3. Future studies will cover a broader range of institutions to gather comprehensive data on the impact of the blockchain across different educational settings. 4. Future Research could investigate how different blockchain applications influence student collaboration and the effects on learning outcomes.
63	Gupta et al. (2021).	Data Analytics for Environmental Science and Engineering Research	1. Future Research should create models that can learn continuously as new data streams in. 2. Future Research focuses on developing methods to handle high-dimensional data, particularly in metagenomics, where the number of variables often exceeds the number of samples. 3. There is a need to explore various machine learning techniques, such as support vector machines (SVMs) and artificial neural networks (ANNs), for supervised learning applications in ESE.
63	Aljohani et al. (2019)	Predicting At-Risk Students Usin g Clickstream Data in the Virtual Learning Environment	1. Future studies could enhance prediction models by integrating student's assessment scores. 2. The current study did not address the performance variations among students who repeat courses. Future

	Alshahrani (2023)	The impact of ChatGPT on Blended Learning: Current Trends and Future Research Directions	Research could analyze these students' behaviors, comparing their first and second attempts to identify factors influencing their academic performance. 3. Future studies should capture the differences in student interactions across various courses, which could help identify key elements that affect academic success. 4. Future Research could explore the impact of student feedback by employing advanced learning techniques and natural language processing.
52	Han & Xu (2021)	Ecological Evolution Path of Innovative Education Platform Based on Deep Learning and Image Detection	1. Future Research should focus on effectively integrating innovative technologies into educational settings. 2. Future Research can explore how ecological factors influence personalized learning experiences and how these can be tailored to meet individual student needs. 3. Future studies could Focus on creating comprehensive models that consider teaching, evaluation, and design aspects to enhance the effectiveness of innovative Education. 4. Future Research can investigate how deep learning can automate and improve the educational process, particularly in areas like image detection and data processing. 5. Future studies should focus on overcoming these challenges to facilitate the successful implementation of innovative learning systems. 6. Conducting longitudinal studies assessing the long-term impact of intelligent education systems on student learning and engagement can provide valuable insights.
52	O'Brien & Sarkis (2014)	The Potential of Community-Based Sustainability Projects for Deep Learning Initiatives	1.There is a need to develop methods for measuring broader and longer-term outcomes of deep learning initiatives. 2. Future Research should create a careful empirical design to generate scales for classroom education research. 3. The paper suggests integrating various instructional methods alongside community-based projects, such as simulation games and in-class exercises. 4. Future Research should also address the quality of client feedback on student work. 5. Future studies could examine how civic engagement evolves after students leave the educational environment.
50	Cavus et al. (2021)	Determinants of Learning Management Systems during COVID-19 Pandemic for Sustainable education	1. The study suggests that future Research should examine the application of other linear and nonlinear AI techniques beyond those already utilized (SVM, GPR, ANN, and BRT). 2. Conduct longitudinal studies could help understand how LMS's determinants evolve, especially as educational institutions adapt to new technologies and methodologies post-pandemic. 3. Future Research could compare the determinants of LMS in different geographical contexts, particularly between developed and developing nations. 4. Future studies could delve deeper into user experience factors, such as interface design and accessibility, to determine how these elements affect LMS engagement and satisfaction. 5. Future Research could explore how integrating multimedia tools (like video, audio, and interactive content) within LMS platforms impacts learning outcomes and user engagement.
43	Carbonell-Carrera et al. (2018)	Teaching with AR as a Tool for Relief Visualization: Usability and Motivation	1. Future Research could explore various user interface designs to enhance usability and engagement, as traditional systems have been more extensively studied.

	Study	2. Future Research could implement longitudinal studies to evaluate the long-term effects of AR on students' spatial abilities and understanding of 3D representations. 3. Future studies could investigate the application of AR in different educational settings and subjects beyond geographical Education. 4. Future studies could explore how AR applications can be customized to meet the diverse needs of students. 5. Future studies could examine how AR impacts cognitive outcomes and emotional and social factors in learning.

Source: Author (Scopus & Biblioshiny)

4. Practical Recommendations

Students should adopt AI-powered learning tools such as adaptive learning systems, virtual tutors, and intelligent feedback mechanisms to enhance their educational experience. Developing AI literacy is essential for remaining competitive in the digital era, and it requires an understanding of AI concepts, ethical considerations, and applications in Education. Increasing awareness of digital sustainability is crucial, as AI can help reduce paper use, minimize energy consumption, and create eco-friendly learning environments. Engaging in discussions on AI ethics, including bias, privacy, and responsible AI implementation, ensures that AI tools are used fairly and effectively.

Universities should integrate AI-driven tools into curriculum development to enhance personalized learning, optimize administrative tasks, and improve student engagement. Investing in AI research and development fosters interdisciplinary collaboration between AI experts and educators, leading to innovative applications in sustainable education. Faculty training in AI-powered teaching methods is necessary to ensure educators can effectively leverage AI for student assessment, course management, and academic advising. AI-based systems should be implemented to optimize resource management, including energy consumption and waste reduction, contributing to sustainable educational practices. AI-driven inclusive education initiatives can support students with disabilities, language barriers, and diverse learning needs, ensuring equitable access to quality education.

Policymakers should mandate the inclusion of AI ethics in teacher training to ensure educators understand responsible and fair AI use. Funding should be directed toward longitudinal studies assessing the environmental impact of AI in education, including its carbon footprint. National guidelines are needed to standardize AI integration across schools, focusing on equity, transparency, and sustainability. Public-private partnerships should be supported to develop ethical and accessible AI tools, especially for underserved communities. Before approving AI-based educational tools, impact assessments on learning outcomes, data privacy, and sustainability should be required. AI literacy campaigns should target rural and marginalized regions to close digital divides and ensure inclusive access. A national registry of approved educational AI tools can help institutions choose solutions that meet ethical and environmental standards. Strong regulations must also govern the use of student data in AI systems, with regular audits and clear accountability measures.

5. Conclusion

This study aimed to explore the role of Artificial Intelligence (AI) in sustainable education by conducting a bibliometric analysis to understand publication trends, key contributors, and emerging themes in the field. AI can potentially transform Education by personalizing learning, automating administrative tasks, and promoting resource-efficient educational practices. This study provides valuable insights into AI's impact on higher Education and sustainability by identifying significant research contributions. A bibliometric and content analysis methodology was employed to examine Scopus literature. This approach combined quantitative (descriptive statistics, citation analysis, co-word analysis, and co-authorship networks) and qualitative (content analysis of highly cited papers) methods. The study analyzed 276 documents published between 2016 and 2025, using VOSviewer and Biblioshiny for data visualization. The results revealed a significant increase in AI-related publications in sustainable education, particularly after 2019. India, the United States, and China emerged as the top contributors, while journals such as Sustainability (Switzerland) and Lecture Notes in Networks and Systems published the highest number of articles. Co-authorship analysis showed strong international collaboration with the UK, Brazil, and China as major research hubs. The thematic analysis identified four key clusters: Environmental Education and AI-driven learning, AI in Education, Sustainable education as a Bridge, and Technical Aspects of AI in Education. These clusters highlight the interdisciplinary nature of AI in Education, connecting sustainability, learning methodologies, and technological advancements. The study's findings emphasize the increasing role of AI in enhancing learning outcomes, optimizing institutional operations, and promoting sustainable educational practices. However, challenges such as AI ethics, digital infrastructure disparities, and the need for interdisciplinary Research must be addressed. Future Research should focus on developing AI-driven educational frameworks, assessing long-term sustainability impacts, and exploring AI's role in bridging digital educational divides.

6. Limitations and Future Research Directions

This study presents several limitations that may impact the generalizability of its findings.

1- Scopus Database Limitation: We recognize that relying solely on Scopus may exclude relevant studies from other databases, such as Web of Science and Google Scholar. This selection, while ensuring high-quality peer-reviewed sources, may introduce selection bias. Future Research should incorporate multiple databases to provide a more comprehensive perspective on AI adoption in sustainable education.

2- Exclusion of Non-English Publications: We acknowledge that limiting the study to English-language articles may overlook valuable Research from non-English-speaking regions. Future studies should include multilingual sources to capture a more diverse global understanding of AI's impact on sustainable education.

3- Limited Scope of Source Types: The exclusion of books, book chapters, and review papers may have restricted the depth of our findings. Future studies should consider a broader range of academic and institutional sources to gain deeper insights into AI applications in sustainable education.

Author Contributions

Conceptualization, Rahmanwali Sahar, Ismail Labib, Mohammed Kazim Kazimi.; methodology, Rahmanwali Sahar, Hamidullah Mobarez, Mohammed Naim Kakar; software, Rahmanwali Sahar. & Ismail Labib; writing—original draft preparation; writing—review and editing, Rahmanwali Sahar, Ismail Labib, Mohammed Kazim Kazimi. All authors have read and agreed to the published version of the manuscript.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflict of interest.

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