DOI: 10.53660/CLM-2872-24C47

Artificial intelligence and sustainability in higher education: A bibliometric analysis and its relations with the UN SDGs

Inteligência artificial e sustentabilidade no ensino superior: Uma análise bibliométrica e suas relações com os ODS da ONU

Received: 15-01-2024 | Accepted: 18-02-2024 | Published: 22-02-2024

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ABSTRACT

This research aimed to analyze the importance of artificial intelligence and sustainability in higher education according to the literature in the field and to present the relationships of this context with the United Nations Sustainable Development Goals (SDGs). The adopted research strategies included bibliometric analysis using VOSviewer software and literature review, considering the Web of Science scientific database. The bibliometric analysis resulted in the clustering of four groups. The blue cluster highlighted the emergence of interest in studies on AI and sustainability in higher education following the Covid-19 pandemic. The green cluster emphasized the importance of more efficient teaching methods adapted to the demands of higher education, as well as the need to empower teachers to use artificial intelligence in developing students' skills and competencies, emphasizing sustainability. The yellow cluster indicated the presence of artificial intelligence in higher education based on the triad of sustainable education and innovation, aiming to prepare students for future challenges. The red cluster emphasized the impact of artificial intelligence in higher education, focusing on student learning, efficiency, and sustainable performance. Finally, the literature analysis identified the main AI technologies in higher education and their relationship with the United Nations SDGs. The reflections presented here can contribute to expanding discussions on the relationship between artificial intelligence and sustainability in higher education. From a practical standpoint, it can serve as a foundation for university managers aiming to promote the integration of AI into their teaching processes, considering the context of sustainability.

Keywords: Artificial Intelligence; Sustainability; Higher Education; Sustainable Development; VOSviewer.

RESUMO

O objetivo desta pesquisa foi analisar a importância da inteligência artificial e sustentabilidade no ensino superior de acordo com a literatura da área e apresentar as relações deste contexto com os ODS da ONU. As estratégias de pesquisa adotada foram análise bibliométrica via software VOSviewer e revisão da literatura, ambas considerando a base científica Web of Science. A análise bibliométrica resultou no agrupamento de quatro clusters. O cluster em azul evidenciou o surgimento de interesse em estudos sobre IA e sustentabilidade no ensino superior a partir da pandemia da Covid-19. O cluster em verde ressalta a importância de métodos de ensino mais eficientes e adaptados às demandas do ensino superior, assim como a necessidade de capacitar os professores para utilizar a inteligência artificial no desenvolvimento de habilidades e competências dos alunos, com ênfase na sustentabilidade. O cluster em amarelo indicou a presença da inteligência artificial no ensino superior fundamentado na tríade da educação sustentável e inovação, visando preparar os alunos para desafios futuros. O cluster em vermelho destacou o impacto da inteligência artificial no ensino superior, focando na aprendizagem dos alunos, eficiência e desempenho sustentável. Por fim, a análise da literatura identificou as principais tecnologias de IA no ensino superior e sua relação com os Objetivos de Desenvolvimento Sustentável (ODS). As reflexões aqui apresentadas podem contribuir com a ampliação dos debates sobre a relação da inteligência artificial e sustentabilidade no ensino superior. Do ponto de vista prático, pode servir de base para gestores universitários que objetivam promover a inserção da IA em seus processos de ensino considerando o contexto da sustentabilidade.

Palavras-chave: Inteligência Artificial; Sustentabilidade; Ensino Superior; Desenvolvimento Sustentável; VOSviewer.

INTRODUCTION

Considering the new demands related to environmental issues, the United Nations (UN) developed, in 2015, 17 Sustainable Development Goals (SDGs) through an agenda called Agenda 2030. The SDGs advocate, in general, for the sustainable development of current and future generations. In an environment that increasingly requires sustainable practices, it is important to understand how technology can be a strong ally in overcoming present and future challenges (SALVIA et al., 2019). The current scenario imposes challenges that humanity needs to address, reinforcing the need for agile actions and technological solutions focused on sustainability (LEAL FILHO et al., 2018).

Within this context, it is worth highlighting the increasingly widespread presence of Artificial Intelligence (AI) in human activities and how it can meet such demands quickly (LEE, 2020). The rapid transformations driven by technology in the contemporary world generate interest in understanding these changes, analyzing their impacts, and evaluating their effects on social, economic, and environmental spheres.

Artificial Intelligence (AI) can be understood as a technology capable of dealing with emerging situations, solving problems, answering questions, planning devices, and performing various other functions that require some level of intelligence, typically evident in humans (CHEN; CHEN; LIN, 2020). According to Dwivedi et al. (2023), AI has significantly impacted organizations, societies, and individuals. Due to its technological potential, AI has garnered attention from researchers worldwide, with its concepts applied in various areas of knowledge, such as culture, politics, business, finance, agriculture, and (ARA SHAIKH et al., 2022). This is because it is a technology that aims to solve complex situations (LEE, 2020; SAHEB; DEHGHANI; SAHEB, 2022). Supporting this understanding, Takala and Korhonen-Yrjänheikki (2019), Goralski and Tan (2022), and Ayanwale et al. (2022) demonstrate the potential relationship between AI and sustainability in higher education and raise questions about the extent to which AI can contribute to achieving sustainable development.

As an example of this technology, many current studies highlight the importance of AI as a technological tool with the potential to help overcome challenges and efforts, such as in health (AHMAD; ECKERT, 2023), workplace safety (JAROTA, 2023), the economy (WANG et al., 2023a), the environment (NTI et al., 2022), and especially in education (HADERER; CIOLACU, 2022). In the context of education, one of the main benefits of using AI is the ability to personalize students' learning (OUYANG; JIAO, 2021). Goralski and Tan (2022) emphasize that artificial intelligence, by analyzing large

sets of data on skills, learning styles, and student preferences, can adapt content and activities to meet their individual needs (OUYANG; JIAO, 2021) enhancing the integration of sustainability. In this sense, Nordgren (2023) argues that by prioritizing the use of AI to educate students about sustainability, it is possible to train professionals committed and prepared to face future challenges.

In this regard, it is possible to perceive the importance of analyzing the context of AI and sustainability in higher education. Therefore, this study aimed to analyze the importance of artificial intelligence and sustainability in higher education according to the literature in the field and to present the relationships of this context with the UN SDGs.

THEORETICAL BACKGROUND

The relationship between Artificial Intelligence (AI) and sustainability in higher education presents significant opportunities. Recent literature highlights various benefits of employing AI in sustainability education, including its ability to analyze large sets of complex data (GORALSKI; TAN, 2022). This enables educators to identify patterns and trends related to sustainability, such as climate change (NORDGREN, 2023), resource depletion, and environmental degradation (QIAN et al., 2023), and to offer teaching strategies tailored to the specific needs of student (CHEN; CHEN; LIN, 2020; TELL; HOVESKOG, 2022).

AI can facilitate personalized learning by analyzing student data and providing specific feedback and guidance. According to Goralski and Tan (2022), these tools can identify areas of student difficulty and provide targeted interventions, thereby improving student engagement and outcomes. However, according to Adams et al. (2023), it is crucial to address concerns and challenges that arise with the use of AI in sustainability education.

One concern is the risk of bias and discrimination resulting from reliance on algorithms based on historical data (CHIU et al., 2023). As stated by Zawacki-Richter et al. (2019), if this data is biased, AI systems will also be biased, perpetuating existing inequalities and discrimination in society.

Additionally, there is a fear that AI could replace human knowledge and critical thinking, compromising the ability to make decisions (BURGER et al., 2023). According to Dwivedi et al. (2023). while AI can provide valuable information and support for sustainability education in higher education, it cannot replace the value of human

experience and knowledge in the field. It is important to ensure that AI is used as a tool to support and enhance human decision-making, not as a substitute for it (BURGER et al., 2023).

Another concern raised by Lee (2020) relates to the security and privacy of data. According to this author, AI systems rely on large volumes of data that can become vulnerable to cyberattacks or misuse. Lee (2020) emphasizes the need for robust data protection measures to ensure the privacy and security of student and institutional data.

In the context of higher education, the rapid technological evolution poses the challenge of ensuring that education professionals and institutions are adequately equipped to incorporate and adapt to the latest trends in AI. According to Khosravi et al. (2022), the integration of AI in higher education requires a continuous commitment to the professional development of educators to ensure they are equipped with the skills and knowledge necessary to effectively integrate these tools into their teaching methods, especially for teaching sustainability through AI.

Despite the concerns about the use of AI technology, especially in teaching sustainability in higher education, Leal Filho (2023a) suggests that one strategy to enhance sustainable development is through the adoption of technology. Despite the challenges emphasized by Rampasso et al. (2018), such as the lack of teacher training, the scarcity of appropriate and up-to-date teaching materials, and the inadequacy of infrastructure and available resources.

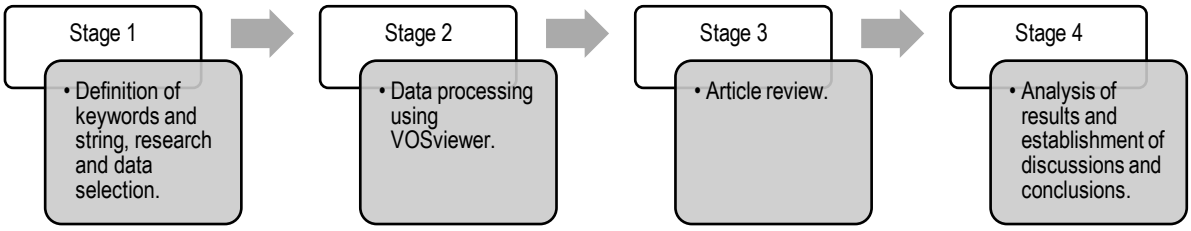
While facing challenges, Leal Filho et al. (2023b) comment that higher education institutions (HEIs) have made considerable efforts to incorporate technological approaches in the context of higher education, emphasizing the positive impact these initiatives can have. Among other advantages, they highlight the potential contribution to the development of a more sustainable society. In this sense, the improvement of university education in terms of sustainability could be leveraged in the future through greater adoption of modern information technologies (SANER; YIU; NGUYEN, 2020), such as artificial intelligence in education (KEIPER et al., 2023)

Thus, it is understood that AI represents a promising opportunity for integrating sustainability principles into the context of higher education, and despite inherent challenges, it is crucial to keep in mind ethical, security, and ongoing updating considerations to ensure that this technology is used responsibly and contributes to the promotion of sustainable development.

METHODOLOGICAL PROCEDURES

The purpose of this research was to analyze the context of artificial intelligence and sustainability in higher education, and additionally, their relationships with the United Nations Sustainable Development Goals (SDGs). To achieve this, a research strategy was adopted, consisting of bibliometric analysis and literature review conducted in four main stages (Figure 1).

Figure 1 - Stages conducted in the development of the research



Source: Created by authors.

In the first stage, articles were searched using the strings "(artificial intelligence in higher education for sustainability") OR ("artificial Intelligence for higher education for sustainability") OR ("artificial-intelligence") AND ("higher education for sustainability") OR ("sustainability in higher education") as topics, in the Web of Science scientific database. The result of this search yielded 315 documents. The search was conducted in October 2023, with no restrictions on publication dates. Within the database itself, a filter was applied only for research articles, resulting in the exclusion of 82 and a total of 233 documents selected for analysis.

In the second stage, the documents were analyzed using the VOSviewer software. VOSviewer, according to Anholon et al. (2022), is widely used in bibliometric studies. Its functionality lies in conducting analyses by generating network maps, which assist in identifying patterns, clusters, and trends present in a given set of (VAN ECK; WALTMAN, 2010). Contributions can be made from data in scientific databases; alternatively, data can be imported from RIS, RefWorks, EndNote, CSV files, and via APIs (VAN ECK; WALTMAN, 2020). In this study, data were imported into VOSviewer from the Web of Science database.

Following the data selection process, a "Thesaurus" file was generated in VOSviewer to cluster similar terms, as outlined by Van and Waltman (2020). This file encompassed synonyms, plural and singular variations, and spelling variations. An

illustrative instance involves the consolidation of terms such as "higher-education" into "higher education" and "artificial-intelligence" into "artificial intelligence." Employing this "Thesaurus" file with the "full count" method, a series of analyses were executed utilizing the software's analysis options. These included: a) Co-occurrence network of publications; b) Co-occurrence network considering the average of publication data; c) Co-occurrence network considering density analysis; and d) Country network. It is essential to underscore that terms for co-occurrence analyses were considered valid only if they occurred at least five times.

In addition to the bibliometric analysis of the data, the review of selected documents was conducted, marking the third stage of this study. In this phase, the documents (articles) were downloaded, and their contents were qualitatively analyzed. The outcome of the review led to the identification of artificial intelligence technologies in higher education and their connection to sustainable development, as discussed and presented in the literature. This stage involved content analysis of the articles following the guidelines proposed by Elo and Kyngäs (2008).

Elo and Kyngäs (2008) emphasize that during the phase of data organization, a study may manifest either deductive or inductive characteristics. Deductive analysis entails the utilization of models and theories to assess data, whereas inductive analysis is advised in situations where there is a lack of prior research on the phenomenon or knowledge is fragmented. Consequently, the current study aligns with inductive analysis, as its objective was to identify the relationship between AI and sustainability with the UN SDGs based on existing literature. This choice is rooted in the understanding that, as suggested by Elo and Kyngäs (2008), inductive analysis is more suitable for the present study.

It is important to highlight that content analysis presents a significant challenge and should be flexible, as there is no correct way to perform it. Therefore, it is important to describe all the steps taken, highlighting its limitations (ELO; KYNGÄS, 2008).

Finally, in the fourth stage, the analysis and discussion of results were established, followed by the development of considerations and final conclusions of the study.

RESULTS AND ASSOCIATED DISCUSSIONS

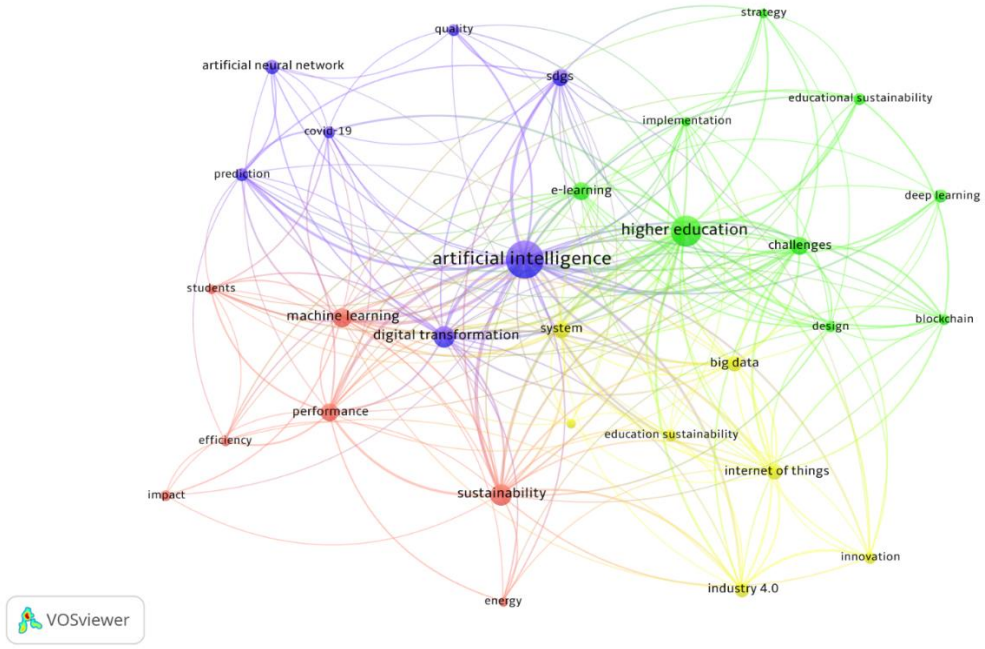
This section consists of three subsections. The first one addresses bibliometric analysis, followed by analyses and discussions. The second one presents the result of the

literature review with the connections to the United Nations Sustainable Development Goals (SDGs). Finally, the third one provides implications for theory and practice.

Bibliometric analysis

As mentioned in the previous stage, bibliometric analysis was conducted for the 233 selected documents, using a minimum occurrence of 5 for terms. In the initial phase, the co-occurrence network of words in the sample was examined. Figure 2 presents the results of this analysis conducted using the VOSviewer software. Notably, the terms "artificial intelligence" and "higher education" stood out as central, establishing connections with all other words in the figure. Additionally, it is possible to identify the presence of four distinct word groups organized into clusters. The understanding of this grouping is facilitated by the visualization of the heatmap presented in Figure 3.

Figure 2 - Co-occurrence Network



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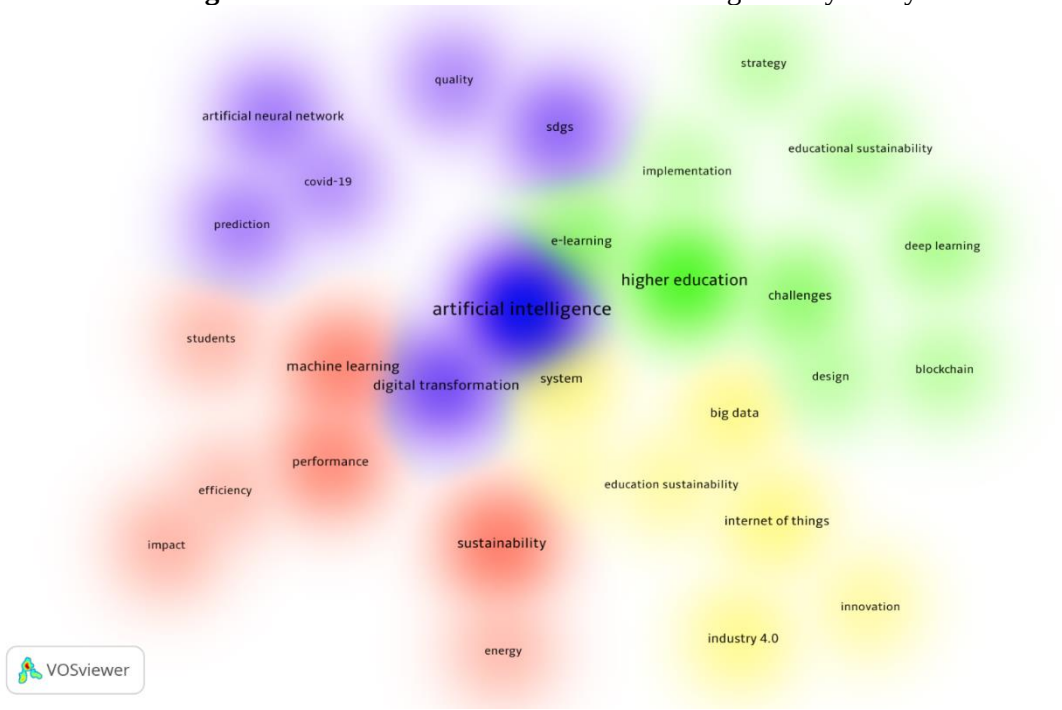
As previously mentioned, the heatmap generated in VOSviewer resulted in the clustering of four groups of words organized in clusters of blue, green, and yellow colors. The blue cluster "artificial intelligence" is related to the words "digital transformation," "SDGs," "covid-19," "quality," "artificial neural network," and "prediction." While there are some connections between these words, the most relevant relationships are those established with "artificial intelligence" and "higher education," highlighting a strong connection between these themes. The clustering confirms the observations of various

authors, such as Ara Shaikh et al. (2022), Aleem et al. (2023), and Ratten (2023), who emphasize that the topic of artificial intelligence in higher education gained relevance with the advent of the Covid-19 pandemic. During this period, there was a significant change in the educational landscape, driving the adoption of innovative technologies to meet the demands of higher education (ALEEM et al., 2023; ARA SHAIKH et al., 2022; RATTEN, 2023). In this context, artificial intelligence emerged as a tool not only to enhance teaching methods but also to integrate sustainability concepts. This emphasis highlights the fundamental role of this technology and its impact on promoting quality education, contributing to the achievement of the Sustainable Development Goals (SDGs) (BELINKY; SARAIVA; MIYAKE, 2022; BERMEJO; JUIZ, 2023; GORALSKI; TAN, 2020).

Figure 3 - Co-occurrence Network Considering Density Analysis



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Leal Filho et al. (2023a) also support this by stating that technology can provide a significant contribution to achieving the United Nations' 17 Sustainable Development Goals (SDGs) through more comprehensive monitoring of data on actions toward the SDGs and sharing information among stakeholders. Tell and Hoveskog (2022) reinforce that, in the sustainability scenario, the adoption of artificial intelligence in higher education can help countries achieve the SDGs, such as poverty reduction, combating hunger, climate management, and specifically promoting quality education.

The green cluster highlights the words "higher education," "e-learning," "challenges," "implementation," "strategy," "educational sustainability," "deep learning," "design," and "blockchain." The current context, marked by the increasing use of technology, has reflected on higher education institutions directing actions with a focus on sustainability, requiring the adaptation of their teaching methodologies to align with artificial intelligence (LIBERTSON, 2023). Although the literature emphasizes the benefits of artificial intelligence in education, in the context of higher education, there are many challenges regarding the use of this technology. Liao et al. (2022) state that one of the challenges is the lack of knowledge and skills of teachers to use AI in teaching. This issue reinforces the statements of Leal Filho et al. (2023c) that the educational community needs to develop new skills to diversify and expand teaching methods aiming to develop skills and competencies in students and teachers through the use of this technology. In this perspective, Nordgren (2023) argues that by focusing efforts on using AI to teach students about sustainability, it is possible to train committed professionals prepared to face the consequent challenges of the future.

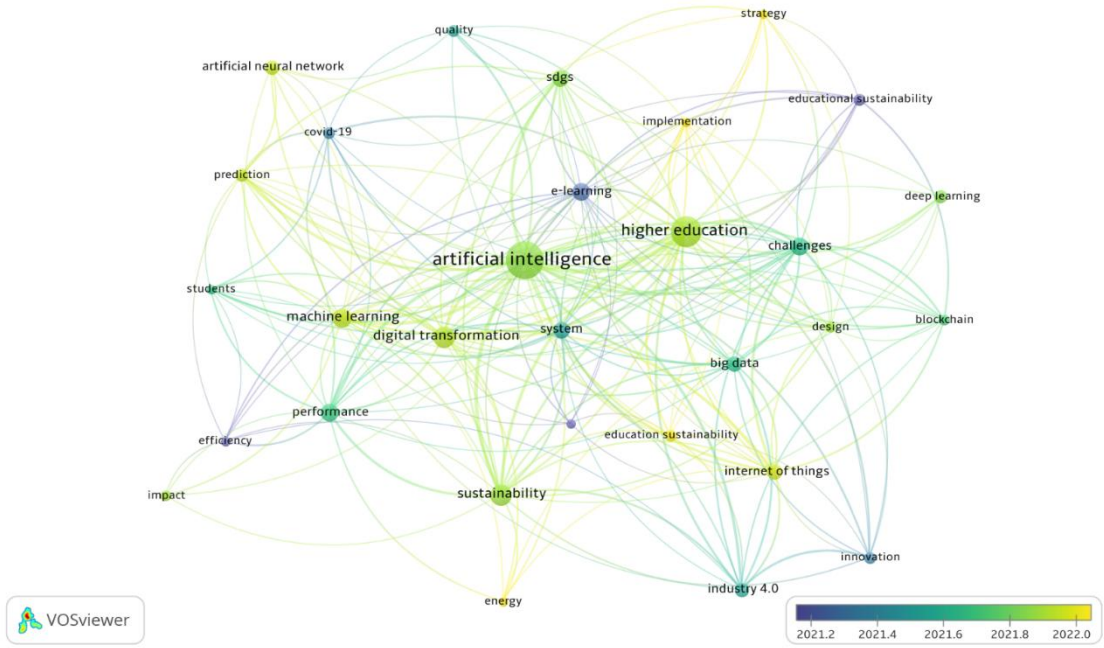
Next, the yellow cluster is composed of the words "system," "education sustainability," "innovation," "big data," "internet of things," and "industry 4.0." According to Al Darayseh (2023), the presence of AI in the higher education system promotes a comprehensive educational revolution, anchored in the triad of sustainable education, innovation, and technological advances of Industry 4.0. According to Okagbue et al. (2023), AI not only personalizes learning to meet individual student needs but also brings a shift in how information is conveyed and absorbed. The connection of AI with Industry 4.0, big data, and the Internet of Things amplifies this transformation, enhancing the adoption of more agile and predictive approaches in higher education (WANG et al., 2023b). This scenario, driven by the relationship of these technologies, not only optimizes operational efficiency but also prepares students for a future filled with challenges and opportunities, thus contributing to the formation of innovative professionals aware of the importance of sustainability in the global context (SOLLOSY; MCINERNEY, 2022).

Finally, the last analyzed grouping is highlighted by the red cluster composed of the words "sustainability," "performance," "student," "efficiency," "impact," "machine learning," and "energy." Regarding the context of AI in higher education, much research has emphasized the impact of this technology on students' teaching and learning, assessing its efficiency with the integration of sustainability performance concepts (AL DARAYSEH, 2023; CHEN; XIE; HWANG, 2020; MARQUEZ et al., 2023). Similarly,

the incorporation of AI technologies like machine learning can be used as an instrument for sustainable data management, addressing environmental and energy-related issues (ANDEOBU; WIBOWO; GRANDHI, 2022; CHIU; CHAI, 2020). This relationship highlights the importance of AI in building a more efficient, student-centered academic environment aligned with emerging sustainability demands.

Following that, Figure 4 illustrates the average publication date of the documents that include the highlighted terms in Figure 3. As mentioned earlier, there was no time restriction on publication. The mapping generated in the software reflects the unfolding of the themes addressed in this study. Therefore, it is possible to observe that various AI-related themes began to be investigated, initially related to Covid-19, e-learning, efficiency, and educational sustainability. Next, there is a highlight for themes involving AI and higher education relating to challenges, performance, systems, big data, innovation, industry 4.0, students, digital transformation, deep learning, design, Sustainable Development Goals (SDGs), artificial neural network, machine learning, and sustainability. Lastly, in the final analysis, a strong connection is observed for themes of education sustainability, implementation, strategy, energy, and the Internet of Things linked with AI and Higher Education becoming the object of study.

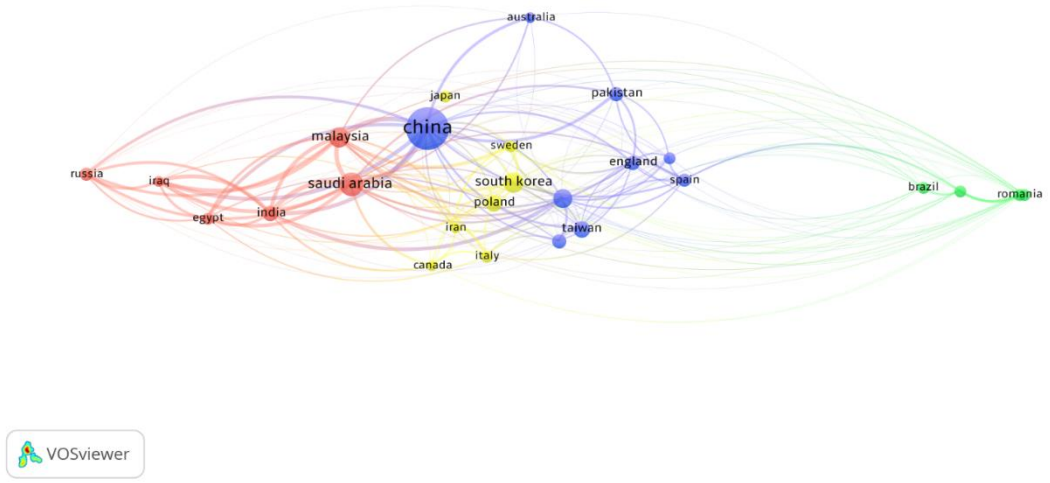
Figure 4 - Average date of terms present in the analyzed documents with a co-occurrence frequency greater than 5



Source: Created by authors.

In the final analysis, Figure 5 presents the co-authorship network concerning the countries of the analyzed documents. China stands out as the central country in this network.

Figure 5 - Co-occurrence of countries



Source: Created by authors.

AI in HE and its relation to SD

Considering the presented context, analyzing the literature and the Sustainable Development Goals (SDGs) proposed by the United Nations, it was possible to create Table 1, which presents the main artificial intelligence technologies used in higher education and how they relate to sustainable development issues, an important topic within the context of teaching and research in sustainability. Additionally, Table 1 also highlights the advantages of this relationship.

Table 1. AI Technologies Used in Higher Education and Their Relationship with Sustainable Development.

AI technologies	Relationship with Sustainable Development	Advantages
• Recommender and personalization systems	They enable personalized learning based on individual student needs, optimizing the use of educational resources and reducing waste. This AI technology, as a result, can ensure that all students acquire the knowledge and skills necessary through education to ideate sustainable solutions and enhance the achievement of SDG 4.7, which aims to	Improves teaching efficiency by increasing student engagement and enhancing academic outcomes (AL KA'BI, 2023; HALAGATTI et al., 2023a; NAVEENKUMAR et al., 2023; SANTOS et al., 2023).

	ensure that all learners acquire the knowledge and skills needed to promote sustainable development.	
• Chatbots and virtual assistants	They can provide support and guidance to students by answering frequently asked questions and delivering relevant information quickly and efficiently. Chatbots and virtual assistants are technologies with potential that can be used to address students' difficulties, enhancing their teaching and learning process and increasing their interest in studies. As a result, they strengthen students' access to information and contribute to the development of scientific research through universal access to information and communication technologies. Therefore, these technologies are related to SDG9 9.C, which aims to significantly increase access to information and communication technologies.	Improves the student experience by reducing waiting time and providing learning support. It promotes discussions by generating new insights into a specific context (EBADI; AMINI, 2022; JEON, 2021, 2022; LIN; YU, 2023; PALLATHADKA et al., 2022).
• Automated assessment systems	Enables quick and accurate grading of assignments and exams, freeing up time for teachers to focus on more interactive and formative activities. The use of this technology can promote quality education by providing personalized learning experiences tailored to individual student needs, improving learning outcomes, and fostering a deeper understanding of the subject matter. This stimulates the achievement of SDG 4.4, which corresponds to the development of relevant skills, including technical and vocational skills, for employment and decent work.	Increases the efficiency of the assessment process by providing immediate feedback to students and streamlining teachers' workflow. This ensures more time for the development of students' competencies aligned with the new demands of the job market (AL KA'BI, 2023; HALAGATTI et al., 2023a; MCGRATH et al., 2023).
• Adaptive learning platforms	They use AI algorithms to personalize teaching content based on each student's performance and learning needs. Adaptive learning platforms can help reduce educational inequalities in higher education, through personalized support and resources, seeking to address learning gaps, offering additional assistance to students, as well as enabling the integration of sustainability-related content in their courses, seeking to raise awareness about the principles of sustainable development and awaken interest in technological solutions considering their realities, thus enhancing the achievement of the goals that make up SDG4, which corresponds to the promotion of quality education for all.	Promotes more effective and engaging learning by meeting individual students' needs and facilitating the acquisition and consolidation of knowledge (MCGRATH et al., 2023; RAZAK et al., 2023; SANTOS et al., 2023).

• Educational data analysis	Enables the collection and analysis of data on students' performance and the functioning of educational institutions, assisting in the identification of areas for improvement and the development of more effective educational strategies. This technology can therefore support teachers or educational institutions in data-driven decision-making and promote collaboration, educational performance analysis, and a more inclusive, equitable, and sustainable educational system, contributing not only to SDG 4 but also to the achievement of SDG 10.2, which aims to promote social, economic, and political inclusion for all.	Facilitates evidence-based decision-making, enhancing the quality of teaching and the management of educational institutions (AL KA'BI, 2023) (HALAGATTI et al., 2023a).

Source: Created by authors based on the analysis of the SDGs proposed by the UN and on the references presented in the table.

In general, these AI technologies applied to the demands of higher education can bring significant benefits to the quality of education, enhancing the student experience and academic performance. Additionally, the use of these technologies can contribute to the sustainability of the educational system, enabling more efficient allocation of educational resources and reducing waste of time, effort, and materials.

Thus, it is observed that in the context of higher education, AI technologies can enhance the learning experience by providing personalized, adaptable, and data-driven solutions that help students learn more efficiently and effectively (AL KA'BI, 2023; HALAGATTI et al., 2023b; NAVEENKUMAR et al., 2023; SANTOS et al., 2023). AI-based educational tools such as chatbots, virtual assistants, and automated assessment systems can save time and improve the quality of education by providing immediate feedback to students (ASLAM et al., 2022; EBADI; AMINI, 2022; JEON, 2021, 2022; LIN; YU, 2023; PALLATHADKA et al., 2022).

To achieve the Sustainable Development Goals (SDGs) of the UN (United Nations) proposed in Agenda 30, AI can help achieve these goals, such as ensuring quality education and access to information (GUPTA et al., 2023; NASIR et al., 2023).

Therefore, AI technologies have a significant role to play in both higher education and sustainable development. By providing personalized and data-driven educational tools, AI can enhance the quality and efficiency of education, as well as contribute to the achievement of the SDGs through its ability to provide data-driven solutions to complex economic, social, and environmental challenges. Educators and policymakers need to

embrace the potential of AI to fully harness its benefits and contribute to a more sustainable future.

Implications for theory and practice

This study carries implications for both theory and practice. On a theoretical level, the combination of bibliometric and literature analysis contributes to a more comprehensive understanding of the relationship between artificial intelligence and sustainability in higher education. Moreover, the study offers valuable insights to fellow researchers, aiding them in future investigations, given the acknowledged relevance of the topic and the recognition that there is still much to be explored.

From a practical perspective, the study furnishes information that can assist managers of higher education institutions in the effective implementation of AI tools, emphasizing sustainability. This, in turn, facilitates student learning and fosters a more thorough grasp of sustainability concepts. Additionally, it contributes to the pursuit of the United Nations Sustainable Development Goals (SDGs).

CONCLUSIONS AND FINAL CONSIDERATIONS

This study aimed to analyze the relationship between artificial intelligence and sustainability in higher education based on the literature in the field. Based on the presented results, it can be stated that this objective was achieved. The analysis conducted using the VOSviewer software resulted in the formation of four thematic clusters regarding the relationship between these themes. Furthermore, the literature review highlighted the strong integration of AI technologies in higher education and their connection to sustainable development. From these results, the following conclusions can be drawn.

The blue cluster revealed the emergence of artificial intelligence during the pandemic, emphasizing its importance in enhancing teaching methods in higher education and integrating sustainability concepts, positively impacting educational quality and contributing to the achievement of the Sustainable Development Goals (SDGs). The green cluster addressed the adaptation of higher education institutions to emerging technologies, including artificial intelligence, emphasizing the need to develop new skills in the educational community to diversify and enhance teaching methods. The yellow cluster indicated the presence of artificial intelligence in higher education based on the triad of sustainable education and innovation, aiming to prepare students for future

challenges. The red cluster highlighted the impact of artificial intelligence on higher education, focusing on student learning, efficiency, and sustainable performance.

Furthermore, the literature analysis delineated the primary AI technologies and their connection to the SDGs. The current landscape underscores the significance of research, empirical evidence, and technology-oriented educational initiatives to contribute to the realization of the United Nations' Sustainable Development Goals. In this context, the escalating importance of artificial intelligence in higher education is conspicuous, alongside the challenges associated with implementation, underscoring the persistent necessity for investments in training and innovative educational strategies to seamlessly integrate AI into higher education, with a particular focus on sustainability.

Lastly, it is crucial to underscore the limitations of this study. Despite utilizing the Web of Science database, deemed one of the most significant globally, other pertinent scientific databases exist. Additionally, it is relevant to acknowledge that variations in search terms may yield different article selections during the evaluation phase. For future studies, it is recommended to conduct research in diverse countries to comprehend how artificial intelligence in higher education is perceived and adopted within the context of sustainability.

ACKNOWLEDGMENT

We would like to thank all those involved who contributed to the development of this research, especially the Universidade do Estado do Pará (UEPA), and funding provided by Fundação Amazônia de Amparo a Estudos e Pesquisas (FAPESPA) and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES).

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