Sustainable Development Education in International Higher Education: A Bibliometric analysis

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Abstract

The importance of sustainable development is increasingly recognized, prompting universities to strive toward achieving the Sustainable Development Goals (SDGs). This review focuses on the meticulous collection and analysis of relevant papers within the context of sustainable development education, followed by the organization and consolidation of these findings into distinct sustainable domains using the PRISMA methodology. A total of 77 existing articles and publications retrieved from the Web of Science database were utilized to conduct an in-depth exploration of current research. This study, based on 77 documents from the Web of Science core database, employs systematic bibliometric analysis to trace the education for sustainable development (ESD) in global universities. Using the PRISMA method, VOS viewer, and Excel tools, research clusters, high-output countries, and major journals were identified. Key findings indicate that research focus has shifted from theoretical exploration to practical innovation, encompassing service-learning, digital tools, and interdisciplinary curriculum integration. Core challenges include fragmented ESD implementation, insufficient sustainability assessment, and unequal resource allocation. This study proposes action strategies: embedding the Sustainable Development Goals (SDGs) into disciplinary frameworks, strengthening teacher training programs, and leveraging artificial intelligence to develop scalable solutions. This analysis provides a roadmap for policymakers, educators, and institutions to enhance ESD effectiveness and university sustainability.

1 Introduction

Sustainable development is widely recognized as a collective responsibility, and education plays a crucial role in achieving this goal. Le Grange L (2020) notes that the term "sustainability" first appeared in 18th-century German forest management practices and entered the English lexicon in the 1970s. Sustainable development is defined as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." This concept has been widely adopted by the United Nations, governments, and businesses [1]. In the context of globalization, the ongoing degradation of ecosystems underscores the urgency of comprehensive environmental education. Research indicates that education plays an irreplaceable role in shaping students' environmental awareness [2]. However, the effectiveness of education remains insufficient, particularly in bridging the gap between knowledge and action [3]. Through this explanation, it is clear that sustainable development and environmental protection are closely intertwined.

Of course, in the face of the ecological crisis, education must guide society to respect nature and cultivate environmental awareness. Universities, given their social influence, should play a key role in sustainable development [4]. Sustainability is an important trend in higher education, involving multiple issues and challenges. The 2030 United Nations Sustainable Development Agenda and its 17 Sustainable Development Goals (SDGs) provide a relevant roadmap for universities committed to sustainability [5]. As centers for knowledge creation, dissemination, and the cultivation of future leaders, universities play an indispensable role in the transition toward sustainability. University sustainability is far more than merely environmental behavior; it is an intrinsic requirement for universities to fulfill their educational missions, research responsibilities, and social service functions. It is a necessary pathway for enhancing institutional resilience and maintaining long-term value, and it is the core capability through which universities, as key social actors, lead the global transition toward a sustainable future.

Monzó-Martínez et al. (2024) demonstrate that universities are key educational entities for achieving the SDGs, shaping sustainable knowledge for future change-makers through their curricula [6]. Gomera et al. (2021) strongly demonstrate the core value of universities as exemplars of sustainable operations, shapers of environmental behavioral norms, practitioners of participatory management, and bridges connecting society through the "Trébol Programme." A university's own sustainable transformation is the foundation for its educational and social influence [7]. Nano et al. (2024) emphasize the importance of universities in cultivating entrepreneurial talent to drive a sustainable economy, promoting interdisciplinary solutions, and driving external change through industry collaboration [8].Sustainable development education in universities can effectively enhance the development of students, teachers, and

schools. Moya Clemente et al. (2020) found that sustainable development education enhances employment competitiveness and talent quality [9]. Chuvieco et al. (2022) found that sustainable development education compensates for deficiencies in the curriculum system and promotes interdisciplinary integration [10]. Fontalvo-Buelvas et al. (2023) found that sustainable development education innovates practical teaching and strengthens social responsibility [11].

Through the aforementioned research findings, it is evident that sustainable development education plays a crucial role in the sustainable development of universities. Therefore, to further promote and achieve in-depth development in sustainable development education at universities, we must make greater efforts from multiple perspectives. This includes, but is not limited to, conducting in-depth analysis and understanding of past theoretical research findings, as well as conducting detailed examinations and studies of actual practical cases. Through such a comprehensive approach, we may be able to explore a clear path and provide practical strategies and directions for the future advancement of sustainable development education at universities.

2 Materials and Methods

2.1 Literature sources and search strategy

Using the following search format in WOS Advanced Search: "TI=sustainability And education And (university Or college)", restricted the time frame to January 1, 2020 to May 22, 2025, and excluded SCI-Expanded search data, resulting in 85 articles. After reading the titles and abstracts, we excluded 8 articles, leaving 77 papers (Figure 1).
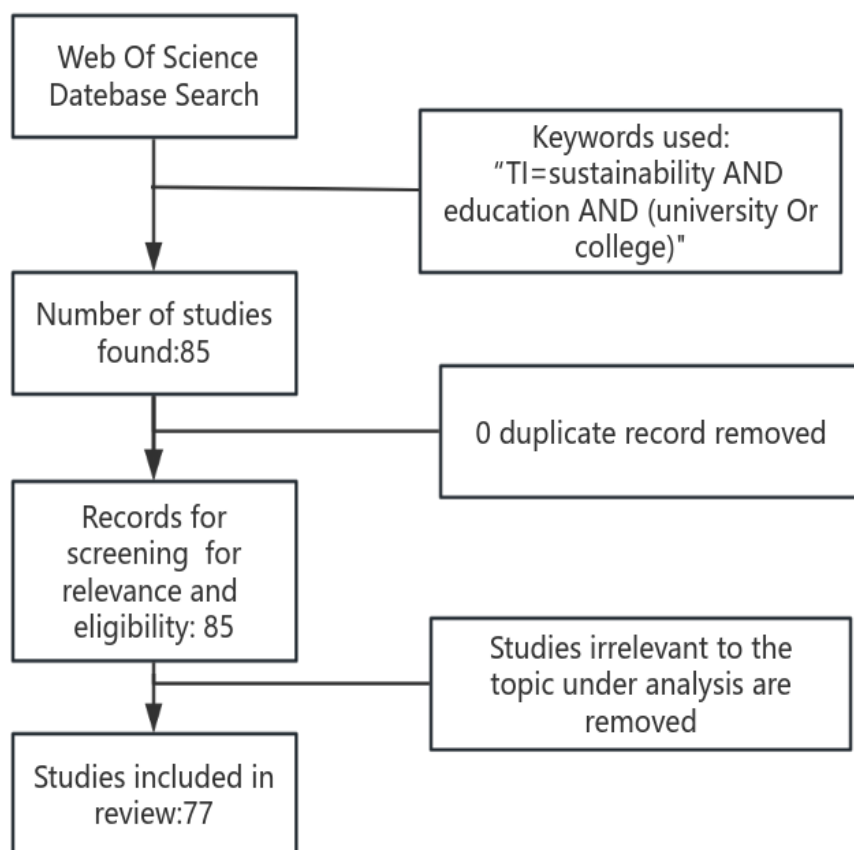

Figure 1. PRISMA literature review research

2.2 Data collection and statistics

First, the raw WOS data was imported into Microsoft Excel 2021 for preliminary organization, and the evaluation results were verified by SJ.W and B.J. Next, we extracted several bibliometric parameters, including: number of papers, citation frequency, and H-index [12]. Statistical methods included: conducting statistical analysis using the bibliometric online analysis platform (https://bibliometric.com/); analyzing the number of publications using Excel; and using VoS viewer to analyze cluster analysis, including Co-Occurrence Map Based on Text Data and Co-occurrence map of author keywords [13]. The frequency, timeline, and interconnections of different author keywords were described using the color, size, and connecting lines of circles [14].

3 Results Analysis

3.1 Publication Analysis

From these data, it can be seen that the number of research publications in this field has fluctuated in recent years. 2020 was a peak year for research output with 19 publications, followed by a decline to 9 in 2021, but then a rebound to 13 in 2022. In 2023, the number remained relatively stable at 12, and in 2024, there was again a significant increase to 20（Figure 2）. This trend may reflect fluctuations in research interest in this field or be influenced by factors such as research funding and policy direction. It is worth noting that, despite variations in the number of publications each year, there is an overall upward trend, indicating that research in this field is gradually gaining more attention.
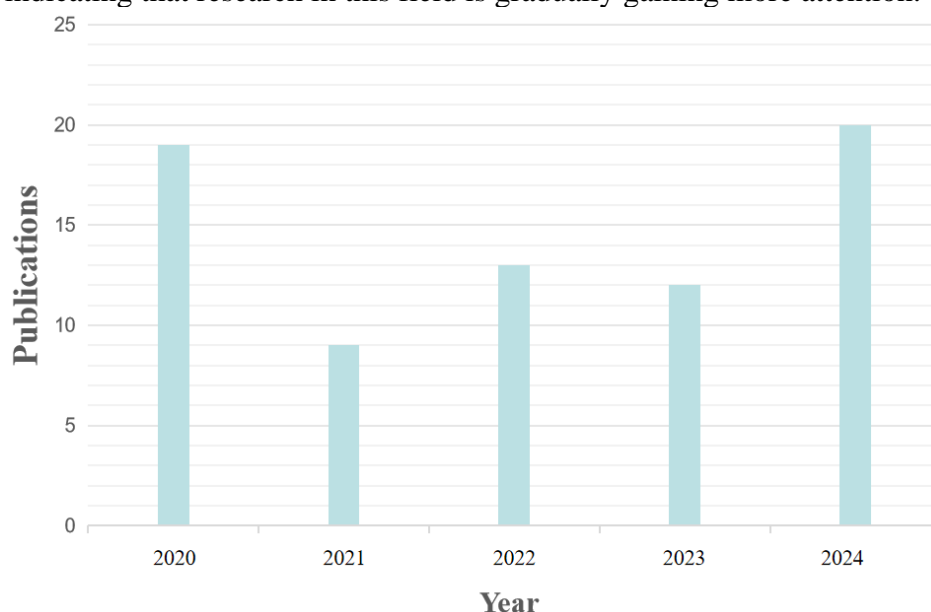
Figure 2. Graph showing variation in research over the years 2020–2024.

3.2 Citation Frequency and H-index

According to data collected by WoS, a total of 77 papers were included, with a total of 4,149 citations, an average of 53.88 citations per paper, and an h-index of 45. In-depth analysis shows that the top 30 papers performed well in the following aspects: they accounted for 58.56% of the total number of citations, with an average of 81 citations per paper.

3.3 Quantity and citations among different nations
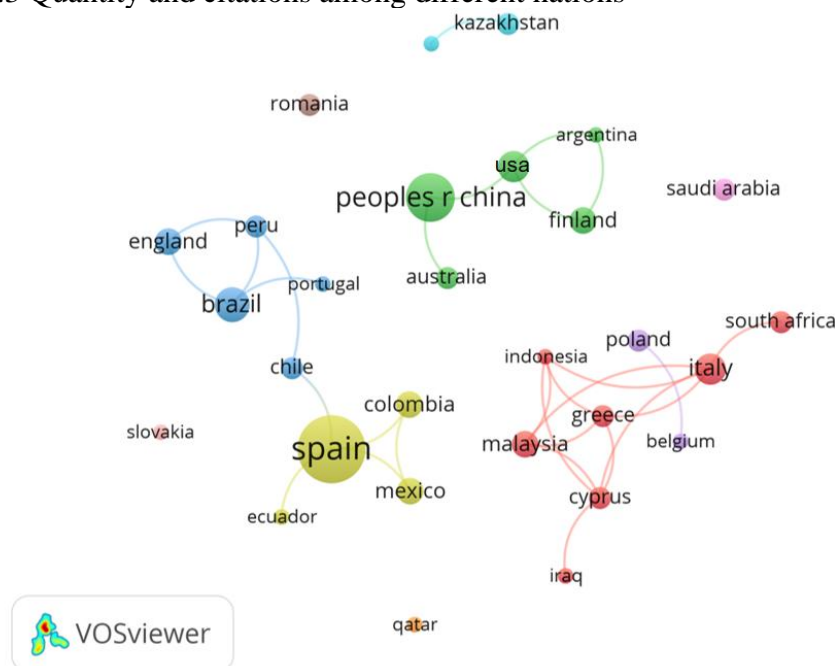
Figure 3. Co-occurrence map of country of authorship.

Spain and China are the most prominent countries, followed by Brazil. They have the highest number of publications and citations. Figure 3A shows an overview of global publications in this field, with China having the highest number of publications. The United States has established a leading position in other key indicators such as total citations, average citations, and H-index (Table 1). As shown in Figure 3B, the United States has the highest number of interrelated targets.

Table1. Top 10 countries by link strength.

Country	Documents	Citations	Total link strength
Spain	19	175	4
Peoples r China	10	53	2
Brazil	5	54	3
Italy	4	41	5
Usa	4	27	3
Malaysia	3	67	4
Colombia	3	5	2
England	3	30	2
Finland	3	22	2

3.4 High-contributing journals

The number of journal publications is relatively concentrated, with a clear preference for certain journals(Figure 4). The journal Sustainability holds significant influence and appeal in the field of higher education sustainability research, making it the preferred platform for researchers in this area. The International Journal of Sustainability in Higher Education also holds an important position, reflecting the journal's emphasis on sustainability issues in higher education. This also suggests that researchers may consider submitting their work to these high-impact journals to gain more attention in this field.

Top of journal by number of publications
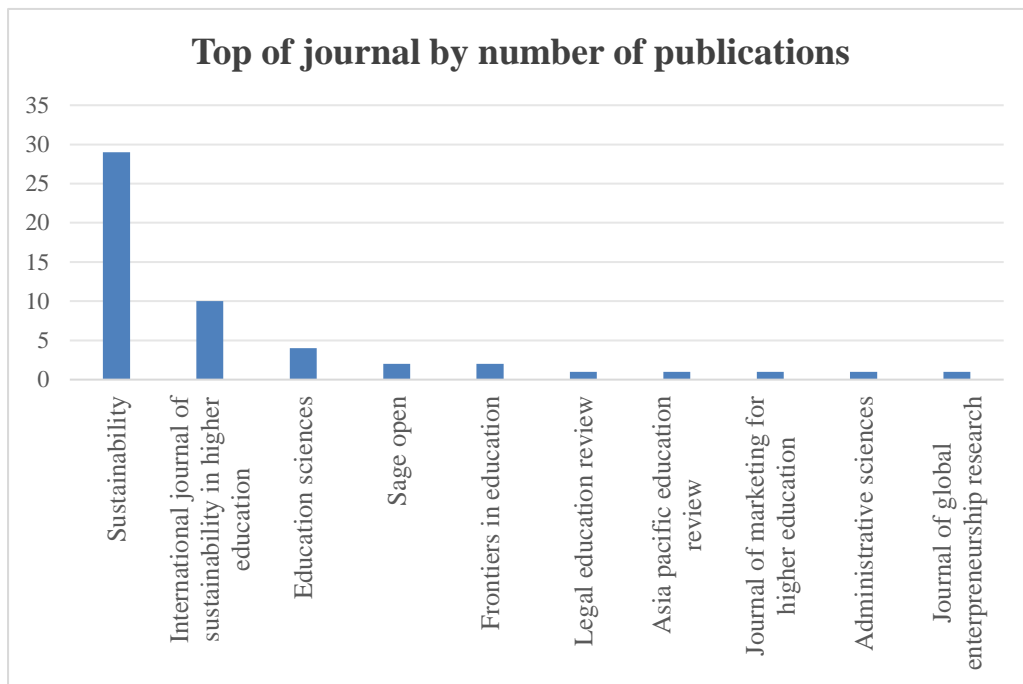
Figure 4.The top 10 journal by number of publications

3.5 Author collaboration network graph

Using VoS viewer to generate an author collaboration network diagram (Figure 5), only one author published more than two articles, forming two clusters. The first cluster is primarily composed of Carmen and Rocio Valderrama-Hernández from the Department of Theory and History of Education and Social Pedagogy, Faculty of Educational Sciences, University of Seville, Seville, Spain, who are the core figures. The second cluster comprises researchers from the Universidad Católica de la Santísima Concepción, Universidad de Granada, Universidad Autónoma de Barcelona, Universidad de Girona, and Universidad de Sevilla. Carmen Solís-Espallargas is involved in research in both clusters.
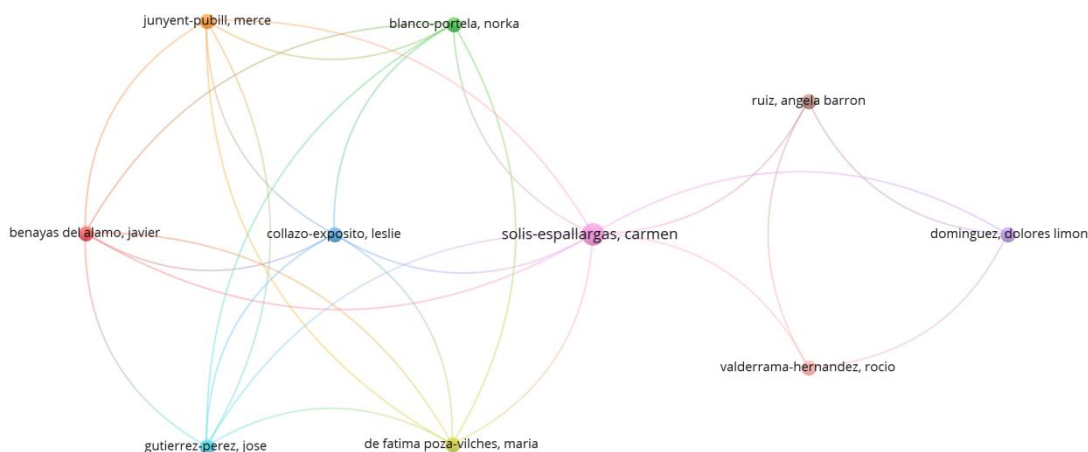
Figure 5. Author collaboration network graph

3.6 Co-Occurrence Map Based on Keywords

Keywords were selected from existing data, yielding a total of 280 terms. To enhance the effectiveness of the graph, the two most frequently occurring terms, "Sustainability" and "higher education," were excluded during keyword selection. The resulting graph, Figure 6A,

was divided into three sections to more clearly illustrate the research directions of educational sustainability within universities. These are: Cluster 1 "Towards comprehensive" represented in red; Cluster 2 "Towards environmental research" represented in green; and Cluster 3 "Towards application-oriented research" represented in blue. The size of the keyword circles within each cluster is proportional to their frequency of occurrence (Appendix Table 2). The main terms in Cluster 1 include: Higher education institution[15][16][17][18]; SDGs[19][20]; sustainable development[21][22]. The main terms in Cluster 2 include: Education for sustainable development[10][23]; environmental education[24][25]. The main terms in Cluster 3 include: Teaching methods[26][27]; efficiency[26][28].

VoS viewer marked the keywords in the figure and used different colors based on the average year of appearance of the keywords. Yellow keywords appeared earlier than green and dark blue keywords (Figure 6B). The transition from yellow to dark blue indicates the progression of keywords.
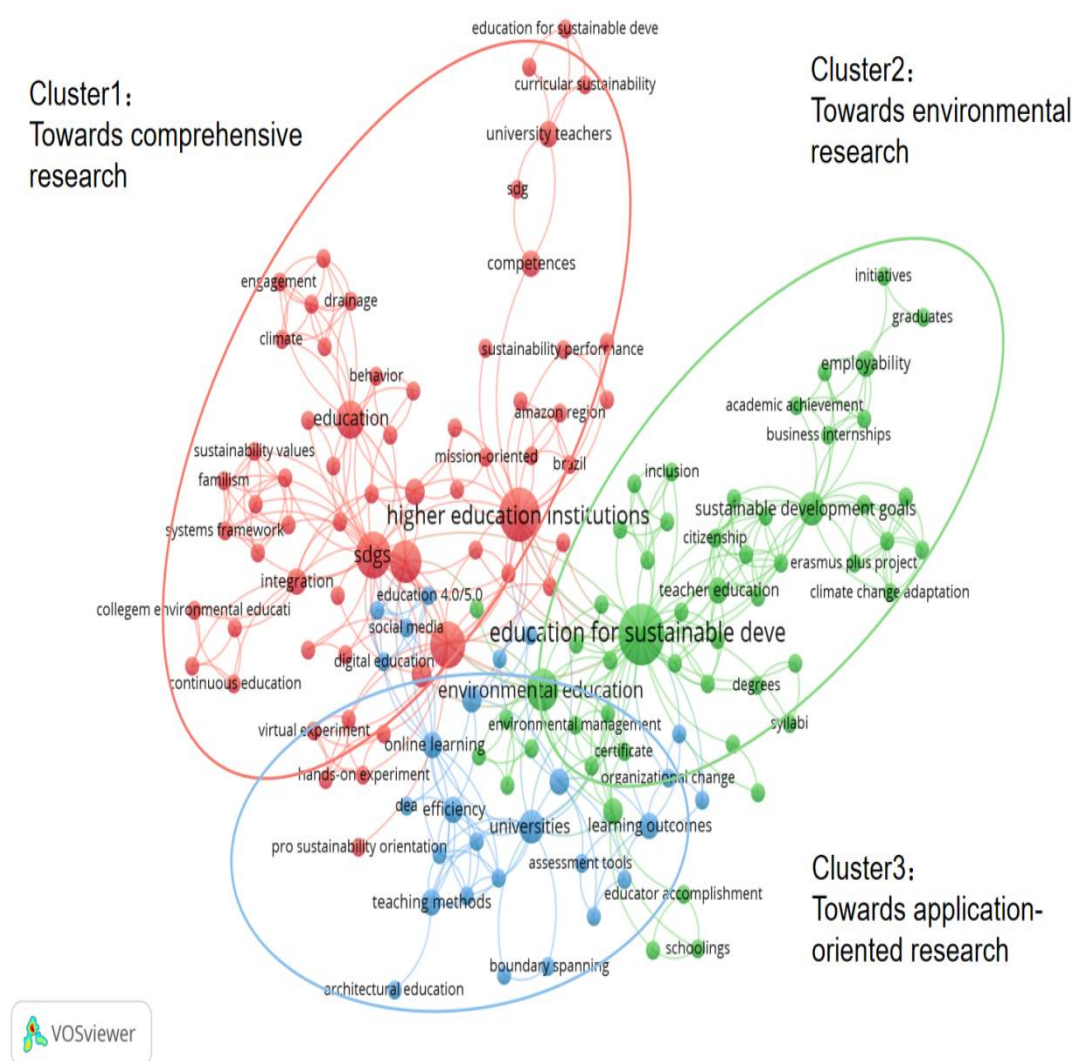
Figure 6A. Co-occurrence map of author keywords

Figure 6B. Keyword co-occurrence networks and keyword evolution over time. Keyword co-occurrence networks are divided into three different colored clusters based on the evolution of research hotspots. The color of keyword B indicates the average publication time of articles containing that keyword.

3.6 Data analysis of document types and research types

Figure 7. Document types and research types

This study conducted a thorough review of 77 academic papers and classified them based on their type, primarily into three categories: academic articles, conference papers, and review articles. These three categories are the only types of literature examined in this study. Among the 77 papers reviewed, the vast majority belong to the academic article category, while the number of conference papers and review articles is relatively small. The specific classification

statistics are as follows: 1 Meeting abstract, 3 Review, 1 Book Review, 2 Early Access, 69 Article, and 1 Editorial Material. （Figure 7）

3.6 Characteristics of the 10 most cited research articles (Table 2)

No	First author	Journal	Year	citations	Descriptions
1	Syed Hammad Mian[29]	Sustainability	2020	122	The modernization of higher education aligns with the principles of Industry 4.0, presenting both opportunities and challenges. While Industry 4.0 is globally recognized, its full adoption is hindered by limitations in workforce skills. Universities should enhance their capabilities through technological innovations such as additive manufacturing and simulation software, as well as through laboratories and courses. Universities must allocate dedicated personnel to adapt to the concepts of Industry 4.0. New colleges or vocational training centers should be established to educate teachers to meet the challenges of the digital age. Upgrading or introducing new courses, such as data analysis and AI design, is essential to ensure that talent meets industry demands. Incorporating Industry 4.0-related courses as core disciplines for developing soft skills is crucial for the sustainable development of university education.
2	Manzoor, Shamima Raihan[30]	Journal of marketing for higher education	2021	59	Global student mobility has transcended traditional regions, with Malaysia, Singapore, and South Korea emerging as new study abroad destinations. Higher education institutions face intense competition, which affects their sustainability. Research has found that expanding university image models can help improve student satisfaction and civic behavior, thereby supporting the sustainable development of higher education institutions.
3	Leslie Mahe Collazo Expósito[31]	Sustainability	2020	41	The "ImpSDGup" course is based on the Training Model for Transformative Action on Sustainable Development (TMTAS), which consists of three main areas: sustainable development content, theoretical methods, and sustainable development education teaching methods. The purpose of this higher education teacher training course on sustainable development professional education skills and competencies is to help scholars reposition their disciplinary curricula to contribute to the United Nations 2030 Agenda for Sustainable Development Goals. It aims to enhance university teachers' professional competencies in Education for Sustainable Development (ESD).
4	Barbara Galleli[17]	International Journal of Sustainability in Higher Education	2022	34	The primary objective of this study is to evaluate the structure of global university sustainability rankings based on the Berlin Principles (BP) framework. The research methodology involves content analysis of two global sustainability university rankings—the UI Green Metric World University Rankings (WUR) and the Times Higher Education World University Rankings (THE-WUR)—and assessing these rankings using the BP framework. The study found that while THE-WUR performed better in this study, both the UI Green Metric World University Rankings (WUR) and the Times Higher Education World University Rankings still have gaps in terms of specificity and room for improvement. The study also noted that while there may not be a single, uniquely suitable ranking, there can be rankings that are more appropriate for specific contexts. This research has practical implications for university administrators in selecting the most suitable ranking and for their institutions' participation in sustainability-related rankings, and it offers suggestions for improving ranking criteria.

5	Giulia Sonetti[16]	Sustainability	2020	28	Organize and describe a set of sustainable development strategies for continuing education that took place in Italian universities from 2016 to 2019. The mission of excellence (teaching) and the universal driving force (top-down) were found to be the most common characteristics of sustainable development goal education initiatives. Secondly, sustainability is often viewed as a separate discipline, inserted into existing curricula and original teaching, or as a conceptual tool to address specific social challenges through on-site activities such as workshops or fieldwork. An analysis of Italian EfS experiences collected through the RUS national call enabled us to map certain recurring features of the actions taking place within the current educational structure.
6	Miriam Hernández-Barco[22]	Sustainability	2020	27	The application of service learning (SL) methods in the Environmental Science Degree Program (FDD) at the University of Extremadura (Spain) was analyzed. The study assessed how the FDD, implemented according to SL principles, contributes to the acquisition of so-called "soft skills" and how these skills can be focused on promoting knowledge and achievements related to the Sustainable Development Goals (SDGs). The conclusion was that higher education should integrate the SDGs into its teaching practices and can successfully achieve this using SL methods.
7	José Manuel Muñoz-Rodríguez[32]	Sustainability	2020	23	Students in the Bachelor of Education program showed significant improvement in sustainable development competencies; however, the performance of students in the Bachelor of Social Education and Bachelor of Early Childhood Education programs improved but not significantly. Finally, elementary teacher students pursuing a Bachelor of Education degree appeared to make no progress. Based on these data, the model used to introduce sustainable development competencies into the Bachelor of Education program appears to be the only one yielding positive results.
8	Marta Rey-Garcia[33]	International Journal of Sustainability in Higher Education	2020	19	An abstract of a research paper on the impact of Education for Sustainable Development (ESD) on social sustainability. The study found that collaborating with community organizations to implement real-world learning not only extends the desired effects beyond individual project learning outcomes but may also update these effects over time. In terms of practical implications, university administrators should promote the creation of new social capital among students and alumni and enhance the social sustainability impact of university ESD through service learning and other credit opportunities.
9	Atif Saleem[9]	International Journal of Sustainability in Higher Education	2023	17	Research findings indicate that holistic, diverse, and action-oriented approaches are widely adopted in Malaysian universities, and these approaches are significantly associated with sustainability awareness. While all three approaches enhance various aspects of sustainability awareness, the results suggest that action-oriented approaches require further development. This study underscores the importance of sustainability education in higher education, provides empirical evidence for developing action-oriented ESD methods, and confirms the practicality of holistic content and diverse teaching methods in sustainability education.
10	Vasiliki Kioupi[34]	Education Sciences	2022	17	An assessment framework was proposed to enable and evaluate the achievement of sustainable development competencies among

university students.A focus on participatory approaches in formulating competences for sustainability that fit an institution's vision, mission, aims, and needs, instead of a prescriptive approach of applying predefined competence frameworks, should be prioritized by all HE institutions.

Table 2. The top 10 most cited research papers

4 Content analysis

4.1 Innovative Teaching Strategies for Sustainable Development Education

This section focuses on exploring innovations in teaching strategies for sustainable development education in universities. The publication of these articles also demonstrates that higher education institutions (HEIs), represented by universities, are actively exploring innovative teaching strategies to effectively implement sustainable development education (ESD) and enhance sustainability awareness, with a focus on interdisciplinary integration, experiential learning, and digital technology empowerment. In terms of interdisciplinary learning, holistic content, diverse teaching methods[15], and the "Teaching Down to Earth" service-learning model[22], which emphasizes real-world application, can significantly enhance students' sustainability awareness. The service-learning model serves as a paradigm for bridging theory with community practice. Stickney et al. (2022) found that implementing a "learning by doing" strategy can significantly enhance students' critical thinking skills and sense of social responsibility[35]. Fontalvo-Buelvas et al. (2023) found that practice-oriented agroecology courses have a significant impact on enhancing educational outcomes in the social and environmental dimensions[11].

Sonetti, G. et al.(2020) pointed out that sustainability education is often integrated into the existing curriculum as an independent subject or as a conceptual tool for addressing specific social issues [16]. Fioramonti L. et al. (2021) revealed that Italy has promoted the development of interdisciplinary research through a series of educational reforms, including adjusting assessment mechanisms, rewarding research projects with practical social impact, and eliminating barriers between disciplines. and introducing new teaching modules centered on the interdisciplinary field of "sustainability." As a result, Italy became the first country globally to incorporate interdisciplinary research on sustainable development into its national curriculum as a required subject [36].

Digital technology is profoundly transforming the teaching model of sustainable development education, becoming a key enabling tool for improving efficiency, expanding boundaries, and ensuring resource sustainability. Virtual simulation technology (such as VR/AR laboratories) has been proven to effectively improve practical skills and theoretical understanding, and optimize resource utilization [37]; Özdemir et al. studied online collaboration platforms at Anadolu University, which expanded the possibilities for cross-border cooperation and social contribution [38].At the same time, Al-Hail, M. et al. call for the optimization of social media platform frameworks and the pursuit of policy support to maximize their role in lifelong sustainable learning [20]. It is also worth noting that emerging technologies show great potential for promoting research and practice in sustainability-related fields, such as how artificial intelligence and big data can promote the development of sustainable tourism, but their in-depth application requires strengthened international cooperation [39].Manzoor, SR., et al. developed an expanded university digital image model that helps improve student satisfaction and civic behavior, supporting institutional sustainability [30]. In addition, Alberto Paucar-Caceres et al. found that the application of systematic methodologies (such as the soft systems methodology, SSM) helps clarify stakeholder roles and build action networks, promoting the achievement of

SDGs [40]. In the future, it will be necessary to focus on exploring how to systematically integrate and deepen the application framework of these technical tools.

4.2 Integration of curriculum system and subject characteristics

Universities face significant challenges in integrating sustainability courses and assessing students' sustainability competencies. Research by Alexa L et al. (2020) and Valderrama-Hernández et al. (2025) indicates that existing courses often exhibit fragmented content [18], and students' acquisition of sustainability competencies is not significant, highlighting the limitations of relying solely on specific course instruction. There is an urgent need to deeply integrate sustainability into all daily activities of the institution [41]. Additionally, Galleli et al. analysis of UI green metrics and THE rankings revealed that the current evaluation system for university sustainability and student capability development is incomplete and lacks specificity [17]. To address these challenges, Kioupi V et al. propose an assessment pathway: higher education institutions should adopt a participatory approach, tailor a sustainability capability framework based on their own vision, mission, and objectives rather than simply applying generic templates, and use assessment tools to identify gaps and barriers to achieve more effective capability development and assessment [34].

Integrating sustainable education into subject-specific curricula may open up new avenues. Effectively integrating sustainable education into specific subject contexts is key to enhancing relevance, but this requires addressing diverse challenges and needs. Research indicates that sustainable education must be closely aligned with national and regional policy directions [42] and the characteristics of specific disciplines (e.g., forestry, architecture, medicine, language education, computer science, etc.). It is important to avoid issues such as the disconnect between cognition and behavior [43], integration with existing course content [27], and significant differences in effectiveness across disciplines [32]. There is an urgent need for integration in specific fields: medical education should incorporate content on the health impacts of climate change [44], language education (such as English) should utilize textbooks to cultivate students' knowledge and attitudes toward addressing sustainable challenges [45], and it is also necessary to foster students' sustainable entrepreneurship intentions (SEI) [46]. Technology integration is key to empowering subject-specific teaching. Additionally, sustainable education must include an equity dimension, addressing the unique challenges faced by marginalized student groups to truly achieve inclusive sustainable development [47].

4.3 Sustainable Development Education System and Governance Innovation

This section focuses on institutional and governance aspects, with higher education institutions establishing core operational mechanisms for sustainable development centered on three key dimensions: financial resilience, resource efficiency, and teaching effectiveness. To ensure financial sustainability, innovative financing channels must be explored, such as the Green Ocean Strategy for Financial Sustainability (GOSFS) proposed in the Saudi case study, which emphasizes social investment and technology commercialization [48]. Enhancing resource utilization efficiency relies on quantitative assessment and optimization [28]. Meanwhile, practice is crucial for teaching effectiveness, which can be achieved through establishing continuous feedback mechanisms, strengthening mentor guidance, and incorporating real-world cases and industry participation [49], thereby fostering students' understanding of complex challenges and enabling them to develop actionable solutions. These three elements collectively form the internal operational "iron triangle" that underpins the institution's long-term stable operations.

Secondly, effective external policy tools and internal teacher professional development serve as the dual engines driving the sustainable transformation of higher education institutions. At the policy level, Ma G et al. found in China that policy tools such as environmental orientation can drive systemic change, acting as a key lever to catalyze teacher development

and governance optimization [50]. At the faculty level, faculty members are the core hub for implementing sustainable education, and their professional capacity building, such as ESD literacy and interdisciplinary integration, is crucial. Blanco-Portela promoted in-depth curriculum reform through the "Latin American Academy for Sustainable Development" (AcSuLa) project [51]. Collazo Expósito, L.M., et al. supplemented this with specialized training programs (such as the "ImpSDGup" course)[31] and subject-specific customized elements to systematically enhance capabilities. However, the effectiveness and sustainability of teacher development heavily depend on robust institutional safeguards. Ultimately, achieving high-quality sustainable education relies on the optimized synergy of policy tools, teacher growth mechanisms, and content elements to form a strong governance synergy [52].

4.4 Campus Ecology and Student Sustainability

Mazó-Quevedo et al. found that environmental education and cultural integration in higher education institutions face the core challenge of students' insufficient understanding and the disconnect between knowledge and action [53]. To address this, a multi-dimensional strategy is needed: on one hand, strengthen knowledge dissemination and behavior transformation mechanisms to bridge the gap between cognition and action [53]; on the other hand, establish the university as a moral exemplar of sustainable practices and clarify that interdisciplinary education should aim to cultivate social attitudes, values, and knowledge [3]. Additionally, the "Green School-Green University" model has demonstrated that integrating environmental education with psychology can effectively shape students' positive environmental attitudes, with the key being to closely integrate theoretical knowledge with practical application to enhance environmental awareness and motivate participation [24]. Notably, Abdullahi AM et al. found a significant positive impact of sustainable development education on Somali university students' environmental behaviors [19]. Bustamante-Mora et al. discovered that classroom ventilation and temperature significantly influence student concentration, and improving environmental conditions can simultaneously enhance learning outcomes and ecological awareness [54].

Building positive teacher-student relationships is a powerful driver for promoting students' sustainable values and behaviors. Checa, C. found that enhancing teacher-student interaction and student-administrator communication helps resolve issues, share knowledge, and directly advance campus sustainability [55]. Students' sustainability outcomes are significantly influenced by multiple relationships: 1. Family. Savelyeva, T. et al. found that in Hong Kong, 85% of students acknowledge the influence of family on sustainable values, with core factors including income, role models, and shared responsibility, laying the foundation for values [56]; 2. Educational interventions. Collado, S., et al. found that participating in sustainable development education interventions effectively and sustainably enhances eco-friendly knowledge, norms, and behaviors [57]; 3. Personality traits. Rafiq, M., et al. found that personality traits and sustainable education significantly influence green entrepreneurship intentions and behaviors [58].

Additionally, the sustainable development cognition of students such as Zhong, F. acts as an intermediary, positively influencing the enhancement of sustainable development behavior through education [59]. Moya Clemente I. et al. found that in Spanish universities, students participating in the Introducing a High Achievement Academic Program (ARA Groups) had no significant differences in evaluations compared to other students. However, graduates of this program are more favored by employers, thereby positively promoting corporate development [9]. This further highlights the critical role of education in empowering students for the future by enhancing their cognitive abilities and connecting them to employment opportunities. However, the effectiveness of sustainability education varies by discipline and is constrained by teachers' cognitive abilities and competencies [60], necessitating the implementation of

differentiated strategies. The ultimate goal is to cultivate students' key competencies required to address sustainability challenges and translate them into positive actions.

4.5 The Global Ranking Challenge and Application of Sustainable Development Education

Higher education institutions face a paradox in their pursuit of sustainable development at the governance level: Wen Y et al. found that excessive focus on world university rankings may undermine the essential functions of education and lead to imbalances in quality [61]. To optimize governance effectiveness, a balanced resource strategy is needed: controlling scale expansion and increasing key investments, such as using tuition increases to improve faculty salaries, to optimize resource allocation [62]. Additionally, resolving the paradox requires restructuring management systems to deeply integrate sustainability goals into the core of academic quality. The sustainable reporting framework proposed by Alfirević offers a pathway for this, emphasizing strategic planning to guide direction, and organically integrating sustainability management, reporting, and academic quality management systems to ensure institutional activities align with sustainability principles—a critical consideration for institutions at intermediate maturity levels [63].

To overcome this paradox, the effective implementation of ESD relies on a combination of diverse innovative approaches and solid supporting conditions. Core teaching methods include: 1. Entrepreneurship education. Examples include government policy legislation, financial support, and empowerment through modern teaching methods in universities [8]; 2. Experiential and real-world learning. Examples include citizen science, hands-on STEM projects [64], problem-based learning (PBL) [25][65], community collaboration [33], and the development of transformative, process-oriented methods and teaching approaches [66]. These practices and methods have been proven to achieve transformative education and cultivate practical skills; 3. Structured classroom interventions. Monzó-Martínez A et al. found that direct classroom interventions have a positive impact on enhancing knowledge of sustainable development [6]. However, their effectiveness is constrained by resource and institutional barriers: sustainability research faces issues such as unequal resource allocation, lack of incentive mechanisms, insufficient campus awareness, and conflicting government policies [67]. It is necessary to address the diversity of students' professional backgrounds through personalized design, optimize resources within universities, enhance awareness, and strengthen teacher training. Klucznik-Törő A et al. developed an entrepreneurship education model that can guide higher education policy formulation, management, and teaching practices [55]. The ultimate goal is to empower students to address future challenges through multidisciplinary collaboration and interdisciplinary integration, utilizing appropriate methods.

4.6 Exploring Specific Practical Cases of Sustainable Development Education

How to implement it is also a hot topic of research. This section will analyze the implementation pathways of education for sustainable development (ESD) in different schools to summarize commonalities in ESD implementation, providing theoretical support for effectively conducting ESD in the future. Universities worldwide have demonstrated diverse ESD practices, revealing their effectiveness, challenges, and future directions. Effective models include: industry-academia collaboration adapted to Industry 4.0. Mian S.H. et al. (2020) explored how university education can adapt to Industry 4.0 to achieve sustainable development, involving updating facilities, assigning specialized personnel, and deepening industry-academia collaboration [29]. The Systematic Environmental Performance Improvement Project (Trébol Programme) at the University of Córdoba in Spain: Gomera A. et al. introduced the University of Córdoba's "Trébol Programme," which improves environmental performance through a continuous, systematic, organized, and participatory process, institutionalizing

environmental commitments in line with ESD principles, and is scalable to other universities [7]. Interdisciplinary collaboration and teacher capacity-building platforms [68], Finland's Uniori STEAM education model [69], Thailand's competency-based general education [70], Malaysia's implementation of skill enhancement and retraining programs [71], Brazil's student identity courses [72], and online hybrid teaching validated during the pandemic [26]. However, challenges remain, including severe inadequacy in curriculum integration [73], insufficient ESD capabilities and attitudes among faculty [10], difficulties in deep institutional capacity building [23], addressing complex governance tensions [5], lack of systematic assessment [74], faculty capability gaps [75], and digital inequality issues [26]. Some cases also confirm that ESD can significantly enhance students' cognitive abilities [76], pro-environmental behaviors [21] (with older students performing better), and improve future thinking and systems thinking [76], emphasizing that students are core participants and are seen as key to rethinking sustainable higher education [1]. Future efforts should focus on overcoming course integration bottlenecks, systematically enhancing teacher capabilities, applying strategic management to address governance tensions, optimizing the inclusivity of innovative models, and improving across multiple dimensions (environmental, social, and governance) [77]. Deepening online education [78] and strengthening long-term impact assessments and cross-case learning can provide HEIs with tailored action guidelines based on global best practices.

5 Conclusion

5.1 Strengths and limitations

Strengths: First, the research methodology employed in this paper is innovative and integrated. By combining bibliometrics with visualization analysis (VOSviewer), the paper systematically reviews the research trends in sustainable development education at universities worldwide from 2015 to 2025. Through tools such as cluster analysis and co-occurrence maps, the paper visually presents research hotspots and evolving trends. Second, the data analysis is representative. Based on the Web of Science (WoS) core database, 77 high-quality English-language literature (2020-2025) were selected, covering high-output countries such as Spain, China, and the United States (19 from Spain, 10 from China). Citation analysis shows a total of 4,149 citations and an H-index of 45, indicating a solid research foundation and significant influence. Third, practical guidance value. The core pathways of sustainable development education were identified: service-learning, school-enterprise collaboration, and innovative teaching strategies such as digital platforms. Policy recommendations were provided to university administrators to optimize ranking indicators, customize competency assessment frameworks, and develop teacher development programs.

Limitations: First, data source limitations. Only literature from the WoS core database was included, excluding other databases (such as Scopus and CNKI), which may have omitted regional practices (such as cases from Latin America and Africa).

Second, the WoS expanded edition (SCI-E) was not used, focusing only on the social sciences perspective and ignoring some interdisciplinary research. Third, timeliness and prediction bias. The search was cut off on May 22, 2025, and subsequent new findings were not included in the analysis. Fourth, insufficient depth of content. Some case studies only outline the model without delving into implementation barriers (such as teacher capacity gaps or unequal resource allocation). Critical analysis of sustainability assessment systems is superficial and does not propose improvement frameworks.

5.2 Future research directions

In the current field of educational research, there are studies focused on the construction of theoretical frameworks, as well as research on practical innovation and contextualized applications. Many scholars are concentrating on service learning, the use of digital tools, and the integration of interdisciplinary curricula, all aimed at addressing the challenges posed by the Sustainable Development Goals (SDGs) on a global scale. Looking ahead, we should further

integrate the SDGs into the frameworks of various disciplines to enhance students' sustainable development capabilities. Additionally, strengthening professional training for teachers in sustainable development education is particularly important. Furthermore, developing scalable solutions using artificial intelligence technology and optimizing the synergistic mechanisms between campus ecosystems and student behavior are key steps in advancing education. Only by breaking down the barriers of disciplinary boundaries, technological isolation, and institutional inertia can we achieve a fundamental transformation in sustainable development education, providing global universities with an action plan that is both academically rigorous and practically feasible, thereby making a substantial contribution to achieving the Sustainable Development Goals.

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